Product design methodology supporting aesthetic evaluation

Shahabeddin Khalighy

ID: 1011996

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تقدیم به پدر و مادر عزیزم که در تمام مراحل زندگی مرا یاری کرده اند

Dedicated to my dear Mom and Dad who have always supported me

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Author’s declaration

I declare that, except where explicit reference is made to the contribution of others, this thesis is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Shahabeddin Khalighy

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Abbreviations

M : Metric

MA : Metric (Analytical)

MC : Metric (Compositional)

σ_F : Standard deviation of the duration of eye fixations

N_F : Number of eye fixations

λ : Standard contrast

F : Fixation

mS : Millisecond (time unit)

S^{-1} : Inverse of Second (time unit)

σ_x : Standard deviation of x coordinates of fixations

σ_y : Standard deviation of y coordinates of fixations

C : Centre point of ellipse with mean of x and mean of y coordinates of fixations

R_x : Horizontal radius of ellipse

R_y : Vertical radius of ellipse

θ : Angle of vertical radius of ellipse with y axis

A : Appropriateness

N : Novelty

B: Beauty

N_A: Number of fixations in Appropriateness area

N_N: Number of fixations in Novelty area

N_T: Total number of fixations

D_A: Duration of fixations in Appropriateness area (sum of all)

D_N: Duration of fixations in Novelty area (sum of all)

D_T: Total duration of fixations (sum of all)

EDF: File extension of eye-tracking raw output data

ASC: Extension of ASCII file

PL: File extension of filtered data using ActivePerl software

FLT: File extension of filtered data using AscFilter software

BAT: Extension of Batch file

TXT: Extension of Text file

e: Euler's number/Napier's constant ($\approx$2.71828)

PU: Pureness

PR: Proportion

NA: Nature of a design element

DI: Dimension of a design element

LO: Location of a design element

FO : Form (design element)

SH : Shape (design element)

CO : Colour (design element)

TE : Texture (design element)

Abstract

Based on the fundamentals of visual art and function, this research has developed a product design methodology capable of quantification of the aesthetic qualities and proposing objective solutions to enhance the appearance related variables and characteristics of a product. The objective evaluation has been done via analysis of involuntary responses using eye-tracking data based on the visual perceiving process of design. This objective evaluation can be summarised into following stages:

- Defining the qualities of aesthetics
- Identifying the relevant measuring tool
- Creating quantifying methodology
- Objective experiments
- Data analysis and extracting the results

The result confirmed the reliability of the methodology by generating constant results and a good match between the measured values and declared preference. In addition, the aesthetic enhancement methods based on quantified metrics with the sample designs have been provided.

The features of the methodology can be summarised as follows:

- The method is not affected by individual tastes in which the relative nature of attractiveness is reflected in the comparison between stimuli.
- The result indicates that the involuntary response is not affected by the declared preference. This shows that the methodology is capable of objective quantification which ignores subjective responses.

The key findings of the research are provided as follows:

- Beauty and attractiveness as the qualities of aesthetics are composed of opposing qualities in which proportion and pureness are against contrast, and appropriateness is against novelty.
- Beauty reaches maximum when the standard contrast is close to half of the total time of the observation.

The research achievements can be summarised as follows:

- Comprehensive definition of aesthetic qualities
- Establishing mathematical equations and measuring methods
- Establishing an objective and relevant measuring tool
- Collaborative research
- Objective quantification of aesthetic
- Establishing aesthetic enhancement methodology

The result of the research suggests that eye-tracking technology is a reliable tool in aesthetic evaluation and has potential for further development.

The main results of the work described in this thesis have been published by the International Journal of Industrial Ergonomics (Khalighy et al., 2015).

Chapter 1: Introduction

1.1. General perspective

1.2. Significance of the research

1.3. Research plan

1.4. Literature review

1.5. Research methodology

1.6. Hypotheses

1.1. General perspective

1.1.1. Aesthetics and its aspects in product design

The design process of function, manufacture, and aesthetics of a product creates three vertices of product design triangle (Baxter, 1995) (see Figure 1).

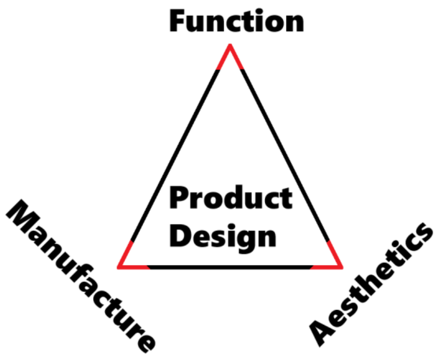


Figure 1: Product Design triangle

These three aspects of product design interact with each other in which improving the manufacture quality and functionality will result in aesthetic enhancement (Sauer & Sonderegger, 2011, 2009; Seva, Gosiaco, Santos, & Pangilinan, 2011; Lee & Koubek, 2010; Cawthon & Moere 2007). Aesthetics in product design consists of visual and non-visual (hearing, smell, taste and touch) aspects (Bloch, Brunel, & Arnold, 2003; MacDonald, 2000; Veryzer, 1993). This research focuses on the 'visual' aspect of aesthetics.

1.1.2. Visual aesthetics

Visual aesthetics refers to a value (Kieran, 1997) which can be subjectively interpreted (Crilly, Moultrie, & Clarkson, 2009) as a voluntary user response (Ulrich, 2006) or can be objectively evaluated (Crilly, Moultrie, & Clarkson, 2004) as an external reality (Khalid & Helander, 2006). The subjective aspect of aesthetic is related to emotional features of a human (Norman, 2004; Khalid & Helander, 2006), while the objective aspect is more intuitive (Crilly, Moultrie, & Clarkson, 2004). While the eye is receiving data (Etcoff, 1999; Arnheim, 1969), it is analysed by brain (Motte, 2009) and compares the data (Hekkert, Snelders, & Van Wieringen, 2003) with information (Coates, 2003) consists of human's knowledge (Liu, 2000) and experiences (Hung & Chen, 2012), and with ‘concinnity’ (concinnity means harmony in the arrangement of the different parts of something) (Crilly, Moultrie, & Clarkson, 2004) which is based on pleasant principles (Hekkert, 2006). Therefore, two types of responses are generated: affective and cognitive (Crilly, Moultrie, & Clarkson, 2004). Balance between these two opposing aspects creates positive impression to the aesthetic (Coates, 2003). In other words, the appearance of a product is perceived pleasant when it is able to satisfy a consumer in both sentimental and logical aspects of aesthetic (Jacobsen, Schubotz, Hofel, & Cramon, 2006; Bloch, 1995) which are linked to the design principles (Kostellow, 2002) as a part of product concinnity (Crilly, Moultrie, & Clarkson, 2004) and human factors (Jordan, 1998), and product characteristics (Breemen & Sudijono, 1999; Langmeyer & Shank, 1994) as a part of product functionality (Verma & Wood, 2001) and usability (Sonderegger, Zbinden, Uebelbacher, & Sauer, 2012; Tuch, Roth, Hornbaek, Opwis, & Bargas-Avila, 2012).

Behavioural aspect of aesthetics generates ‘attractiveness’ (Desmet, 2003; Norman, 2002), and cognitive aspect creates ‘beauty’ (Crilly, Moultrie, & Clarkson, 2004; Coates, 2003) as the main constituent factors of aesthetics (Khalighy, Green, Scheepers, & Whittet, 2014).

1.1.3. Visual references

‘Visual references’ refers to an existent source of design elements which may be applied by designers to a function and it is divided into two categories: nature and artefacts (Crilly, Moultrie, & Clarkson, 2004). ‘Visual references’ has been the major inspiring source, in creation and application of the design elements, for designers during the history of product design (Crilly, Moultrie, & Clarkson, 2009; Hsiao & Chen, 1997). ‘Visual references’ is also one of the main effective factors in determining, controlling, and evaluating the ‘product personality’ (Prieto, Fantoni, & Campolmi, 2013; Govers & Schoormans, 2005).

1.2. Significance of the research

1.2.1. Aesthetic role

Aesthetics, as one of the three forming elements of product design (Baxter, 1995), has been considerably highlighted (Hoegg, Alba, & Dahl, 2010; Kim, 2010; Herr, 2000) as a significant factor (Kieran, 1997) which can determine the level of success of a product in the market (Postrel, 2001; Perks, Coopers, & Jones, 2005). In other words, aesthetic quality is a major factor in enhancing customer satisfaction (Ranscombe, Hicks, Mullineux, & Singh, 2012; Fynes & Burca, 2005; Yamamoto & Lambert, 1994; Swift, 1997). Munari (1971) emphasises on the role of beauty in product success. Ulrich (2006) **argues** that aesthetics as a first response to a product can persuade a consumer to purchase or not to purchase the product within a few seconds. Norman (2004) **expresses** that pleasing appearance of a product is the key reason for generating positive impressions towards the product. Schindler & Holbrook (2003) **believe** most of the consumers make their final decision based on the aesthetic of a product. Veryzer (1995) **highlights** aesthetics of a product as a crucial factor in determining the product's identity. Bloch (1995) **mentions** that aesthetic can improve user's perception of product quality. Aesthetics also closely interacts with function (Verma & Wood, 2001) so that it is generally believed that beautiful and attractive products work better (Tractinsky, Katz, & Ikar, 2000; Norman, 2002). Lai (2005) **states** that aesthetic products can be successful and popular even without high qualities of function and technology. Norman (2004) **concludes** that aesthetics can completely change the perception of a product. As mentioned in **section 1.1.1** aesthetic also improves the functionality and manufacture quality. Opwis & Bargas-Avila (2012) showed how enhancement of the aesthetic will result in improvement of the functionality. Therefore, it is widely believed that aesthetics has a significant role in enhancing the quality of product design and the product success.

1.2.2. Problem

Interpreting the aesthetic of a product has been always difficult due to its multidimensional nature (Chen & Chuang, 2008). Designers often interpret their designs subjectively which may differ from the user's interpretation (You, Ryu, Oh, Yun, & Kim, 2006; Yun, Han, Hong, & Kim, 2003; Hsu, Chuang, & Chang, 2000). The reason is consumers judge a product based on their own perception of product image (Hsiao & Liu, 2002), while designers design a product by applying the physical characteristics or design elements to the product based on different factors (Matsubara & Nagamachi, 1997). Moreover, the essence of achieving the optimum aesthetic quality in designer's point of view has not been theoretically (Warell, 2001) and practically formulated (Chuang, Chang, & Hsu, 2001) because of two potential reasons: firstly, designers apply various approaches to enhance their design quality and to impress the customer (Baxter, 1995; Mono, 1997; Muller, 2001) while they are either reluctant (Lawson, 1997; Choueiri, 2003) or find it difficult to reveal their own design process due to its inherent intuitive nature (Tovey, 1997; Coates, 2003). Secondly, design researchers often do not evaluate the aesthetic in a same way as an artist does which causes misinterpreting of the aesthetic qualities (Crilly, Moultrie, & Clarkson, 2004). Therefore, the main issue in evaluation of aesthetic is the lack of an objective methodology capable of quantification of the effective qualities.

1.2.3. Effective factors in aesthetic judgment

In order to find the solution to the above problem, it is essential to identify the effective factors in aesthetic judgment. There are five major factors in aesthetic judgment: Design principles (Pham, 2000; Veryzer, 1993), novelty and typicality (Hung & Chen, 2012), perception of function (Hsiao & Liu, 2002), visual traits and characteristics (Breemen & Sudijono, 1999), and moderators (Crilly, Moultrie, & Clarkson, 2004).

1.2.3.1. Design principles

'Design principles' in visual art refers to a collection of standard visual rules which can be manipulated in order to create a standard artwork (Kostellow, 2002; Suh, 1993). Although these rules may vary depending on the definitions, there are a few which are often used such as 'harmony', 'pattern', 'contrast', 'proportion', 'balance', and 'emphasis' (Lidwell, Holden, & Butler, 2003). Although these rules are designed to enhance the aesthetic, there is no defined relationship between design principles and aesthetic preference (De Angeli, Sutcliffe, & Hartmann, 2006). For instance, what amount of contrast generates the highest pleasantness is unknown. Designers often control these principles in their artwork based on the subjective interpretation and feeling (Norman, 2007; Lai, Chang, & Chang 2005).

1.2.3.2. Novelty and typicality

'Novelty and typicality' in product design refers to a degree of visual recognition which interacts with knowledge and experience (Liu, 2000). Hung & Chen (2012) according to Schoormans & Robben (1997) argue that there is an 'inverted-U-shaped' relationship between novelty and aesthetic preference (see Figure 2).

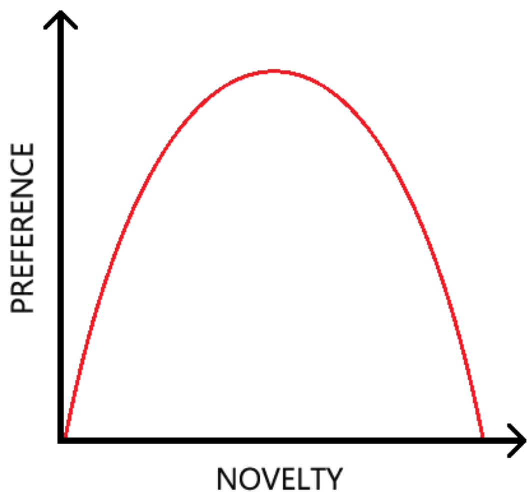


Figure 2: Argued relationship between novelty and preference

1.2.3.3. Perception of the function

Perception of function reflects a preferred 'product image' of a known function (Hsiao & Liu, 2002). For example, some people may perceive a design of a sport car as a preferred form of function of road mobility and some other may prefer truck form for this functionality. This factor is subjective (Crilly, Moultrie, & Clarkson, 2009) and can be affected by a large number of stimuli (Crilly, Moultrie, & Clarkson, 2004).

1.2.3.4. Visual traits and characteristics

'Visual traits and characteristics' (also known as 'product personality' (Brunel & Kumar, 2007)) refer to the properties of the appearance of a product which reflect a known human image (Langmeyer & Shank, 1994). For instance a car may look happy, aggressive or sad. This is a subjective factor which can be interpreted differently (Khalid & Helander, 2006).

1.2.3.5. Moderators

Moderators are external (out of the design) factors which influence the final aesthetic judgment (Reich, 1993) and are divided into three categories: personal characteristics, cultural attributes, and situational elements (Crilly, Moultrie, & Clarkson, 2004). ‘Personal characteristics’ refers to general human attributes such as gender, age (Holbrook & Schindler, 1994), experience (Berkowitz, 1987), and personality (Bell, Holbrook, & Solomon, 1991). ‘Cultural attributes’ refers to social futures which can affect a person who lives in that society in terms of taste (Bourdieu, 1984). ‘Situational elements’ refers to the factors which can affect the consumer’s response by influencing the motivation in observing a product (Veryzer, 1995).

1.2.4. Solution

As can be seen from the **section 1.2.3**, although the effective factors, to some extent, have been defined, the relationship between these factors and the aesthetic judgement has not been established and developed. Therefore, two steps are required to be taken in order to find the solution to the problem: first, the effective aesthetic qualities which can be quantified must be defined. Second, the relationship between these qualities and the preference has to be developed. In other words, it is required to link the physical design elements to consumer’s perception of the product (Aitken, Childerhouse, & Towill, 2003).

1.2.5. Aim of the research

This research aims to develop a methodology capable of quantification and enhancement of the qualities of aesthetics by focusing on three main areas: art, science, and psychology.

1.2.5.1. Aesthetics and art:

Aesthetics is related to visual properties of an object which can be manipulated via art's principles (Kostellow, 2002; Veryzer, 1993). Therefore, knowledge of art is required to evaluate the aesthetic.

1.2.5.2. Aesthetics and science:

Development of an objective measuring tool requires science and engineering methods (Liu, 2003; Nagamachi, 2002). Moreover, mathematics as a part of engineered models is essential in quantifying the aesthetic qualities (Courant & Robbins, 1996).

1.2.5.3. Aesthetics and psychology:

The main actor in aesthetic judgment is the 'user' composed of consumers and designers (Lai, Lin, Yeh, & Wei, 2006). Therefore, psychology as an interactive science which deals with human's attributes is essential in development of aesthetic measure.

1.3. Research plan

1.3.1. Beginning

The research begins with reviewing the literature and previous related studies by assessing journal and conference articles and books in order to determine and clarify the situation of this study among the design research world. The investigation has focused on three aspects: first defining and developing the fundamental concepts and constituent factors of aesthetics. Second, the research tries to investigate current methods in measuring user's response. Third, it aims to find the possible solutions in linking the attributes of product appearance and user's preference.

1.3.2. Methods

Two major experimental methodologies are considered as the main approaches of the research: subjective and objective methods (Robson, 1993). Subjective methods evaluate user's response using their declared preference while the involuntary responses are measured via objective methods.

1.3.3. Plan schedule

The research is composed of three frameworks: theoretical, experimental and practical which are summarised as follows:

1. Theoretical framework: based on the fundamentals of visual art, related aesthetic qualities are defined in order to identify required experimental tools.

2. Experimental framework: by using the defined aesthetic qualities, subjective and objective experiments are conducted in order to determine and evaluate the quantification methodology.

3. Practical framework: the procedures, instruction, and samples of applying the quantification methodology to the design process in different design stages will be established.

Therefore, the research plan has been scheduled as follows:

Year 1: Literature review, identifying the research situation, determining research question and hypotheses, and developing the potential responses.

Year 2: Identifying the responses to unanswered questions via conducting subjective experiments, and Identifying appropriate measuring tools.

Year 3: Conducting objective experiments using identified measuring tool, and studying practical solutions of enhancing effective aesthetic qualities.

Year 4: Running a case study as an example of application of the proposed methodology, writing up the thesis, and publishing journal papers.

1.3.4. Gantt chart

Task 01: Literature review

Task 02: Developing research question

Task 03: Writing a paper for ICDC 2012 conference

Task 04: Identifying main hypotheses

Task 05: Identifying potential responses

Task 06: Attending ICDC 2012 conference

Task 07: Literature review

Task 08: Conducting visual test and data analysis

Task 09: Conducting visual test through online questionnaire and data analysis

Task 10: Identifying measuring tools

Task 11: Preparing measuring methodology

Task 12: Preparing first eye-tracking experiment

Task 13: Conducting pilot eye-tracking experiment

Task 14: Data analysis and evaluating results

Task 15: Writing a paper for Design Conference 2014

Task 16: Preparing second eye-tracking experiment

Task 17: Conducting second eye-tracking experiment

Task 18: Data analysis and evaluating results

Task 19: Attending Design Conference 2014

Task 20: Preparing third eye-tracking experiment

Task 21: Conducting third eye-tracking experiment

Task 22: Data analysis and evaluating results

Task 23: Writing first journal paper

Task 24: Writing the thesis

Task 25: Preparing fourth eye-tracking experiment

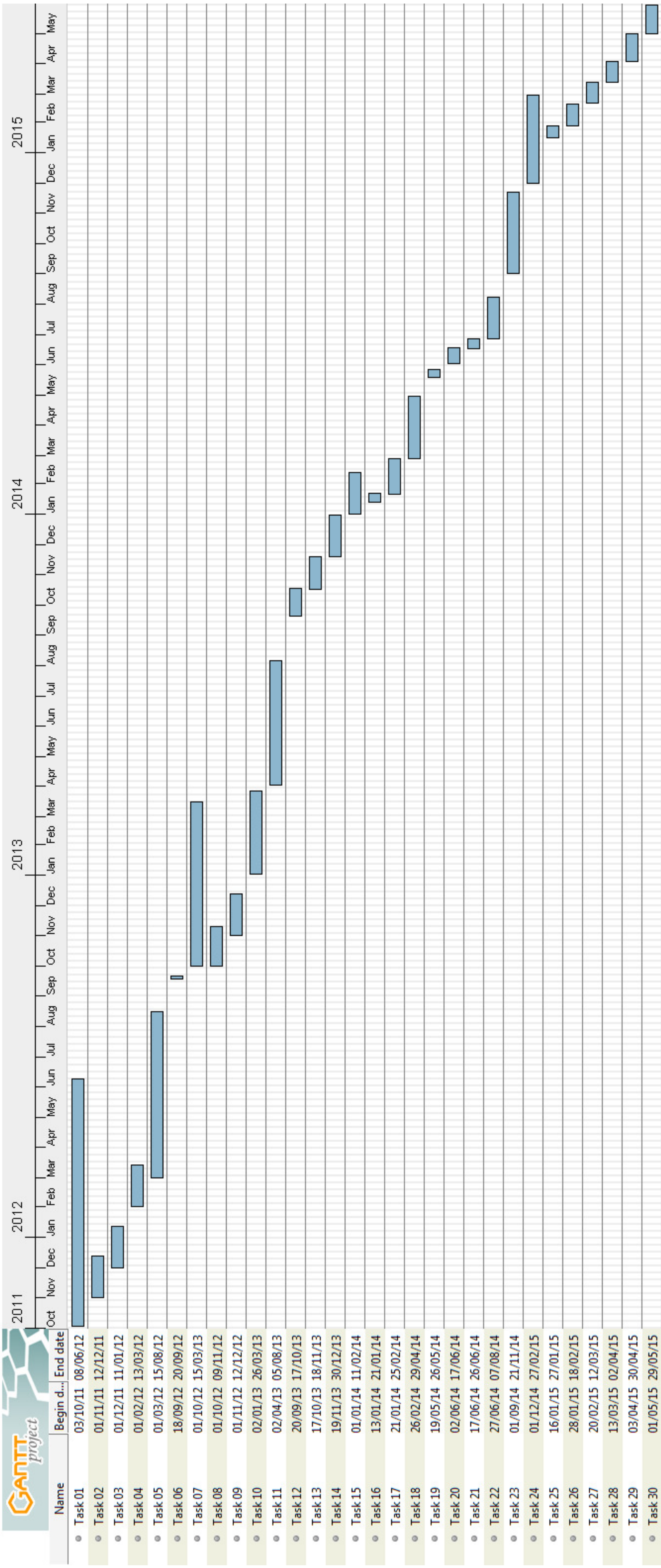
Task 26: Conducting fourth eye-tracking experiment

Task 27: Data analysis and evaluating results

Task 28: Establishing aesthetic enhancement methodology with sample designs

Task 29: Writing second and third journal papers

Task 30: Thesis correction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1.4. Literature review

1.4.1. General review

Several attempts have been made in order to develop an objective methodology to quantify the qualities of aesthetics (Khalighy, Green, & Whittet, 2012). Previous research in this field can be divided into two main categories: first, studies which have tried to investigate theoretical concepts of aesthetics and also to analyse different aspects of product appearance perception and psychological effects such as cognitive and affective (Bloch, 1995), information and concinnity (Coates, 2003), typicality and novelty (Hekkert, Snelders, & Van Wieringen, 2003; Hekkert & Leder, 2008), subjectivity and objectivity (Khalid & Helander, 2006), characters and attributes (Langmeyer & Shank, 1994), functional and emotional (Noble & Kumar, 2008), recognition and identification (Crilly, Moultrie, & Clarkson, 2009), neuroaesthetic (Galanter, 2010), simplicity and complexity (Cox & Cox, 2002; Norman, 2010), aesthetic style (Vyncke, 2002), effect of gender and age on aesthetic taste (Demarest & Allen, 2010; Holbrook & Schindler, 1994), engineered aesthetics (Liu, 2003), aesthetic adaptations (Ulrich, 2006), and computer-supported methodologies (Pham, 1999: A; B; Knoop, Breemen, Horvath, Vergeest, & Pham, 1998). Second, studies which have aimed to propose and construct a practical aesthetic models capable of quantification with experimental examples by applying known engineering and statistical analysis methods such as “quantifying shape descriptors” (Zuniga, Prieto, & Fantoni, 2014), “effect of novelty on aesthetic” (Hung & Chen, 2012), “product-form design model based on genetic algorithms” (Hsiao, Chiu, & Lu, 2010), “integrating the Kano model into robust design approach” (Chen & Chuang, 2008), “aesthetic measurement” (Hsiao, Chiu, & Chen, 2008), “use of shape preference information in product design” (Kelly & Papalambros, 2007), “user-oriented design” (applying Kansei Engineering method) (Lai, Lin, Yeh, & Wei, 2006), “enhancing feeling quality of a product” (applying Taguchi method) (Fowlkes & Creveling, 2012; Lai & Chang, 2005), “measuring consumer perceptions” (Petiot & Yannou, 2004), and “applying semantic methods” (Karlsson, Aronsson, & Svensson, 2003; Hsiao & Wang, 1998). In the next section, the detailed review is provided in order to clarify all relevant design methods suggested by researchers.

1.4.2. Critical evaluation

Although some studies have one-dimensional approach (Lowgren, 2006; Lavie & Tractinsky, 2004; Liu, 2003; Rashid, MacDonald, & Hashmi, 2004; Schenkman & Jonsson, 2000), the other studies apply multidimensional criteria to their proposed methodologies (Krish, 2011; Kovach & Cho, 2009; Bottani and Rizzi, 2008; Wang, Chu, & Wu, 2007; Eddy & Lewis, 2002; Jiao & Tseng, 2000). One-dimensional studies are often based on consumer-oriented techniques (Yun, Han, Hong, & Kim, 2003; Fukushima & Kawata, 1995; Jindo, Hirasago, & Nagamachi, 1995; Karnes, Sridharan, & Kanet, 1995) such as Kansei Engineering (Nagamachi, 1995). Kansei technique tries to translate user's emotion and feeling into the product's design elements (Hsiao & Chen, 1997; Ishihara, Ishihara, Nagamachi, & Matsubara, 1995, 1997; Jindo & Hirasago, 1997; Kashiwagi, Matsubara, & Nagamachi, 1994; Tanoue, Ishizaka, & Nagamachi, 1997; Yang, Nagamachi, & Lee, 1999; Youji & Tomio, 1995) in order to identify the relationship between consumer's preference (Schindler & Holbrook, 2003) and the elements of design (Perona & Saccani, 2004; Salvador & Forza, 2004). Although some of the multidimensional techniques are based on two-dimensional models such as Kano model (Kano, Hinterhuber, Bailon, & Sauerwein, 1984), some studies have tried to integrate different models and generate more than two dimensions in their proposed methods (Chen & Chuang, 2008). In this section **nine** recent studies over ten years (2004 - 2014) which have developed aesthetic measuring methods 'with various approaches' are critically evaluated. These studies are selected based on relevance, diversity of applied methods, and the quality.

1.4.2.1. Quantifying shape descriptors for aesthetic concept

This study tries to link the shape of a product to two aggressive-gentle attributes with the aim of predicting the product personality using "accumulated angular difference descriptors (A2D2)". This method creates a value based on the contours of the shape in four stages: first, it measures the angle of each contour. Second, it calculates the difference between the angles. Third, Angular difference histogram is generated by gathering the values of all angular differences and set it as "predefined bins". Fourth, each bin represents a feature of A2D2 (such as smoothness or sharpness) which is "invariant to scale and rotation". 10 silhouettes of glass are employed as stimuli of the survey in which 54 people are asked to assign the degree of being aggressive or gentle from -5 to +5 to each stimulus. Then, the mean of subjective responses are compared with the result of A2D2 analysis which shows a close match in some comparisons. There are some positive and negative points about this method.

Positive points: First, it tries to directly compare the result of shape descriptor with user's perception. Second, in the method of measuring the shape "angular difference histogram" is used which represents the whole shape. Third, the samples were chosen from a variety of results which were generated by a computer-based algorithm using 'perception degree' of the applied attributes in an "artificial neural network" (Igel & Husken, 2000).

Negative points: First, it is argued that the eye begins with the boundary of a product then focus on inner details (and it is used as a reason of applying contour-based technique rather than region-based method) while this has not been proved or referenced in the article. Second, silhouette of a product has a very limited impact on the viewer compared to the real product. Third, the detail on a product as one of the major descriptors of the product personality has been completely ignored. Forth, the relationship between applied attributes as product personality with user's preference is not defined. Fifth, the relationship between applied attributes and aesthetic is not discussed. Sixth, the process of validating the result of A2D2 is subjective.

Although this study is a positive approach in translating the product shape into user's view, its limited applied criteria and the level of subjectivity in validating the final result make it far from an ultimate practical solution.

1.4.2.2. Effects of novelty and its dimensions on aesthetic preference in product design

This study tries to indicate the relationship between novelty, typicality, and aesthetic preference by applying subjective measures. 523 photos of different chairs (as stimuli) are reduced to 213 by two designers in order to eliminate similar designs. The rest of the photos are then sorted in different clusters depends on degree of similarity by five students with design background. Finally 88 photos are selected "using the hierarchical clustering function" in SPSS. Then

60 undergraduate students were asked to assign defined attributes to the stimuli using “semantic differential method to measure aesthetic preference, novelty, complexity, emotion, and trendiness”. Ugly or beautiful is used for aesthetic preference; typical or unique for novelty; simple or complex for complexity; rational or emotional for emotion; and traditional or modern for trendiness. Participants divide the images into nine groups in terms of level of novelty then they rate the images for other pairs of adjectives from 1 to 9. The mean of the scores for each image then is compared with the level of novelty and using SPSS analysis it shows the inverted-U relationship between novelty and aesthetic preference in which “moderate level of novelty generates the highest level of aesthetic preference”. By comparing the level of novelty with other adjectives it is shown that “a typical chair is simple, rational, and traditional, while a novel chair is complex, emotional, and modern”.

This study is an example of conducting a subjective experiment. It employs a large number of stimuli and uses relevant process of data analysis. However, it lacks some fundamental points: first, aesthetic preference is not only affected by novelty. There are more factors in physical properties of a chair that influence the judgment of participants which are not included in processing the data. Second, participants are asked to judge various adjectives at the same time which can result in noisy responses due to over-processing of the brain. Third, some of the applied adjectives are too strong. For example, ‘ugly-beautiful’ can change to ‘least beautiful-most beautiful’ to soften the level of emotional responses. Fourth, assigning simple, rational and traditional to typical design and opposite attributes to novelty does not seem helpful. For instance, a novel design can be simple or complex (Norman, 2010; Hekkert, Snelders, & Van Wieringen, 2003) and it is obvious that a novel design cannot be traditional while their definitions are opposing.

1.4.2.3. Product-form design model based on genetic algorithms

Genetic algorithm (GA) in artificial intelligence area refers to an evolutionary model which tries to optimise the data based on the evolution of previous generations which is inspired by natural genetic evolution (Mitchell, 1996). This study tries to optimise the form of a product by applying genetic algorithm. The reasons of using this method are mentioned in the study as follows:

1. There is large number of parameters in developing the solution which are analysed by coding instead of using a defined algorithm.

2. The search model is population-based and not single-based.

3. Only numerical data are required in this model.

4. This model is random-based. Therefore, defining the range of deterministic questions is not required.

The input data are “linguistic variables” obtained from responses of customers over the period of product evolution. These data are firstly entered into quantization process using a combination of ‘Kansei Engineering’ (“to quantize consumer responses to product style”) and ‘Quantification Type I Analysis’ (to create “contribution values of product styles from each component”) methods in order to develop the design concepts. These linguistic variables are chosen from 100 words using informal survey filled by 20 design students. ‘Drip coffee maker’ is used as a sample of applying the optimisation method. Therefore, seven variables which are mostly suitable to describe the product features are selected as elegant, graceful, high-tech, applied, creative, rigid, and quality. The product is divided into two parts: body (including reservoir, filter basket, and warming plate) and the carafe. Using morphological analysis the product form then is categorised based on three criteria:

1. Size limit: based on analysis of a ten-cup drip coffee maker, if capacity of each cup is 250cc, the capacity of the carafe and the reservoir “must exceed 2500cc”.

2. Integer proportion: there are two integer proportion defined in the sample product based on side and front views: filter basket/warming plate and filter basket/reservoir.

3. Figure design: five shapes are defined “according to the rules of gradation, subtraction, and addition” for the reservoir.

Genetic algorithm is applied in the study in 5 steps as follows:

1. Encoding the solutions using binary method as chromosomes such as 101101100.

2. Quantifying the initial population base on the origin of evaluation.

3. Defining the fitness value as “the survival rate of the chromosomes”.

4. Obtaining the optimum chromosome from “two high quality chromosomes via four evaluation mechanisms: selection, reproduction, mutation and crossover”.

5. Decoding the optimum chromosome based on consumer needs in which three kinds of values emerge: “reasonable and feasible, reasonable and infeasible, or unreasonable”.

Number of required samples is generated. “The reliability of the 95% confidence interval” shows Z = 1.65 based on “the conditional probability table”. Margin of error is defined as 30%. The standard deviation of the population is calculated as 0.92. Therefore, number of samples (n) is calculated as 26. Therefore 26 possible configurations of 8 defined categories are created. Then 20 design students score the 26 designs in terms of 7 linguistic variables and the mean of each score is calculated. By applying the quantification Type I analysis, the contribution score of each sample is measured. “Analytic hierarchy process” is applied in order to determine the weight of each linguistic variable. The “fitness value” is determined by applying the weight of each score to the contribution score of each sample.

‘Customer demand value’ is calculated in the case study by applying genetic algorithm in 8 steps as follows:

1. Inputting the initial population which is assumed 100 in the study.

2. Setting variable numbers which is 7.

3. Inputting binary length of variables which is 20 in this study.

4. Setting the range of scores which is 1 to 10 in the study.

5. Setting fitness value using “Analytic Hierarchy Process”.

6. Inputting the convergence in order to “terminate the evolution” by setting the allowance value of fitness changing between two generations and setting the maximum value for operation time.

7. Inputting the mutation rate in order to control the evolution process. This number after nine experiments is set to 0.07 which means 7% of genes are modified in the mutation process.

8. Calculating “customer demand value” for seven variables based on defined genetic algorithm.

The optimum solution which is coded as 11323113 then selected through the algorithm calculation which is programmed in MATLAB software. Then it is decoded as a design concept and the CAD model is generated.

Although the study has tried to implement the genetic algorithm into the product design process, lack of basic data affects the final outcome which is discussed as follows:

1. The seven variables which dominate the whole process are selected based on the relevance to the product features while there is no explanation of the reasons behind this classification.

2. Five different shapes are selected for the reservoir of the coffee maker without any further explanation. Moreover, these five shapes are too limited compared to the possibilities of the form evolution.

3. Genes are made based on binary codes which employs possible combinations of the categories rather than morphing the form. This puts the evolution process far from its original meaning and aim.

4. Defined categories for the target product are too limited. There are more details on this product which are not included.

5. Subjective data is highly affecting the methodology.

6. Number of possible solutions which are created in the algorithm is too limited compared to the optimum results and the difference between them is not outstanding. It again shows the input data is very limited and consequently results in very limited solutions.

7. The figures (shapes) are selected based on the 2D model while in final solutions 3D models are created without any further explanation.

8. The models are interpreted by designers in order to make the final CAD model. This makes the result subjective and less reliable.

9. The time is not defined in the methodology. There are variables which are affected by time which influence the product evolution.

10. There are other variables ignored such as technology which can affect the product evolution.

1.4.2.4. Integrating the Kano model into a robust design approach to enhance customer satisfaction with product design

This study describes the integration of three different methodologies consist of 'Kano model', 'grey relational analysis', and 'Taguchi method' in order to "enhance customer satisfaction and the aesthetic qualities of the product". The study has employed 'mobile phone' design as an example of applying the robust design model. It is argued that the final proposed design has enhanced the "aesthetic performance". Moreover, it is claimed that this methodology can be applied to all types of products as "a universal robust design approach". Two methods have been used in this study:

1. Kano model (1984): This is a questionnaire-based model which tries to reveal related attributes for level of consumer satisfaction in the presence or absence of a certain quality (criterion). In both situations of the presence or absence of the quality, five levels of answers are suggested which represent the level of satisfaction from completely satisfied to completely dissatisfied, depending on the feeling of the user. "By combining the two answers in the Kano evaluation table the product criterion can be identified as attractive, must-be, one-dimensional, indifference or reversal."

2. The robust design approach based on grey relational analysis (Deng, 1989) and Taguchi method (1990): The purpose of applying this combination, which is called “grey-based Taguchi method (TM)”, is to optimise “the multiple performance characteristics”. Grey relational analysis (GRA) “measures the relationship between factors based on their degree of similarity in development trends in which if the trend for the change between two factors is consistent, it produces a higher grey relational grade (GRG)”. It applies three different formulas in order to measure the effectiveness of three “signal-to-noise ratio” performance characteristics consist of “lower-better, higher-better, and nominal-better”. “The grey relational coefficient” is the normalised “signal-to-noise ratio” which has to be calculated based on a weighting method which “is used to integrate the grey relational coefficients of each criterion into the GRG to reflect the importance of each criterion. The optimal combination of design parameters is the one with the highest GRG. The Taguchi method is combined with GRA in order to simplify optimisation procedures for determining the optimal parameters for multiple performance characteristics”.

There are main concerns about applying these methodologies in achieving the claimed targets: First, the Kano model has been designed in order to reveal the level of satisfaction for a certain product which already exists. As it also has been mentioned in the paper (“However, it cannot illustrate how to design and improve product quality to meet customer requirements”) applying this model as a part of design methodology does not suggest any design criteria which can result in an unreliable outcome. Second, the Kano model is completely subjective and does not propose any objective quality and consequently cannot be reliable in all the situations. Third, the GRA combined with Taguchi method is a general method which can potentially optimise the different relationships between different criteria in multidimensional models but it does not contain any aesthetical or visual design-based solutions. Consequently, the integration of these two models (Kano and GRA-TM) also cannot provide any product aesthetic solution as none of them contains any aesthetical design bases.

In the proposed sample, ten modifiable criteria (“control factors”) for mobile phone design have been suggested facing four levels of modifying (except one criterion which is facing two levels of modifying). The reason has been explained that “the six experts were then asked to review the information and extract design attributes using morphological analysis. The design attributes that were thought most likely to influence aesthetics were identified.” Moreover 32 mobile phone designs have been used in the Kano model questionnaire and Taguchi method in order to reveal the optimised level of each control factor. Based on the proposed methodology, the optimum relationship between selected control factors has been calculated and ten mobile phone design elements (based on ten control factors) are suggested as an optimal form design. There are several issues with this processing. First, the paper has not mentioned about the reason behind selection of that ten control factors, whereas, it is highly effective part of the sample analysis. Second, the design elements of product design have different nature and are more than the mentioned elements. For example, **material** and **colour** are not included. Third, there is no mention about the functionality which is the main target of a product. Forth, the preferred analysed elements may not certainly be pleasant in combination. Fifth, there is no even one word about aesthetic qualities. Sixth, the control factors have been provided in a two-dimensional model whereas a product is three dimensional.

The proposed design model which is the outcome of applying the methodology is called ‘optimised design’. However, it does not seem to offer a better aesthetic compared to the original design so that it lacks the basis of aesthetic principle which is ‘symmetry’. The other negative point is proposing the 2D-based elements while at the end a 3D design is shown with some elements on the side without any further explanation.

The final result of the study indicates that achieving the customer satisfaction in aesthetic point of view is dominated by different criteria. It is vague how the methodology can perform for a new function of a product while the functionality as the most important factor of product design has been ignored. In addition, creating a comprehensive methodology based on a limited number of subjective responses can result in unreliable outcome. The proposed model shows that achieving the optimum result is not possible if the methodology employs irrelevant or insufficient data.

1.4.2.5. Applying aesthetics measurement to product design

This study tries to develop a method capable of optimising colour harmony in a product. This process is summarised in 4 following steps:

1. Selecting a product as a stimulus which is already manufactured and accessible.

2. Determining “image words” using questionnaire and ‘semantic differential method’.

3. Dividing the product into parts and creating a basic form and ‘SOLID’ model of each component.

4. Identifying related functions of each component using “image words” in order to present the optimum colour harmony.

The purpose of the study is to develop “a model of aesthetics measurement for product colour matching” by constructing the relationship between ‘aesthetic measurement’, ‘colour match’, and ‘consumer perception’.

A cell phone is chosen as a stimulus of the study. Then using “two-phase image-semantic survey” 100 words which are able to “describe the colour image” are collected. By removing synonyms, 32 opposing image words are selected. Then 30 design students are asked to choose 10 image word pairs out of 32. The top three words are: ‘female-male’, ‘futuristic-classical’, and ‘fancy-plain’. Then they are asked to assign four colours out of 129 to each image word. These 129 colours are selected from ‘Practical Colour Co-ordinate System’. Three attributes are used in order to describe the colour: Hue, Value, and Chroma. Hue is the colour essence. 10 hues are used in this study: red, yellow-red, yellow green-yellow, green, blue-green, blue, purple-blue, purple, and red-purple. Value is the amount of colour lightness or darkness which means how much white or black is mixed with the colour. Chroma is colour saturation which means how much grey is mixed with the colour. Lower level of grey in the colour means higher saturation. The study then tries to establish a measuring formula based on “Munsell colour system” in 4 following steps:

1. Assigning image value of hues: a value of 1 or 0 is assigned to colour's hue based on the image word. For example, colour 10R fits female, so female value will be 1. By contrast, colour 5B fits male, so female value of this colour is 0. Then the hue values are divided into 55 equal segments from 10R (highest female value) to 5B (highest male value) and 45 equal segments from 5B to 10R in a hue circle. For instance, for colour 4YR the female value is 51x1 which is divided by total 55 segments and the result is 0.93. For colour 6PB (in 45-segment section) the female value is 11x1 divided by 45 which equals 0.24 (in total 100 segments).

2. Assigning the weight to each value: each colour based on the image word (e.g. female-male) has a weight. For example, the highest weight is 8.5 for colour 10R as a female and lowest is 3.5 for colour 5B. Then this weight scale is divided into two portions: one from 0 to 3.5 and other 8.5 to 10 in order to make a weight scale from 0 to 10. For instance, colour 2Y has a weight of 9 which is divided by 10 equals 0.9.

3. Defining the relationship between Value and Chroma: According to Moon and Spencer (1944), in order to create a better harmony, colours with higher Value and Chroma are required to be allocated a smaller area.

4. Defining the aesthetic colour match formula: based on the colour of each component, U_i is used to describe "the contribution of the colour on component i to the image perception of the product ($0 \le i \le n$ in which n is the number of colours used for a product)" using pixel ratio. Based on the relationship between Value, Chroma, and the Area of the colour, "contribution of the Value and Chroma of component i to the perception of the product" (Q_i) is calculated and the final aesthetic measurement formula is suggested.

The cell-phone then is divided into 8 components: case-front-top, case-back-top, case-side, function-key, case-front-down, case-back-down, screen, and numeral key based on "function, position, and production process". Calculation of aesthetic measurement (M_P) for colour matching of the cell-phone for each component is then done using Visual Basic for three colours. Software then generates different possibilities of colour matching for three colours. The highest M_P is measured for the word female which is 0.60.

This study focuses on colour as an effective factor in aesthetic judgment. Positive point about this study is including the pixel area as it is observed from different viewing angles. However, the basic construction of the methodology lacks fundamental elements:

1. The colour is made in applied software can be noticeably different from the production colour.

2. The formula which is used to determine the area against the Value and Chroma of the colour is relative to two colours. There is no absolute measurement provided.

3. Harmony of a colour is not only relative to the size of the area. It is also relative to the shape of the area (Itten, 1974) which is ignored in the study.

4. Functionality as a highly effective factor in the aesthetic judgment is missing. The colours are chosen based on the attributes which are not connected to the function of the sample product.

5. Colour variation effect is not included in the formula: for instance, how many colours required in a cell phone design.

6. Variation of the area is not considered. It can optimise the colour harmony by changing the area to match the colour properties.

1.4.2.6. Use of shape preference information in product design

This study tries to develop a model capable of determining user preference for different shape design in a product. The study has examined two statistical analysis techniques: ‘PREFMAP’ and ‘Conjoint’.

‘PREFMAP’ is used as a quantitative method in order to link design variables to the shape preference. PREFMAP “generates an external mapping of preference” using different variables of stimuli in four phases in which phase 1 to 3 are point-based (ideal point) and phase 4 is vector-based. Phase 1 data analysis which is employed in the study is an ‘elliptical paraboloid’ capable of rotating among the plane (which means variables are able to interact).

‘Conjoint’ analysis identifies the optimum combination of attributes obtained from a large sample of user response based on the principles that maximise consumer’s utilities (Green, Carroll, & Goldberg, 1981). In this method, several products in a same category are shown to the users and the responses are collected. These two statistical analysis methods are then compared and ‘conjoint’ method is chosen due its more accurate results. Cola bottle is used as a sample of the study. The cola bottle is represented by a symmetrical shape composed of bottle mouth and a spline which defines the contour of the bottle. The spline fits via 5 points in which 2 points as variables horizontally move (between 25mm and 50mm) in order to change the shape. Each point is allocated 5 steps of movement; therefore, 25 designs are created. These 25 designs are then used in 16 five-choice questions (consist of 4 designs and one no-choice option) and 39 college students are asked to answer the questions via 39 unique questionnaire. By applying conjoint data analysis the optimum shape is defined.

This study is a sample of applying statistical analysis techniques to the limited number of constituent variables of the shape in product design. The main advantage of the study is clear application of the analysis method to the aesthetical variables. Moreover, using multi-choice questionnaire seems to match the nature of conjoint method which is more relevant to the environments in which users choose a product among a set of similar category. However, there are some disadvantages regarding the approach which are mentioned as follows:

1. The reasons of selecting the variables (points) which change the design are not discussed in the study. For example: why 5 points; Why those 5 points; Why only 2 variables; and why 5 steps of change.

2. The condition of the images which are presented to the respondents is not mentioned.

3. It is not clear how the proposed methodology works for more complicated designs with more variables.

4. The method is heavily dependent on subjective responses and consequently very prone to noisy results.

5. The applied variables are too limited compared to the effective qualities in the aesthetic judgment.

6. The analysis method is only compared with one more method. It is not discussed that how the proposed approach excels other techniques.

7. Although it is mentioned that conjoint method is used for large sample numbers, the responses of only 39 subjects are collected.

8. The allocated time in the responding process is not discussed.

1.4.2.7. User-oriented design for the optimal combination on product design

This study suggests a method of applying user's perception (Redstrom, 2006) to the product design elements using 'Kansei Engineering', 'Quantitative Theory Type I', and 'Neural Networks' (Hsiao & Tsai, 2005; Hsiao & Huang, 2002). The approach focuses on colour as well as form as the elements of design and employs mobile phone as stimuli.

'Kansei Engineering' is used to extract the experimental samples. First, the stimuli are classified in 9 steps in order to extract the sample of the product 'form':

1. Selecting 30 mobile phones which exist in the market.

2. Making 30 paper cards based on the size of the selected samples.

3. Separating the paper cards into 7 groups according to their degree of similarity by 15 product designers using the 'Kawakita Jiro' (K-J) methodology (Cross, 1994).

4. Building a matrix of similarity based on the result of step 3.

5. Transforming the matrix obtained in step for to dissimilar data.

6. Applying 'multiple dimension scaling' analysis (Hair, Anderson, Tatham, & Black, 1995) to the dissimilar data.

7. Choosing 5 dimensions obtained from the step 6.

8. Applying cluster analysis to the selected dimensions in step 7.

9. Choosing 4 clusters as the experiment samples.

Then, the sample of the product 'colour' is extracted using 8 values of 'Hue', 3 values of 'Chroma', and 3 values of 'Lightness' from CIE colour system. Therefore, 72 (3x3x8) colour samples are generated. By rendering 4 form samples and applying 72 colours, 288 (4x72) samples are created. Then each sample is printed in a size of 35mmx12mm. In order to apply Kansei engineering, 'image word' is extracted which represents "a user's perception of a product" (Nagamachi, 1995) in 3 steps:

1. Collecting more than 100 image word pairs from product catalogue and magazines.

2. Evaluating the image word pairs applying 'semantic difference' method (Osgood & Suci, 1957).

3. Applying factor analysis (Hair, Anderson, Tatham, & Black, 1995) to the obtained result in step 2.

Therefore, 3 image word pairs are selected: Simple-Complex, Handsome-Rustic, and Leisure-Formal. These 3 image words are assigned to 288 samples; therefore 864 (3x288) product images are created. 15 product designers are then asked to rate each product image in terms of the image word pairs from 1 to 7.

'Quantitative Theory Type I' is used to measure "relative importance of product image". 4 variables represent form and colour of the sample product and 3 variables represent the image word pairs. The results show the relationship between the variables. For instance, it shows that 'lightness' of colour mostly affects 'simple-complexity' and 'leisure-formal' while 'hue' mostly affects 'handsome-rustic' and 'chroma' is least effective on image word pairs. The results also indicate the level of effectiveness of the colour properties on each image word. For example, when lightness is high the image is perceived as simple compared to darker colours which is more perceived as complex. It is also shown that product form has lowest "partial correlation coefficients" compared to colour variables which means it is less effective in product image perception.

'Neural Networks' as a non-linear model (Golden, 1996) is applied to evaluate the optimum combination of product image. Two different neural networks models are developed in the study in order to examine the efficiency of the model: mixed and single. The input neurons in the mixed model are 4 product samples plus 3 colours attributes which are 7 in total and the output neurons are 3 image word pairs. Number of hidden neurons is defined by the mean of the number of input and output neurons. In the single model the input variables are 3 colour attributes and the output is same as the mixed model. In order to compare the performance of these models 15 subjects rate 12 rendered phone image using 3 word pairs (36 in total). The results show that single model has higher consistency ("correlation between model's prediction and subject's perception") compared to the mixed model. In terms of word image the consistency is higher for 'simple-complex' and the lowest is for 'leisure-formal'. Finally 4 samples are given as the optimum combination of the form and colours for the set of image word pairs.

The study claims that "the NN models can determine what combination of form and colour can best match the desired product image". However it is not discussed that how this method is linked to the final user's satisfaction. In addition, there are some concerns about the objectivity of the approach and the usefulness of the proposed methodology and the samples, which are discussed as follows:

1. Image word is highly subjective. People can interpret the words differently.

2. The relationship between image word and aesthetic perfection is not mentioned. For example, how simplicity or complexity can change the aesthetic preference of a particular product.

3. Only 4 form samples are used in the study which seems too limited.

4. Only 2D images are used in the study. Form and colour perception can change by using images of the 3D models.

5. The colour variation is only applied to the main body of the phone and the other components are ignored which can dramatically change the colour combination and consequently the final preference.

Although the study tries to implement some known engineering and statistical methods to the practical industrial design process, its limited input variables and its unknown relationship with optimum aesthetic preference make it far from a capable and comprehensive methodology.

1.4.2.8. A robust design approach for enhancing the feeling quality of a product: a car profile case study

This study tries to develop a method to reduce the discrepancy between the "consumer feeling and the target feeling" in product design. For instance, if the target feeling is "luxurious" the method determines to what percentage, the consumer perception of the product matches the luxurious feeling. The study defines the discrepancy between target and consumer feeling (output). In addition to the discrepancy between target and consumer feeling, also a feeling can be differently interpreted by different consumers which is called 'feeling ambiguity'. Taguchi method (1990) is used to identify "optimal product design parameters" in order to enhance "the feeling performance of the product" and decreasing the effectiveness of the discrepancy between individual characteristics. First, the target analysis is performed in order to "specify the position of the target feeling in a feeling space composed of various critical image scales". Then, Taguchi method is employed using "inner and outer orthogonal arrays". 'Inner arrays' is related to the number of control factors (e.g. design parameters) and 'outer arrays' is determined by the number of uncontrollable factors (e.g. user characteristics). Then, the optimal parameter for each factor is identified using signal to noise ratio formula.

The car profile design is selected as stimuli in order to test the proposed methodology. In order to construct the target feeling of the sample, three image word pairs are defined: ‘young-mature’, ‘field-city’, and ‘personal-family’. 9 scales are allocated to each word pairs and the scale of 2, 2, and 7 are chosen for the group words respectively. Therefore, the target feeling is defined as $T=[2,2,7]$. Then three product designers are asked to generate ‘three’ car profile designs (control factor) according to the defined target feeling by compiling 125 existing images using 13 variables. These 13 variables are (1) the ratio of car’s height to car’s length, (2) the ratio of chassis’s height to wheel axle’s height, (3) the ratio of wheel’s diameter to car’s height, (4) the ratio of fender’s length to car’s height, (5) the ratio of fore region’s length to whole length, (6) the ratio of fore protruded part to car’s length, (7) the ratio of apex’s position on whole hood line, (8) the gradient of fore windshield, (9) the gradient of fore fender’s bottom, (10) the ratio of rear region’s length to whole length, (11) the gradient of rear windshield, (12) the gradient of trunk’s rear, and (13) the gradient of rear fender’s bottom. These variables are used in 3 levels: minimum, average, and maximum. Then four psychological attributes are selected as uncontrollable factors: “involvement, personal trait, peer relation, and social support”. These factors are applied in three levels: low, medium, and high for involvement, introvert, medium, and extrovert for personal trait, aloof, medium, and intimate for peer relation, and scanty, medium, and abundant for social support. 27 subjects are then asked to express their feeling about 27 combined designs which are displayed on A4-sized cards by rating the designs from 1 to 9 for each image word pairs. Then, the discrepancy between the subjects is calculated. The standard deviation for all the parameters is lower than 1; therefore, all values are acceptable.

Using Taguchi formula, signal to noise ratio for each combination of 13 shape factors (3 designs for each factor based on 3 levels) is measured. The higher signal to noise ratio of each shape factors shows the higher effectiveness of the feeling quality. Therefore, the maximum level of each factor is selected in order to create the “optimal setting”. Although applying all the factors which is associated to the maximum feeling quality has the highest influence, the target of Taguchi method is achieving optimum redesigning by minimum activity. Since each factor has different level of impact on feeling quality, the factors with highest influence are selected. Therefore, 8 shape variables are selected as the highest effective factors and three original designs (control factors) are then redesigned by applying these 8 variables while the original design is used for other 5 variables. The feeling discrepancy and ambiguity of redesign models also are reduced.

Although the study tries to implement Taguchi robust design method in the experiment, the approach and the final results seem to be unreliable due to the following reasons:

1. Although rate 7 of 'family' against 'personal' as an image word is chosen at the beginning of the study, all three proposed redesigned shapes are smaller than the original designs. It is obvious that family cars must be bigger.

2. Although each design factor may or can influence the feeling quality, the combination may have a completely different impact.

3. The experiment is highly depending on subjective interpretations. This affects the objectivity and consequently the robustness of the proposed methodology.

4. It is not mentioned that how 'feeling quality' can enhance the final preference of the product appearance.

5. The visual impressions are generated based on a number of factors while only one (silhouette shape) is used in the study. The final preference can be completely different for a real product.

6. The process of generating the initial designs (as the main stimuli of the experiment) is not discussed.

7. The process of creating 13 shape variables as the main factors in modifying and redesigning the car profiles is not mentioned.

8. The condition of the experiments (e.g. allocated time) is not provided.

1.4.2.9. Measuring consumer perceptions for a better comprehension, specification and assessment of product semantics

This study tries to develop a methodology to link the 'product semantics' and consumer's need. 'Perceptual space' is built in order to assess consumer's need using three methods: 'semantic differential' (SDM), 'multidimensional scaling' (MDS), and 'pairwise comparison' (PC). 'SDM' is used to assess the user's taste based on pairs of adjectives. 'MDS' creates a visual representation of the 'perceptual space' using "dissimilarity assessment" based on subjective evaluation of the "degree of similarity" of the pairs of stimuli. 'PC' technique aims to estimate the relative value of a score of pairs of stimuli according to a defined criterion. The proposed methodology tries to evaluate 'product semantics' in 8 steps:

1. Defining semantic attributes in which subjects are asked to express their feeling about the existing products and then relevant word pairs are extracted.

2. Using MDS method to determine dissimilarities between products in order to find "perceptual dimensions".

3. Using SDM to identify the "reasons for product differentiations". 'Principle component analysis (PCA)' is applied to SDM data to detect synonym pairs of adjectives and the pairs which are less effective on the variance of the evaluation in order to remove irrelevant word pairs and consequently "to reduce the dimensions of the semantic space".

4. Using **PC** method to give each semantic attribute a weight which is performed by subjects.

5. Defining the semantic space of user's need by identifying the position of the new product in the perceptual space and determining the specifications of the ideal product.

6. Designing the first concept of the new potential products using achieved specifications in step 5.

7. Using PC method to score potential products according to semantic attributes.

8. Rating the designed products based on their distance to the ideal product using decision-making method (AHP).

15 glasses are chosen as stimuli and 10 subjects are asked to express the attributes and characteristics of the glasses based on their perception. Therefore, 17 pairs of adjectives are created (traditional-modern, classy-vulgar, easy for drinking-not easy for drinking, common-particular, decorative-practical, unoriginal-creative, unstable-stable, existing-new, complicated-simple, good perceived quality-bad perceived quality, multi-usage-occasional, strong-fragile, easy to fill-not easy to fill, masculine-feminine, flashy-discreet, coarse-delicate, and easy to handle-not easy to handle). Subjects are then asked to group the glasses based on their similarities in order to define 'dissimilarity matrix' in MDS. Based on these classifications, the "perceptual coordinate" of glasses is calculated and presented in 2D space. Subjects are then asked to rate the glasses based on the 17 pairs of adjectives in 7 levels. After analysing the adjectives, 13 semantic words are selected for each pair (Modernity, Smartness, Ease of drinking, Decorativeness, Originality, Stability, Simplicity, Fragility, Quality, Ordinariness, Ease of filling, Showiness, and Ease of handle).

Using PC method, each glass is then assessed based on each semantic attribute. Therefore, all 15 glasses in pairs are compared with each other and approximately 30 subsets for each semantic attribute are rated from 1 to 7. The mean of each score is then weighted using PC matrix. The consistency of the declared scores is evaluated and it shows low consistency for two semantic attributes (decorativeness and ease of drinking) and high consistency for originality and showiness which indicates how much these attributes are meaningful for the subjects. Two stages are proposed in order to define the semantic space of user's need: first, determining the position of the ideal glass in the perceptual space by calculating linear combination of the vectors of semantic attributes rated by the subjects. Second, the specifications of the new glasses are suggested by comparing the existing glasses with the ideal one for each semantic attribute. Therefore, two new glasses are proposed for two different purposes: occasional (N1) and regular use (N2). The new glasses are then rated and the result is compared with other glasses. By applying the relevant semantic attributes, the satisfaction score for N1 and N2 is calculated. By comparing the score of N1 and N2 with the ideal product it is then revealed that N1 is a satisfactory option and N2 can be improved.

The study tries to develop a methodology of proposing ideal product based on the semantic attributes of similar products which are obtained from subjective expressions. The main advantage of the model is combining the adjectives related to both appearance and the function. However, there are major disadvantages which decrease the reliability of the approach which are discussed as follows:

1. The result of the proposed method is relative to other products while the relationship between this link and aesthetic preference is not discussed.

2. Semantic attributes are highly subjective and can be interpreted differently by different group of people.

3. The process of selecting 17 word pairs is not discussed.

4. Number of subjects participated in the study is too low (only 10).

5. The glass as a stimulus has very limited functionality. It is unclear how the method can perform for more complex products.

6. The method of determining the weight of the attributes is affected by the level of consistency of the declared preference. This can be eliminated by swapping the order of these two stages.

7. Potential variation of the design elements is not mentioned. For instance, how the colour of glasses can be evaluated compared to the other stimuli in the same category while selecting the ideal product.

1.4.3. Outcome of previous research

As can be seen from the applied approaches and methods of previous research most of them focus on developing engineering and statistical analysis rather than fundamental effective qualities. Figure 3 summarises how previous studies have approached the aesthetic evaluation.

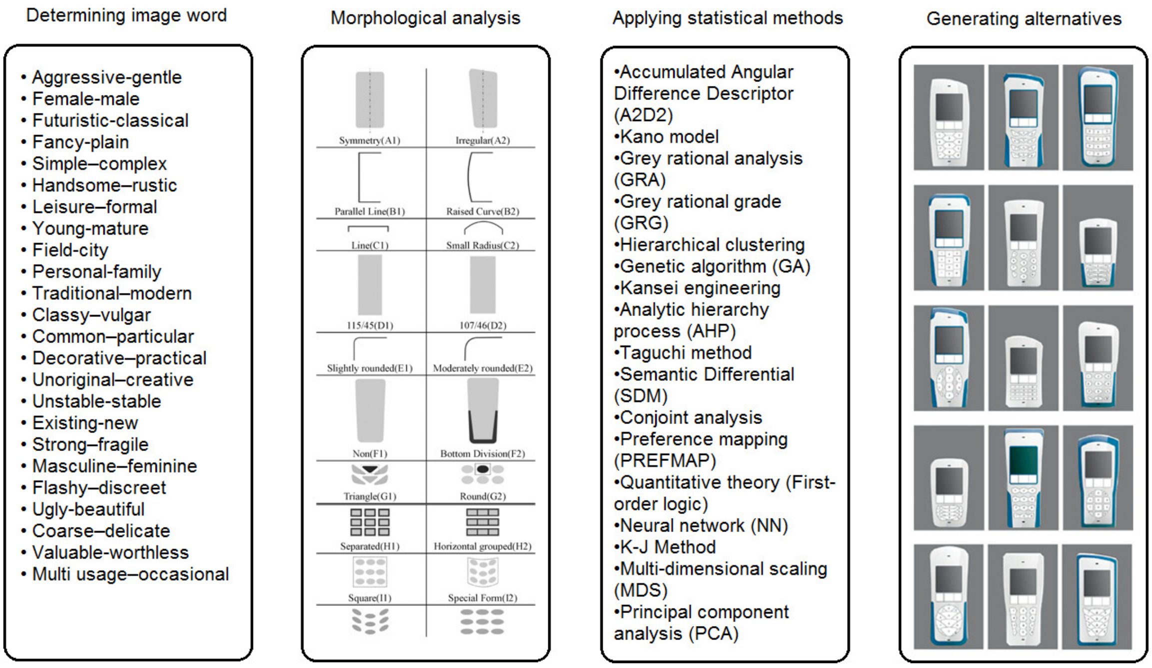


Figure 3: Summary of previous approaches in aesthetic evaluation (figures have been obtained from Chen & Chuang, 2008)

Variables of the applied stimuli are very limited, and subjective interpretations dominate the foundation of the studies. Most of the results are far from an optimised design and some of them even provide lower quality compared to the original design. While 'art' is the main foundation of product aesthetic, no clue of art knowledge or application is seen in the studies. Although user's preference is highlighted in the studies, no psychological related investigation is conducted. Most of the load in the approaches is associated with the analysis method while the importance of the input data is ignored. The reason is engineering methods singly cannot provide a comprehensive solution to the problem. As already discussed, aesthetic is multidimensional and other than science and engineering methods, the related studies of art and psychology are also required in developing a design methodology. Therefore, this research aims to develop a universal and capable design methodology by making a balance between input data and the analysis processing based on effective dimensions in aesthetic judgment to produce valid and reliable outcome (see Figure 4).

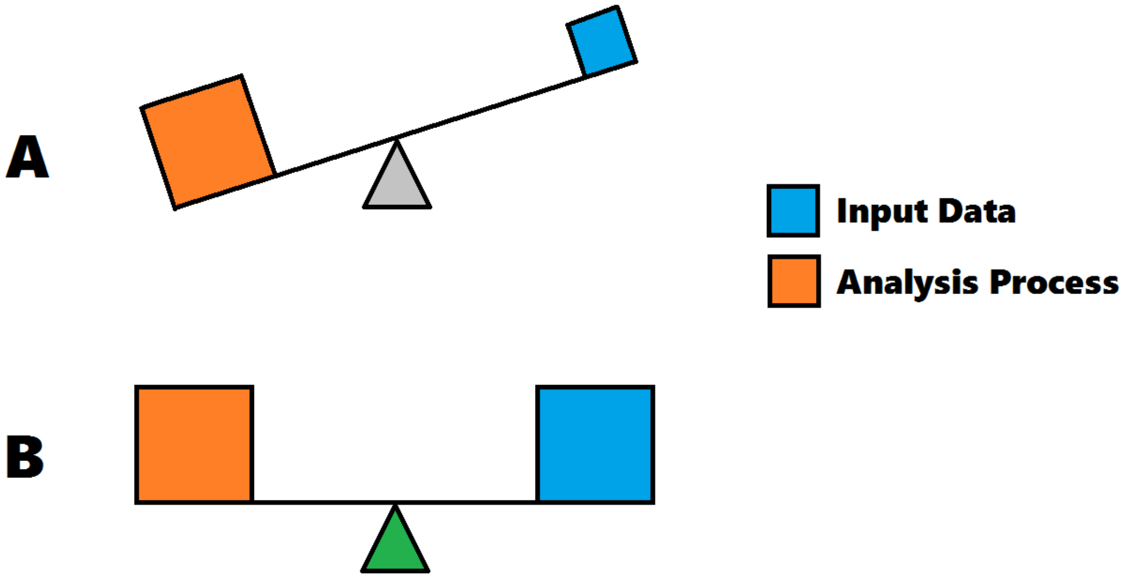


Figure 4: A: Previous research load in terms of input data and the process of data analysis. B: The research methodology makes a balance between input data and the analysis process in order to achieve the optimum and universal result.

1.5. Research methodology

After reviewing relevant literature and identifying research question, 5 steps are considered in research methodology.

1.5.1. Identifying and clarifying the qualities of aesthetic

As part of theoretical framework of the research, the qualities of aesthetic are identified based on the fundamental of visual art such as visual properties and visual elements. Moreover, previous definitions are clarified in order to create quantifiable visual variables.

1.5.2. Visual tests

The defined aesthetic qualities are examined using subjective experiments in order to evaluate the nature of relationship between preference and aesthetic variables.

1.5.3. Identifying relevant measuring tool

In order to precisely quantify the qualities of aesthetic interacting with viewers' preference, a measuring tool is required. This tool has to be capable of determining the related visual qualities via measuring involuntary responses.

1.5.4. Objective experiment

Using the identified measuring tool, the qualities of aesthetic are quantified via the experiments in which relevant stimuli are used. The stimuli have to be designed in a way that the required data related to aesthetic qualities are measurable.

1.5.5. Data analysis and defining equations

Based on three sources (fundamentals of visual art, declared preference, and output data of the measuring tool), the mathematical equations are defined.

Using the defined variables (quantified via the measuring tool), the equations will be able to calculate the exact value of each quality of aesthetic which shows how much the visual property of a stimulus is close to the viewer's preference.

1.5.6. Developing design methodology to enhance aesthetic

Visual metrics are defined based on interactions between aesthetic qualities and design elements. Using the defined quantification methodology, each metric is measured. Finally, the instruction of applying the quantified metrics is defined. The sample products are provided in order to illustrate how applying the visual metrics can enhance the aesthetic.

1.6. Hypotheses

This research contains three kinds of hypothesis: theoretical, experimental, and practical. Theoretical hypothesis are related to the fundamental definitions of aesthetic qualities. Experimental hypothesis require objective experiments, and practical hypothesis are related to the design process.

1.6.1. Theoretical hypothesis

1. Given the definition of the qualities of beauty; beauty is a certain balance between proportion, pureness, and contrast.

2. Given the definition of the qualities of aesthetic; beauty, novelty, and appropriateness are major effective factors in the final aesthetic judgment.

1.6.2. Experimental hypothesis

1. Aesthetic and its qualities can be quantified via a mathematical formula by analysing the eye movement.

2. Level of influence of attractiveness in aesthetic preference is dependent upon the function.

1.6.3. Practical hypothesis

1. Designers are biased in judging their own design compared to other's work in which the declared preference does not always match their involuntary response.

2. Refinement of the design sketch and rendering affects the qualities of aesthetics and the final preference.

Chapter 2: Theoretical framework

2.1. Terminology

2.2. Qualities of aesthetics

2.3. Qualities of beauty

2.4. Qualities of attractiveness

2.5. Interaction of design elements and aesthetic qualities

2.1. Terminology

This section explains the visual design related terms which are essential in understanding the aesthetic concept in design.

2.1.1. Elements of design

'Elements of design' refers to the visual properties of a 2-dimenstional or a 3-dimensional material-made construction (Kostellow, 2002) consist of 'form', 'shape', 'colour' and 'texture' (White, 2011; Boulton, 2009).

2.1.1.1. Form and shape

'Form' refers to 3-dimensional boundary of an object while 'shape' is a 2-dimensional representation (e.g. a square is a shape of the profile of a cube) which can be defined as 'organic' or 'geometric'. Organic forms/shapes are mathematically unknown which are mostly inspired by natural forms/shapes such as form/shape of a rock while a geometric form/shape is known and can be mathematically defined such as sphere or cube, circle or square (William, 2013) (see Figure 5).

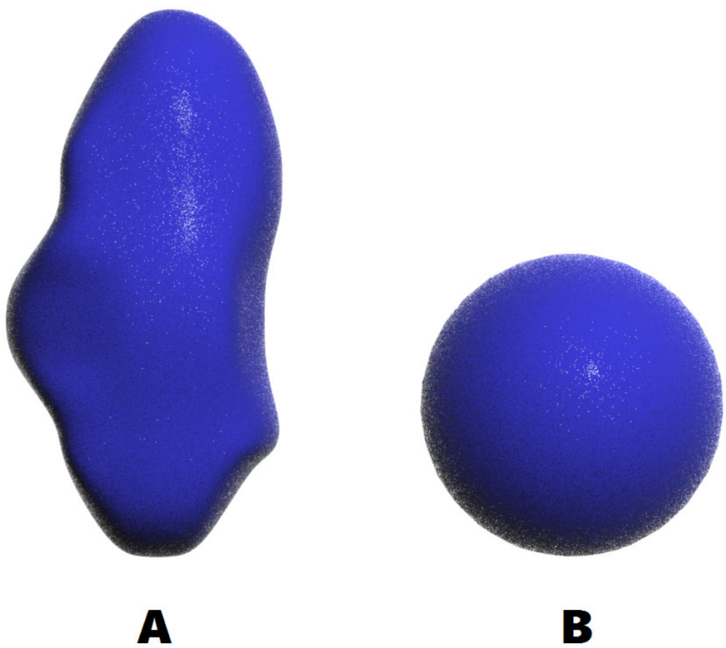


Figure 5: Organic form (A) vs geometric form (B)

2.1.1.2. Colour

'Colour' attributes consist of 'hue', 'saturation', and 'luminosity (or value or lightness)'. Hue is the main property of a colour which consist of the main hues: 'red', 'yellow' and 'blue' in material and 'red', 'green', and 'blue' in light. All other hues are created by combination of the main hues. Saturation indicates how much 'grey' is mixed with hue in which less grey means higher saturation. Luminosity shows how much 'white' or 'black' is mixed with hue. 'More white' means higher luminosity and 'more black' means lower luminosity (Itten, 1974). In the digital environment, these variables, depending on the colour depth, can be allocated a number. In 24-bit colour depth (known as true-colour) each attribute of hue, saturation, and luminosity has 256 levels. Therefore, $256^3 = 16{,}777{,}216$ different colours are generated (Poynton, 2003). Each colour can be defined using a code between 0 and 255. For instance, the colour used in Figure 4 is identified in specific software by the codes (170,190,220) which indicates hue, saturation, and luminosity respectively.

2.1.1.3. Texture

'Texture' is associated with the surface of the material. Although it is related to the sense of touch, it can be visually perceived (Kostellow, 2002). Generally, there are two types of properties related to the texture of a material: smoothness/roughness (surface) and natural/artificial (pattern) (Gatto, 2000) (see Figure 6). Natural or artificial textures can follow a known pattern or they can be erratic (Kostellow, 2002).

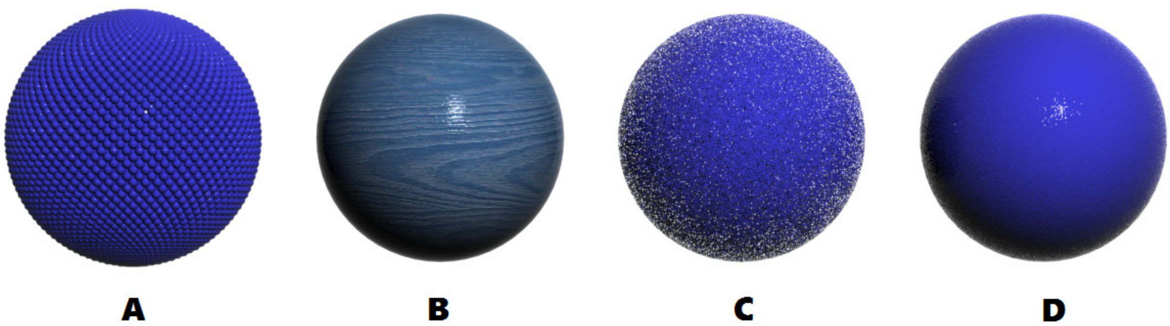


Figure 6: A: artificial texture; B: natural texture; C: rough texture; D: smooth texture

2.1.2. Gestalt

Gestalt refers to the whole design elements when implemented as one. In other words, gestalt is the final outcome of the applied visual elements (Suh, 1993).

2.1.3. Composition

Composition indicates how design elements are implemented beside each other. In other words, composition determines the arrangement of the visual elements of a 'gestalt' (Lidwell, Holden, & Butler, 2003).

2.1.4. Visual force

Visual forces are generated by the design elements which can control the eye movement and the 'visual weight' (Bradley, 2013) (see Figure 7).

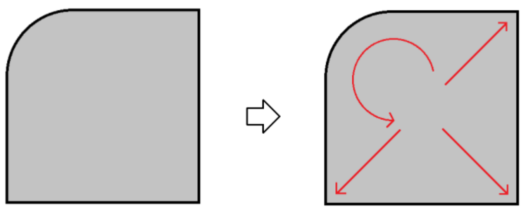


Figure 7: the visual force is different on the top left of the design (indicated by the red colour).

2.1.4. Visual weight

Visual weight refers to the amount of eye attraction among different areas of a 'gestalt' generated by design elements which is controlled by 'visual force' created by the 'composition' of the design (Bradley, 2013) (see Figure 8).

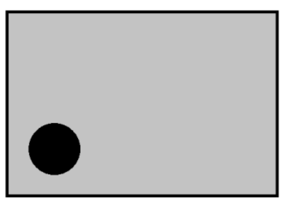


Figure 8: the visual weight is more at the bottom left of the design.

2.1.5. Design elements and visual weight

The properties of the design elements can control the visual weight in a composition. For instance, changing shape's and form's nature, colour (hue, saturation, and luminosity), texture, and size, position, and the orientation of the elements change the visual forces (Bradley, 2013). As Table 1 shows, each visual property contributes in controlling the visual forces and consequently determines the visual weight.

Visual property	High visual weight	Low visual weight
Size of element	Large elements	Small elements
Position of element	Lower in the composition	Higher in the composition
Orientation of element	Vertical/Diagonal	Horizontal
Density of elements	Higher density	Lower density
Shape's nature	Geometric	Organic
Form's nature	Geometric	Organic
Colour hue	Red, Blue	Green, Yellow
Colour Saturation	Higher saturation	Lower saturation
Colour luminosity	Lower luminosity	Higher luminosity
Texture surface	Rough	Smooth
Texture pattern	Artificial	Natural

Table 1: example of how visual properties control the visual weight

2.2. Qualities of aesthetics

As mentioned in **section 1.1.2**, product aesthetic is related to concinnity and functionality. ‘Beauty’ is related to concinnity and ‘attractiveness’ is associated with functionality.

2.2.1. Beauty

‘Beauty’ refers to a pleasant composition in a gestalt (Etcoff, 1999; Elam, 2001, Kostellow, 2002). In other words, beauty defines what relationship between the properties of the design elements is visually perceived delightful (Kostellow, 2002). Beauty is ‘rational’ (Khalid & Helander, 2006), ‘objective’ (Crilly, Moultrie, & Clarkson, 2004), ‘timeless’ (Etcoff, 1999), ‘absolute’ (Coates, 2003), and ‘independent of function’ (Norman, 2004). ‘Rational’ means it follows a specific (Jacobsen, Schubotz, Hofel, & Cramon, 2006) and definable pattern (Zain & Tey, 2008). ‘Objective’ means the judgment does not vary among people (Kumar & Garg, 2010). ‘Timeless’ means the beauty pattern is independent of time (e.g. if something is beautiful now it is beautiful at any time) (Etcoff, 1999). ‘Absolute’ means beauty is only affected by the external variables (Coates, 2003). ‘Independent of function’ means beauty of an object is not connected to the perception of what the object can do (Norman, 2004).

2.2.2. Attractiveness

‘Attractiveness’ refers to a positive response to a functional stimulus (Khalid & Helander, 2006; Crilly, Moultrie, & Clarkson, 2004). In other words, something is perceived attractive when it can satisfy the sentimental requirements (Lai, Lin, Yeh, & Wei, 2006). Unlike beauty, attractiveness is ‘emotional’ (Norman, 2004), ‘subjective’ (Khalid & Helander, 2006), ‘time dependent’ (Crilly, Moultrie, & Clarkson, 2004), ‘relative’ (Hung & Chen, 2012), and ‘function dependent’ (Sylcott, Cagan, & Tabibnia, 2011). ‘Emotional’ means it does not follow any defined pattern (Norman, 2004). ‘Subjective’ means perception of an attractive object varies among different people (Huang & Henry, 2009). ‘Time dependent’ means it changes over time (Crilly, Moultrie, & Clarkson, 2004). ‘Relative’ means attractiveness is affected by the external variables (Hung & Chen, 2012).

‘Function dependent’ means attractiveness does not exist when the function is unknown (Sylcott, Cagan, & Tabibnia, 2011).

Beauty and attractiveness as cognitive and affective responses to an external stimulus (Crilly, Moultrie, & Clarkson, 2004) constitute the product aesthetic (Coates, 2003). As can be seen from the features of beauty and attractiveness (and it was mentioned in **section 1.1.2**), these two qualities have opposite variables. In order to define these variables, the constituent factors of each quality must be defined.

2.3. Qualities of beauty

A General definition of beauty is given in the previous section. However, in order to develop a model capable of measuring beauty, it has to be technically and fundamentally defined.

2.3.1. Contrast

Because visual aesthetic is visual, it is directly connected to what is seen. The reason that the eye can recognise an object is a difference between the properties of the object and the properties of the background (Kostellow, 2002). For instance, what makes you able to see the text on this paper is a difference between the colour of the text and the colour of the paper. This phenomenon is called ‘contrast’ (Coates, 2003). This concept of difference is not only limited to the subject and to the context, it is also related to the physical properties of that subject (Bradley, 2013). For example, the difference between the height and the length of an object makes a contrast (Elam, 2001). In addition, the number of these differences increases the contrast (Coates, 2003). Thus, contrast is made by the quality and the quantity of the difference generated by the elements and the ‘composition’ of the ‘gestalt’. More difference means higher contrast and vice versa (Khalighy et al., 2015).

2.3.2. Pureness

Pureness is a quantitative part of contrast (Kostellow, 2002). It determines number of elements which exist and attract the eye (Coates, 2003). Therefore, higher pureness means fewer attention-grabber elements and vice versa (Khalighy et al., 2015).

2.3.3. Proportion

Proportion is a qualitative part of contrast (Kostellow, 2002). Proportion refers to the similarity between the properties of the elements (such as nature, size, colour, and position) (Papanek, 1974). In other words proportion determines the balance between the ‘visual weights’ generated by the composition of the gestalt (Coates, 2003). Higher similarity means higher proportion and vice versa (Khalighy et al., 2015).

2.3.4. Interaction of the qualities of beauty

As can be seen from the definitions of effective qualities of beauty, contrast has inverse relationship with proportion and pureness. In other words, when proportion and pureness increase, 'contrast' drops and vice versa (see Figure 9).

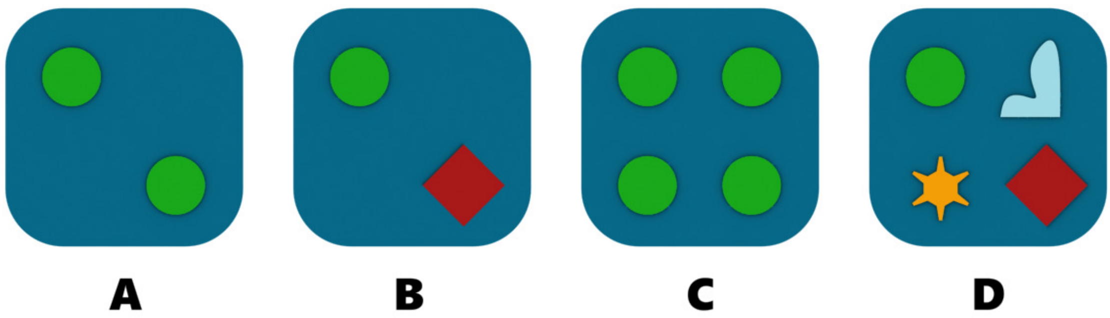


Figure 9: increasing the contrast of figure A by increasing the difference between the properties of the elements (decreasing the proportion) (figure B), increasing the quantity of the elements (decreasing the pureness) (figure C), and increasing both features (decreasing proportion and pureness) (figure D).

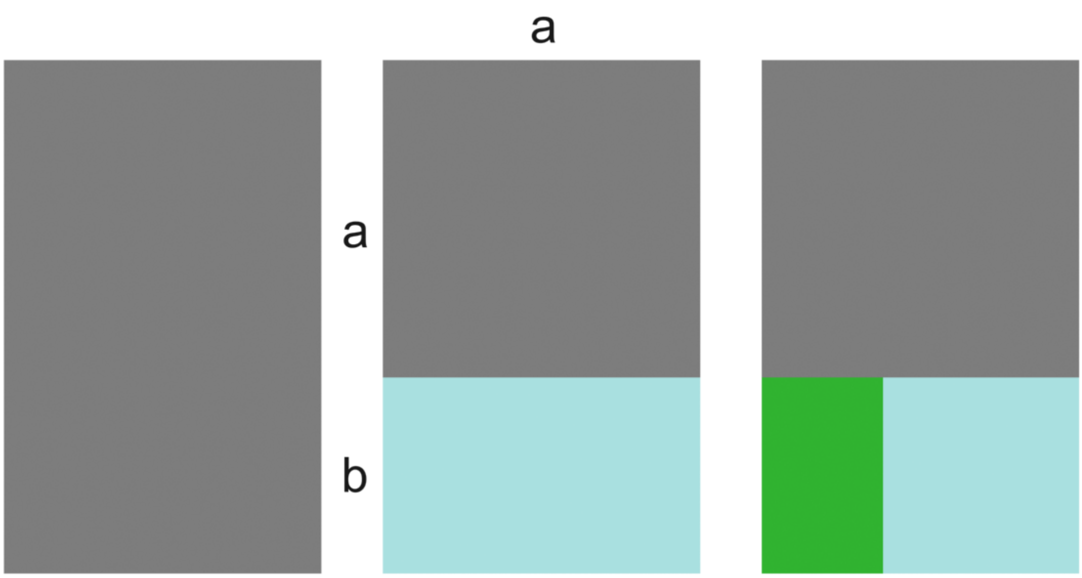
Thus, 'contrast' makes the eye able to recognise an object and it determines the proportion and the pureness of the composition of the gestalt. Therefore:

$$contrast = f(\frac{1}{pureness}, \frac{1}{proprtion})$$

Beauty is defined by contrast, pureness, and proportion. Therefore, the optimum beauty is a certain balance between its qualities:

$$beauty = f(contrast, pureness, proportion)$$

This theory can explain the reasons behind preference of a known phenomenon. For example, the golden ratio has been the most preferred ratio since it was discovered (Elam, 2001). If a golden rectangle as a representative of golden ratio is compared with a square, it provides a lower proportion compared to the square because unlike a rectangle, it has same length and width. But contrast is needed as one of the qualities of beauty. Therefore, the preferred shape must be a rectangle rather than a square and golden rectangle is the answer because it is the only ratio in which smaller and bigger rectangles are similar if it starts to drift away from a perfect square. In other words, the golden rectangle is composed of a square plus another golden rectangle (see Figure 10).



$$\frac{a+b}{a}=\frac{a}{b}$$

Figure 10: in golden ratio, the smaller (blue) and the bigger (grey) rectangle are similar. This similarity shows that the golden rectangle is the most proportional rectangle which is why it is the most preferred ratio.

2.4. Qualities of attractiveness

As discussed, attractiveness is the emotional part of the aesthetic preference. It emerges when an object subjectively becomes meaningful. This meaning varies depending on the function (Verma & Wood, 2001) and consumer's features (Breemen, Knoop, Horvath, Vergeest, & Pham, 1998; Noble & Kumar, 2008). Attractiveness is determined by the variables of 'creativity' (Christiaans, 2010; Sternberg, 2006; Gero & Maher, 1993) and these variables are 'appropriateness' and 'novelty' (Paletz & Peng, 2008; Lubart & Sternberg, 1995).

2.4.1. Appropriateness

'Appropriateness' determines the preference of a gestalt for a known function (Chang, Lai, & Chang, 2006; 2007). For instance, people may perceive 'low height' appropriate for a sport car and find it attractive. Appropriateness is associated with the product character (Langmeyer & Shank, 1994) and because of the factor of familiarity (known function) it includes the elements of 'typicality' (Veryzer & Hutchinson, 1998; Barsalou, 1985). The preference increases when consumers perceive the product more appropriate for the function (Hekkert, 2006). The following example is provided in order to clarify how appropriateness interacts with the properties of the design elements. In this example the design of user interface of two mobile operating systems will be compared: 'iOS' form Apple® Inc. and 'Windows Phone' from Microsoft® Corp. 'Icon' as a dominated element in designing the interface is selected. In both operating systems, the shape of the 'icon' is a square. The difference in the icon design is that 'iOS' square has round corners while in 'Windows' the corners of the square are sharp (see Figure 11).

Figure 11: A: icon's shape in 'iOS' vs B: icon's shape in 'Windows Phone'

As discussed ‘appropriateness’ is associated with the function. Here, each icon represents a different application. Therefore, in terms of the character, each icon has to offer an ‘independent’ character. By looking at the shape of the icons, the visual forces in the square with round corners are incoming while in the sharp-cornered square the visual forces are outgoing (see Figure 12).

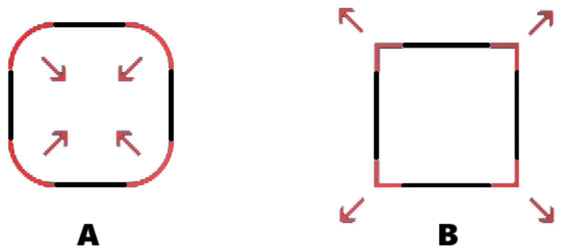


Figure 12: A: the visual forces are incoming because of the round corners. B: The visual forces are outgoing because of the sharp corners.

The incoming visual forces of the ‘iOS’ icon provide an ‘independent’ character compared to the ‘Windows’ icon which matches the defined function’s character and therefore the ‘iOS’ icon design is more appropriate.

2.4.2. Novelty

‘Novelty’ indicates the level of unfamiliarity (Berlyne, 1971) of a gestalt for a familiar function (Hekkert, Snelders, & Van Wieringen, 2003). Each category of a product generates an ‘image’ in consumer’s mind over time (Hung & Chen, 2012). Novelty determines the degree of discrepancy between a new proposed composition and the ‘product image’. The target product is perceived novel for higher discrepancies and perceived typical if the discrepancy is lower (Liu, 2000). Schoormans & Robben (1997) showed that if the discrepancy is too high or too low (very novel or very typical) the preference becomes low. They suggested that the maximum preference lies somewhere in between maximum typicality and maximum novelty. The main factor in generating the ‘product image’ is the ‘main element’ which is associated with the main function (Hsiao & Liu, 2002). Therefore, novelty is not created by eliminating the main element and the category of the product will instead change. For example, wheels are the main elements in a car. If the wheels are removed, the product is not perceived as a novel car because it no longer belongs to the car category

(Khalighy, Green, Scheepers, & Whittet, 2014). Applying untypical elements, orientation, and form size are a few examples of creating a novel design (see Figure 13, 14, 15).

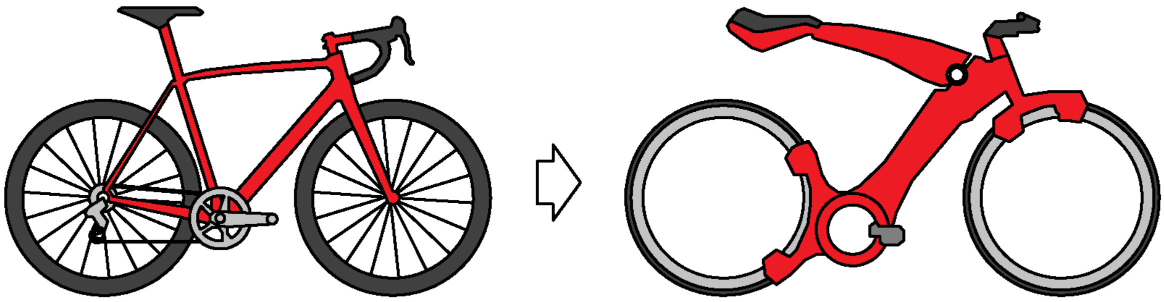


Figure 13: generating a novel design by applying untypical elements

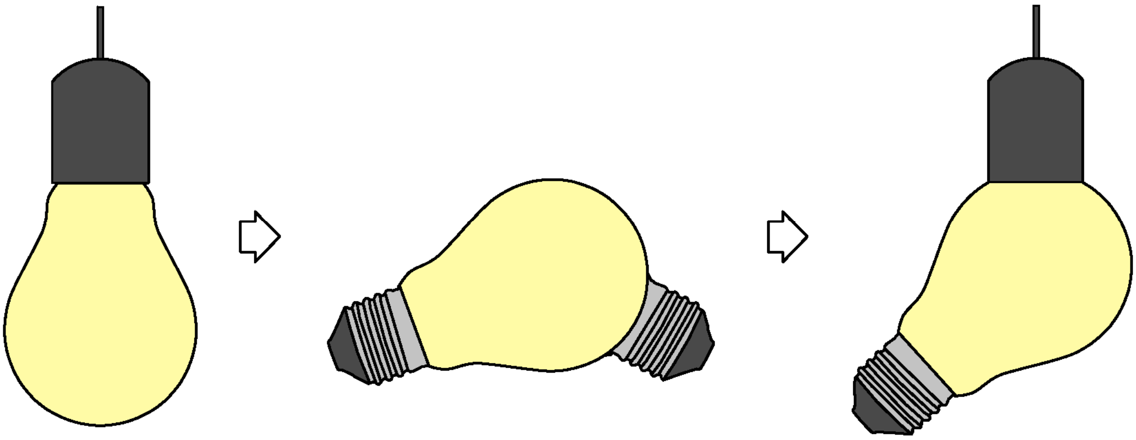


Figure 14: generating a novel design by applying untypical orientation

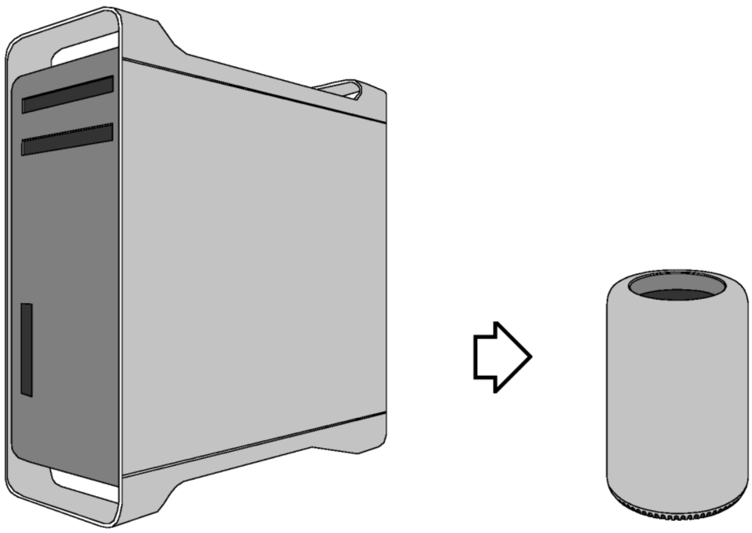


Figure 15: generating a novel design by applying untypical form size

2.5. Interaction of design elements and aesthetic qualities

The process of applying the design elements is divided into two stages: type of the elements and relationships between the elements (Coates, 2003; Norman, 1988). Thus, the optimum 'relationship' between properties of the elements is determined by the qualities of 'beauty' and the optimum 'type' of the elements is identified by the qualities of 'attractiveness' (see Figure 16).

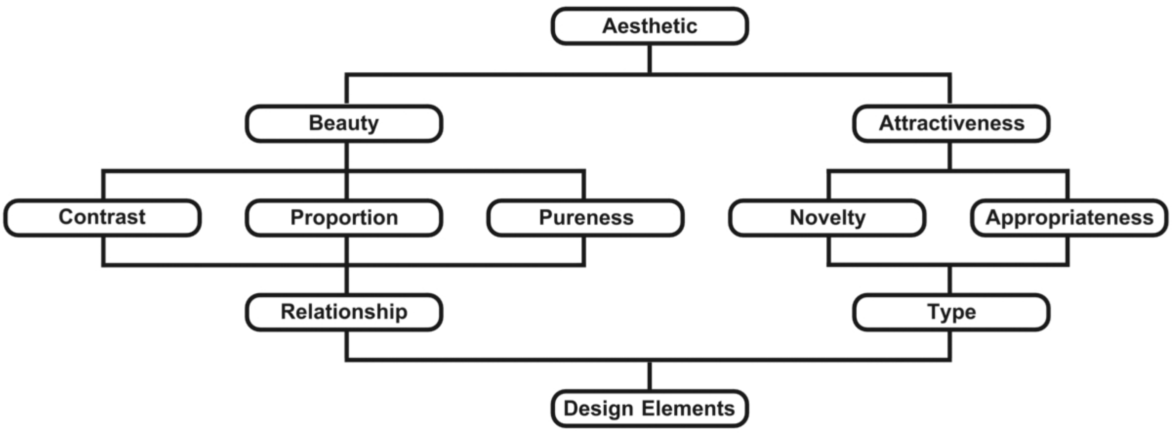


Figure 16: linking the design elements and the aesthetic qualities

If the design elements face the qualities of aesthetics, the intersection of each quality and each element, generates an 'analytical metric' (MA). Table 2 shows the analytical metrics.

Aesthetic qualities	Design elements			
	Form	Shape	Colour	Texture
Contrast	MA01	MA02	MA03	MA04
Proportion	MA05	MA06	MA07	MA08
Pureness	MA09	MA10	MA11	MA12
Appropriateness	MA13	MA14	MA15	MA16
Novelty	MA17	MA18	MA19	MA20

Table 2: MA01-MA20 show the analytical metrics in application of the design elements

If the aesthetic qualities face the combination of the design elements, each intersection creates a 'compositional metric'. Table 3 shows the compositional metrics (MC).

Aesthetic qualities	Design elements							
	1	2	3	4	5	6	7	8
Contrast	MC01	MC02	MC03	MC04	MC05	MC06	MC07	MC08
Proportion	MC09	MC10	MC11	MC12	MC13	MC14	MC15	MC16
Pureness	MC17	MC18	MC19	MC20	MC21	MC22	MC23	MC24
Appropriateness	MC25	MC26	MC27	MC28	MC29	MC30	MC31	MC32
Novelty	MC33	MC34	MC35	MC36	MC37	MC38	MC39	MC40

Table 3: MC01-MC40 shows the compositional metrics in optimum application of the design elements. Each number stands for a combination: 1: Form-Shape, 2: Form-Colour, 3: Form-Texture, 4: Form-Shape-Colour, 5: Form-Shape-Colour-Texture, 6: Shape-Colour, 7: Shape-Texture, 8: Colour-Texture.

Each metric can be applied in different ways depending on the properties of the elements such as size, nature and location which generates sub-metrics. Measuring the aesthetic qualities for each sub-metric creates a comprehensive optimisation database capable of proposing potential solutions in enhancing the product aesthetic. This database can be updated over time by adding more quantified metrics data to be used in the design process (see Figure 17).

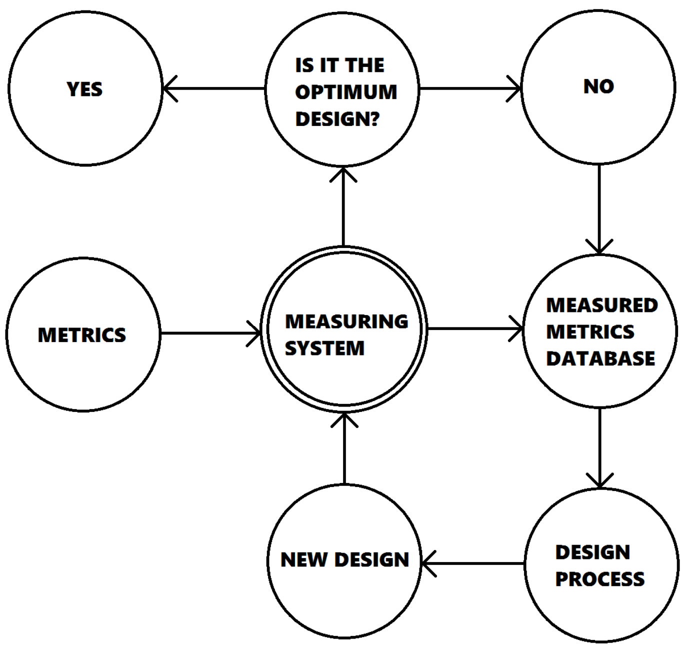


Figure 17: Design process using the effective metrics

An objective measuring methodology is required in order to develop the quantification system by using an appropriate measuring tool. The process of generating the aesthetic quantification system is discussed in the next chapter.

Chapter 3: Building the methodology

3.1. Interaction of beauty and attractiveness

3.2. Interaction of beauty qualities

3.3. Measuring tools

3.4. Eye-tracking technology

3.5. Quantification methodology

3.1. Interaction of beauty and attractiveness

Subjective experiments have been undertaken in order to study the effectiveness of the theoretical qualities of aesthetic on the user's preference. The first experiment evaluates how attractiveness affects the aesthetic judgment. The images of various types of products were selected as stimuli. As discussed, attractiveness is meaningless in the absence of function. Therefore, a copy of an image was manipulated so that the indication of product function was removed. Thus, two similar pictures with different purposes were used: one with the explanation of product in which the judgment contains both beauty and attractiveness and the other without any clue of the function in which the judgment is only based on the beauty. In addition, images of one object with the same design elements but with different functionality (used in different contexts) were provided. 56 subjects were selected from design students. 9 images were shown via a projector one by one (see Figure 18).

Figure 18: The images used in the experiment as stimuli

Each image stayed on until all the subjects rated the images (no time limitation was applied). First, the pictures without indication of function (1 to 4) and then, pictures which were indicated as a known product (5 to 9) were shown. The answer sheet was distributed among the subjects and they were asked to tick one number from 1 to 10 in terms of the level of pleasantness (see Appendix 1). The age and the gender of the students also were recorded. The results show that the preference is different when the function is revealed (in some cases lower and in some other higher). Figure 19 shows the result of the experiment which is divided by gender. Blue bars are the judgments based on the beauty of an object while red and the green bars indicate the preference when attractiveness interferes. As can be seen from the graphs, for image 1-5, the preference of the known product is higher while for image 3-8 and image 2-6 the preference of the actual product is lower. The preference of the image 4 is lower when it is used as a tray (image 7) while the preference is higher when it is used as a tablet computer (image 9). Thus, the role of attractiveness and its connection with function in aesthetic judgment is shown via the experiment.

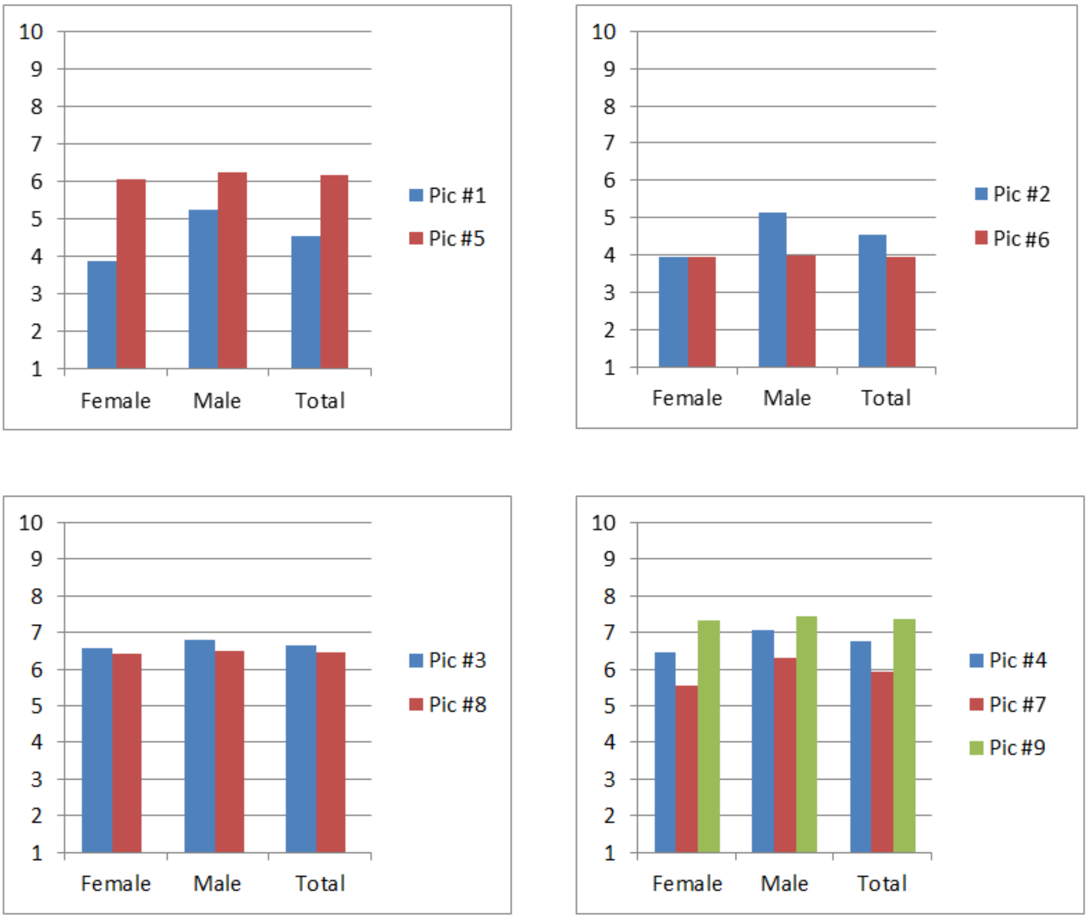


Figure 19: The result of the subjective experiment

3.2. Interaction of beauty qualities

A second experiment is conducted in order to identify the role of the qualities of beauty (contrast, proportion and pureness) on user's preference. Therefore, the images which suggest different levels of application of the beauty qualities are designed and presented via an online questionnaire. There is also an option to magnify each image in the questionnaire (see Figure 20).

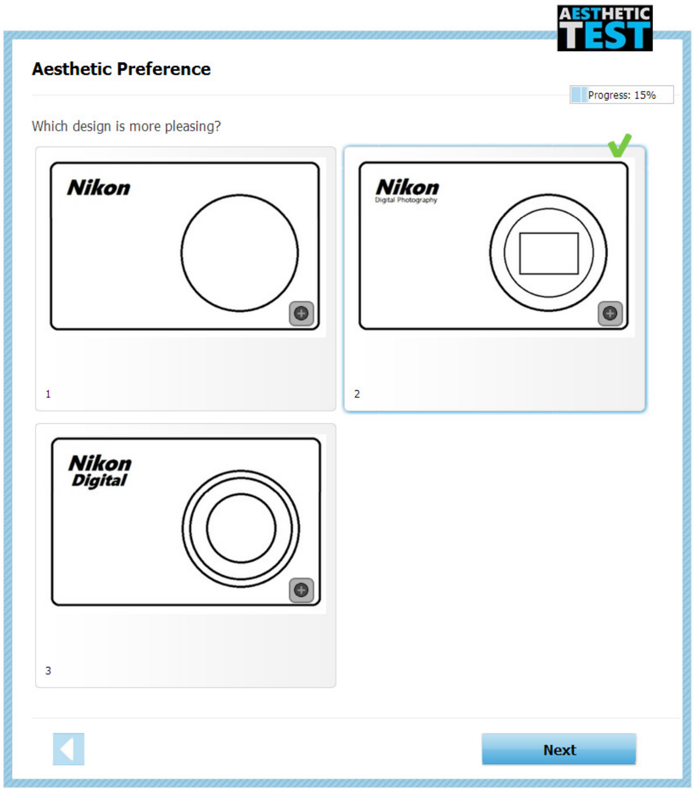


Figure 20: Sample of a question in the online questionnaire

51 participants from different parts of the world (see blue pins in Figure 21) answered the questions by choosing one design as the most preferred one.

Figure 21: 51 subjects from different parts of the world participated in the experiment

Figure 22 shows the images were used in the test and the related answers.

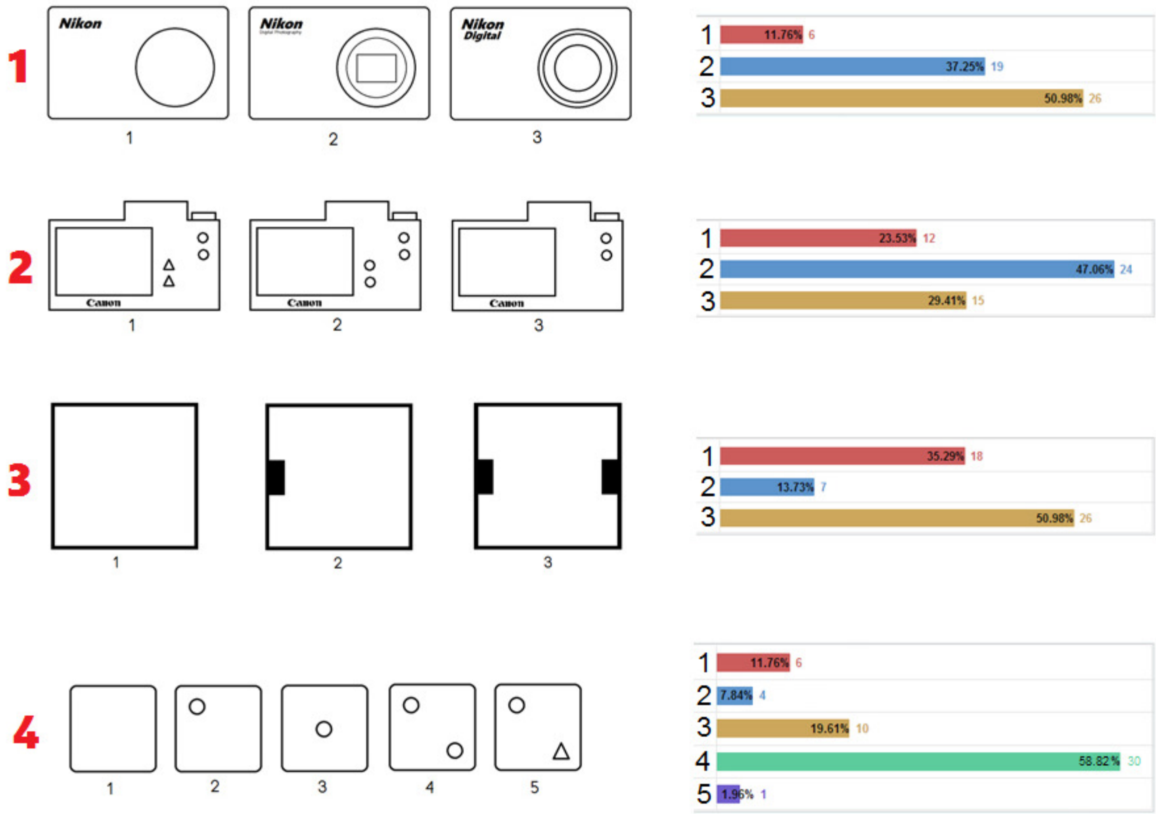


Figure 22: Images which were used in the questionnaire and the responses

Each image is evaluated according to the level of similarity and number of elements which determine the proportion and the pureness respectively. As can be seen from Figure 22 in the first question, camera (1) has the highest pureness and the lowest contrast while camera (2) has the highest contrast. The highest preference is related to camera (3) which has better proportion compared to camera (2) and higher contrast compared to camera (1). As can be seen from the other examples in questions 2 to 4, the same preference pattern has repeated. The maximum preference occurs when a design maintains a certain amount of pureness, proportion, and contrast. Therefore, the result of the experiment showed that contrast, proportion, and pureness as the qualities of beauty are effective in the aesthetic preference.

In order to identify the optimum relationship between these qualities, a measuring tool is required to quantify each quality. Next section will discuss potential solutions in measuring the qualities of aesthetics.

3.3. Measuring tools

A number of methods have been developed in order to measure involuntary responses to product appearance (Green & Jordan, 2002) such as ‘EEG’ (Makin, Wilton, Pecchinenda, & Bertamini, 2012; Motte, 2009; Luck, 2005), ‘body temperature’ (McCrea, 2007), ‘pupil dilation’ (Ho & Lu, 2014; Carbon, Hutzler, & Minge, 2006), ‘eye blink’ (Srinidhi & Ip, 2012), and ‘facial expression’ (Landis, 2010; Tian, Kanade, & Cohn, 2001; Lang, Greenwald, Bradley, & Hamm, 1993). However, these methods have been criticised in terms of reliability due to employing psychophysiological instruments which can only measure the amount of arousal (Desmet, Hekkert, & Jacobs, 2000). Other methods such as PrEmo (Erdogan & Bayazit, 2008; Desmet, Hekkert, & Jacobs, 2000) are also suggested which entirely rely on subjective voluntary responses. Thus, it is required to begin with the fundamentals in order to find a relevant tool which is able to measure involuntary responses.

Visual aesthetic is perceived via the eye. Therefore, a relevant measuring tool is required to determine the eye behaviour while observing a stimulus. Thus ‘eye-tracking’ technology has been identified as an appropriate tool in evaluation of how users look at stimuli for following reasons:

1. It measures the involuntary response which is directly connected to the visual perceiving process. Therefore, it is objective and relevant.

2. It is easy to setup and unlike other methods such as EEG is less complicated and can be setup in a shorter time.

3. The output data is easy to extract and translate.

4. It has been widely used and unlike other methods, its precision and reliability have been confirmed.

Eye-tracking technology has been employed mostly to reveal the interest points on a stimulus (Sun, Xiang, Chai, Yang, & Zhang, 2014; Park, Woods, & DeLong, 2010). In this research this technology is employed as a measure of quantifying the qualities of aesthetics.

3.4. Eye-tracking technology

Eye-tracking refers to the process of measuring eye movement (saccade). The time between each saccade is called 'fixation' (gaze) which is usually measured in millisecond. This is the time which eye fixates on an area before it moves to another area (Duchowski, 2007).

3.4.1. History

Interests in eye movement studies were raised in early 80s in which it was being assessed by direct observation. In 1879, it was discovered that eye movement is not smooth while reading but it is composed of short stops instead. This observation lead to other questions such as the areas that eye fixates on. In 1908, the first eye-tracker composed of contact lenses which were connected to a pointer was built. The early observation of eye behaviour while reading was confirmed by this very first eye-tracker which eye does not fixate on all the words (Duchowski, 2007). 50 years later, series of records of eye movement were made and it was shown that while an observer is looking at a picture, only specific elements attract the eyes (Yarbus, 1967). In 1980, eye-mind hypothesis declared that eye-movement is not a cognitive process (Posner, 1980; Wright & Ward, 2008). The first software-based eye tracker was built in 1982 in order to evaluate the computer's user interface (Hyona, Radach, & Deubel, 2003).

3.4.2. Methods of eye-tracking

Four methods have been used in order to track eye movement (oculography): electro-oculography (EOG), scleral search coil, infrared oculography, and video oculography (Chennamma & Yuan, 2013).

3.4.2.1. Electro-oculography (EOG)

This type of tracking uses electrical sensors which are placed around the eyes. It employs electrodes to measure the eye movement and blink. Unlike optical tracker, it can monitor the eye even when the eye is closed by monitoring muscle movement (Mazo, Barea, Boquete, & Lopez, 2002). EOG has lower accuracy in detecting the eye fixation. Therefore, this type of tracker is mostly used to measure very quick saccades and blinks. The major application of EOG is for disabled people. EOG makes them able to communicate through the eye movement (Bulling, Roggen, & Troster, 2009).

3.4.2.2. Scleral search coil

In this method, wire coil is attached to the eye using contact lens. While eye moves, the coil which is in magnetic field generates a voltage and a signal of the eye position. Although this method produces very accurate result, it is difficult to use due to its direct contact to the user’s eye. Medical research is the main usage area of this tracking method (Chennamma & Yuan, 2013).

3.4.2.3. Infrared oculography

This method uses the measurement of infrared light intensity which is reflected by the eye sclera. The difference between the amounts of light intensity determines the position of the eye. This method compared to EOG is less noisy but more sensitive to the changes in external light. The main disadvantage of this method is that it can measure limited degree of eye movement and rotation. The main advantage is the ability to track the eye in darkness. This method is mostly used in MRI examinations (Chennamma & Yuan, 2013).

3.4.2.2. Video oculography (optical)

Video oculography is the most popular method of commercial eye-tracking due to its safe and quick operation. This method employs video cameras in order to monitor the eye movement based on detecting the pupil due to its darker colour compared to the iris. Therefore, for very dark eyes it may lose the track because of the low contrast between eye pupil and the iris (Duchowski, 2007). There are two types of optical eye tracker (Chennamma & Yuan 2013):

1. Head mounted systems: in this system a headband composed of high speed cameras (to monitor the eye movement) and infrared sensors (to compensate the head movement) is utilised. In this method a headband is set on the user’s head and the eye cameras are adjusted until it can detect the pupil. While eye moves it detects the position of the pupil. The infrared light works with the

sensors which are attached to the corners of the screen. The main advantages of this system are ease of use and high precision (Duchowski, 2007).

2. Remote eye tracker: this system, which does not require a headband, employs video cameras in a defined distance to monitor the eye movement. There are two types of remote eye trackers. First, long-range mount system which has high precision but does not compensate the head movement (therefore, the head must be fixed in a certain position during the tracking process). This type of tracker is mostly used in medical applications. Second, the free head system which has lower accuracy compared to long-range mount system but the head can freely move while monitoring the eye movement (Huchuan, Shipeng, & Gang, 2012).

3.4.3. Eye-tracking terms

Relevant eye-tracking related terms are discussed in this section.

3.4.3.1. Eye fixation

Eye fixation is created when eyes look at a certain area (Theeuwes, 1994; Jonides & Yantis, 1988; Yantis & Jonides, 1984) and it is usually measured in millisecond (see Figure 23).

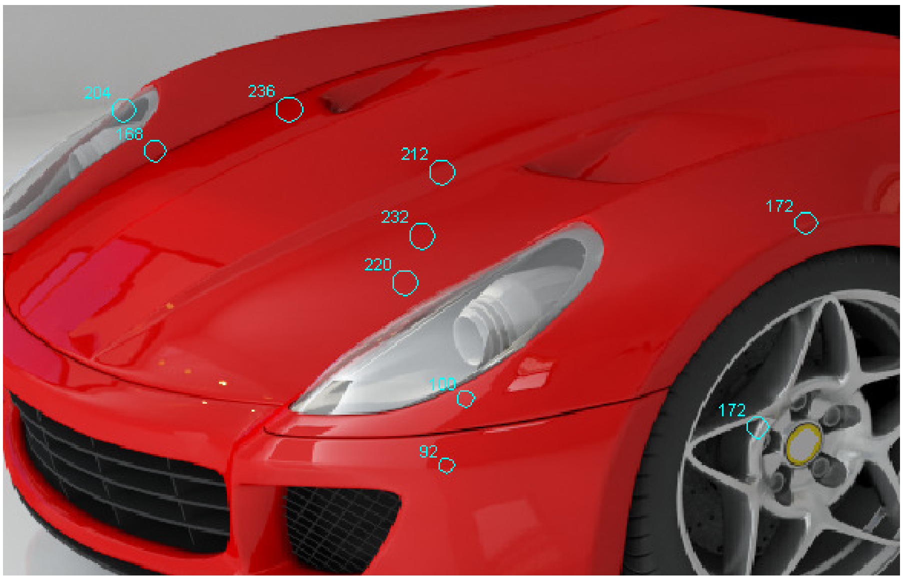


Figure 23: Data viewer software shows the fixations on the trial. Each circle indicates a fixation and the numbers next to it is the duration in millisecond.

3.4.3.2. Saccade

Quick eye movement during visual exploration is called saccade. The direction of saccade is displayable via relevant eye-tracking software. The duration of each saccade is recorded in eye-tracking output data (Duchowski, 2007).

3.4.3.3. Dominant eye

Although both eyes have very similar behaviour, one can be slightly different in terms of saccade and fixations. Due to a complex process of analysis the data generated by both eyes, a dominant eye is selected and the eye-tracking is only performed for the dominant eye (left or right). There are a few methods used in identifying the dominant eye. The frequent method is looking with both eyes open at a target though a triangular hole made by both hands (see Figure 24) and then bringing the hands close to the face. It is assumed that each eye which hands come closer to is the dominant eye (Mapp, Ono, & Barbeito, 2003).

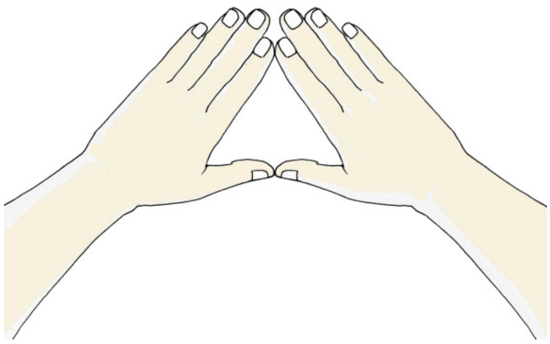


Figure 24: Making triangular shape by hands in order to identify the dominant eye

3.4.3.4. Eye-tracking calibration

The process of matching the real eye position and the software detection of eye position is called calibration. Users are usually asked to look at a black dot on the white screen and fixate on it. While the dot moves to different locations of the screen it calibrates the eye position and the dot position. The reason is it is assumed that the user is looking at the dot because there is only a black dot on the white screen (Hansen & Ji, 2010).

3.4.3.5. Sensitivity threshold

In video oculography the eye pupil is detected as the position of the eye due to its black colour. However, some darker eyes have lower contrast between pupil and the iris. Therefore, the sensitivity threshold of contrast detection is adjusted in order to secure the portion of eye while tracking (see Figure 25).

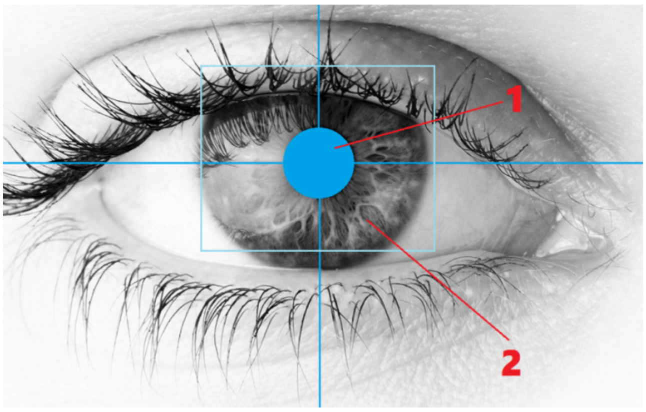


Figure 25: In video oculography pupil detection sensitivity can change in order to secure the eye position while tracking process. 1: pupil detection 2: iris. The detection system works based on the contrast between the pupil and the iris.

3.4.4. Applications

Eye-tracking has been widely used in psychology and medical related studies. Other than that, human factors, vehicle simulation, virtual reality, sports training, web design, advertising, and user interface design are the other popular applications of eye-tracking. It has been also used in camera's view finder in order to detect the focus point according to the user's eye fixation (Duchowski, 2007).

3.4.5. Applied eye-tracker

This research has used the video oculography and head mounted tracker due to its ease of use and precision. The applied tracker is called **EyeLink® II** from 'SR Research Company'. In this section, physical features, technical specifications, running instruction and the input/output data will be discussed. The information in this section has been obtained from the Company's website (http://www.sr-research.com).

3.4.5.1. Physical features

The EyeLink II tracker is composed of a headband and three cameras attached. Two cameras are meant to monitor the eyes and the other one is used to capture a video. The headband size and eye camera position can be adjusted using the rotating screws (see Figure 26).

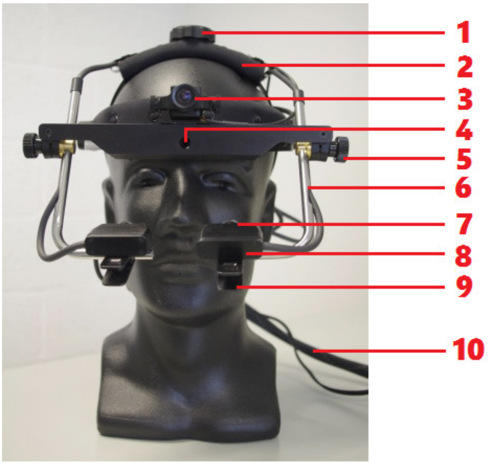


Figure 26: EyeLink II tracker: 1: Headband screw for height adjustment 2: Headband frame 3: Third camera to shoot a video 4: Infrared sensor 5: Camera adjustment screw 6: Camera arm 7: Camera lens focus adjustment 8: Eye camera 9: Camera clamp 10: Connection wire

3.4.5.2. Technical specifications

Table 4 shows the technical specifications of **EyeLink II** tracker.

EyeLink II eye tracker device	
Monocular/Binocular Sampling Rate	250, 500 Hz
Average Accuracy	<0.5° typical
Saccade Event Resolution	0.05° micro saccades
Spatial Resolution (RMS)	0.01° Dark Pupil
End to End Sample Delay	M < 3.0 msec, SD=1.11 msec
Blink Recovery Time	msec @ 500 Hz
Pupil Detection Models	Centroid
Gaze Tracking Range	40° horizontally, 36° vertically
Allowable Head Movement	±/-30° display
Optimal Camera-Eye Distance	40 - 80 mm
Glasses Compatibility	Excellent
Infrared Wavelength	900 and 925 nm

Table 4: EyeLink II technical specifications

3.4.5.3. Running instruction

EyeLink® II system is composed of one optical tracker device and two personal computers. One computer is meant to display the trials (stimuli) (subject PC) and another computer is used to control and monitor the tracking process (operator PC). Four sensors are attached to the corners of the display in order to work with the infrared light on the tracker to adjust the position of user's head. This will help to compensate and control the head movements during the tracking process. The subject sits in front of the display monitor and eye tracking relevant software is run on both computers: first on operator PC and then on the subject PC. The tracker headband is then set on the subject's head and is adjusted in terms of height and size using the adjustment screws. The eye camera for the dominant eye is selected from the operator PC and adjusted until it is centred in the defined area which is displayed on subject PC monitor. Then the camera focus is adjusted using the related screw. By adjusting the sensitivity threshold, the eye pupil will be detected. The headband and cameras are required to be tightened in order to prevent any undesired movements. The eye movement is now ready to be calibrated before starting the tracking process.

3.4.5.4. Input/output data

Eye-tracking software, depending on the model, accepts different bitmap images as input data. The EyeLink® II system accepts 1024x768 pixels 24-bit bitmap images (.BMP). The images are saved into subject PC using EyeLink® II Data Builder Software. The image presenting process is programmed using this software. For example, the duration of displaying each image or defining the keys in order to make manual changes can be commanded. Also, the order of displaying the images can be defined or it can be chosen as random. After building the input data, it is saved as an executive file which is run to begin the eye tracking process. The output data is saved as an EDF file. This file is readable via EyeLink® II Data Viewer software. It shows the fixations and saccades on the trials (see Figure 27). The EDF file contains the trial images, trial ID (file name), the start and end time (in millisecond), pupil size at each fixation, blinks rate and duration, and fixation coordinates and duration.

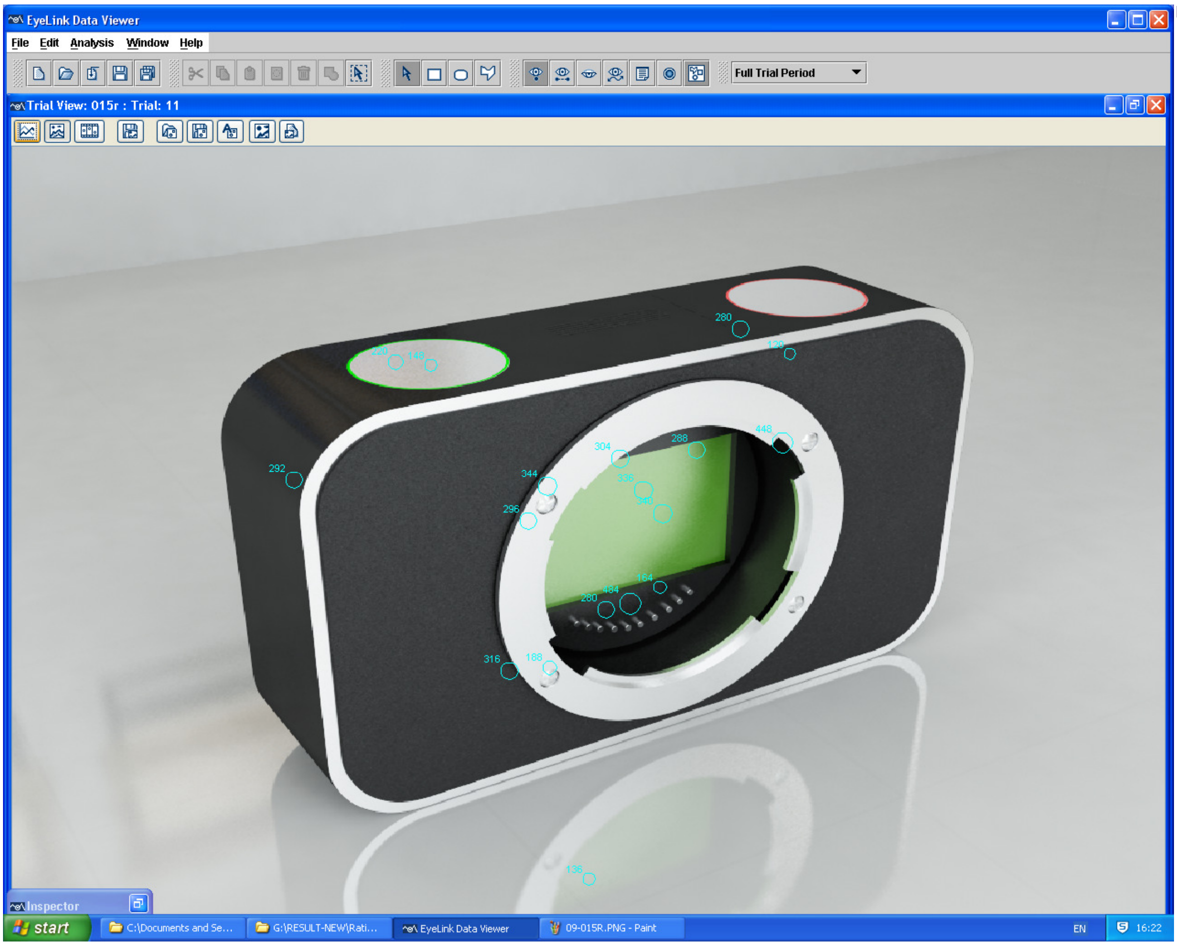


Figure 27: EyeLink® II Data Viewer software reads the EDF files as the output data of the tracking process which shows fixations and saccades on each trial for each subject.

3.5. Quantification methodology

The quantification methodology is developed based on the eye-tracking data and the defined qualities of aesthetics. Mathematical equations are applied to the entire process of data analysis in order to generate a robust measuring model.

3.5.1. Eye-tracking data

The main output data of eye-tracking consist of ‘number’, ‘duration’, and the ‘location’ of each fixation. Unit of fixation duration is millisecond and location of each fixation is determined by coordinate of (x, y) according to number of pixels of the input image. For instance, if the input image has a resolution of 1024 by 768, the coordinate space is based on $0 \le x \le 1024$ and $0 \le y \le 768$.

3.5.2. Linking eye-tracking data and qualities of aesthetics

The theoretical definitions of aesthetic qualities are required to be associated with the eye-tracking output data in order to create mathematical measuring formula. Although the calculation process using defined formula can be done without using any software, due to the large quantity of data, using relevant software is recommended in order to save time and to avoid any mistake. In this section examples are provided for each calculation but the software calculation process will be discussed in **chapter 4**.

3.5.2.1. Proportion

As mentioned in **section 2.3.3**, proportion is determined by making a balance between visual weights. In addition, as mentioned in **section 2.1.4**, visual weight is associated with eye attraction. In other words, eyes look at the areas which have visual weight. As discussed in **section 3.4.3**, eye-tracking fixation is generated when eyes look at the area. Therefore, each fixation represents visual weight. The unit of visual weight is time which means the parts with higher visual weight attract the eye for a longer time. Thus, proportion is a balance between the duration of fixations. Higher standard deviation of fixation duration shows the lower balance and vice versa. Therefore, proportion is the inverse of the standard deviation of fixation duration (σ_F) (Equation 1).

$$proportion = \frac{1}{\sigma_F} \quad (1)$$

3.5.2.2. Pureness

As discussed in **section 2.3.2**, pureness is associated with number of areas which attract the eye. Each fixation is generated when an element attracts the eye. Thus, pureness is determined by number of fixations in which more fixations means lower pureness and vice versa. Therefore, pureness is the inverse of the number of fixations (N_F) (Equation 2).

$$pureness = \frac{1}{N_F} \quad (2)$$

3.5.2.3. Contrast

As mention in **section 2.3.4**, contrast is a function of the inverted pureness and proportion. Because both qualities influence the contrast the equation is the product of the inverse of pureness and proportion (Equation 3).

$$contrast = N_F \times \sigma_F \quad (3)$$

A similar formula has been used in order to determine the contrast of an image by calculating the standard deviation of pixels based on the value of grey level (Gonzalez, Wood, & Eddins, 2009; Shi, Jin, Wang, & Chen, 2005; Peli, 1990).

3.5.2.4. Standard contrast

If contrast is divided by total time of observation (T) (which is sum of all the fixations (F)) the result is called ‘standard contrast’ (λ) (Equation 4).

$$\lambda = \frac{contrast}{T} = \frac{N_F \times \sigma_F}{\sum_{i=1}^{n} F_i} \quad (4)$$

Table 5 shows an example of calculating proportion, pureness, contrast, and standard contrast using the Equations 1-4.

Fixation duration (ms)	Number of fixations	Standard deviation (ms)	Proportion (s^{-1})	Pureness	Contrast (ms)	Standard contrast
120	7	95.82	10.44	0.14	670.74	0.39
120						
220						
300						
320						
320						
340						

Table 5: Calculation sample of beauty qualities according to fixations

3.5.2.4. Appropriateness and novelty

Appropriateness and novelty are the qualities of attractiveness. In order to measure these qualities, an up-to-date visual pattern is required. This pattern is determined by other products in the same category (because attractiveness is relative). Therefore, the location of fixation is used to generate the patterns. All the products are required to be placed in the exact same location and have the same viewing angle and scale to be comparable. For novelty, the typicality pattern is made from common fixations of all products and for appropriateness the pattern is generated from most preferred product. The target product is then compared with the pattern. Novelty is determined by number of fixations which are not included in the common fixation area of typical products. Appropriateness is determined by number of fixations which are in the area of common fixations of the most preferred design. The common fixation area is an ellipse in which the radius (R_x, R_y) are the standard deviation of fixation coordinates (x, y) (Equation 5) with the centre (C) which is determined by the mean of the coordinates of the fixations (Equation 6). The angle of the ellipse with 'y' axis (θ) is determined using Equation 7 in which if (x) value which is associated with the minimum of (y) is greater than mean of (x) coordinates the ellipse is toward 'right' otherwise it is towards 'left'. In the $\arcsin$ fraction, denominator must be always greater than numerator.

$$R_x = \sigma_x \, , \; R_y = \sigma_y \tag{5}$$

$$C = (\bar{x}, \bar{y}) \tag{6}$$

$$\theta = \frac{\arcsin\left(\dfrac{R_x}{Min(x)}\right) + \arcsin\left(\dfrac{R_y}{Min(y)}\right)}{2} \tag{7}$$

Appropriateness (A) is then calculated by dividing the number of fixations in the common fixation area of the most preferred design (N_A) by the total number of fixations (N_T), and novelty (N) is calculated by dividing the number of fixations which are not included in the common fixation area of the typical designs (N_N) by total number of fixations (N_T) (Equation 8).

$$Appropriateness(A) = \frac{N_A}{N_T} \;,\;\; Novelty(N) = \frac{N_N}{N_T} \tag{8}$$

Another procedure of calculating the appropriateness and novelty is using the duration of related fixations instead of the number of fixations. Therefore, appropriateness (A) is calculated by dividing the duration of fixations in the common fixation area of the most preferred design (D_A) by total time of fixations (T_T) and the novelty (N) is calculated by dividing the duration of fixations which are not included in the common fixation area of the typical designs (D_N) by total time of fixations (T_T) (Equation 9).

$$Appropriateness(A) = \frac{D_A}{T_T} \, , Novelty(N) = \frac{D_N}{D_T} \tag{9}$$

These two approaches were shown to generate similar results in the conducted experiments. The first approach is selected in order to calculate appropriateness and novelty since the calculation process is easier.

Table 6 shows the sample of generating appropriateness and novelty patterns based on the coordinates of the fixations. Then both values are measured using the related equations.

Fixation coordinates of the preferred design				Fixation coordinates of all designs			
x		y		x		y	
501		350		507		336	
520		473		505		533	
552		386		558		381	
554		355		676		306	
516		395		575		603	
529		467		577		442	
520		378		607		398	
534		349		530		466	
492		379		666		324	
497		379		645		326	
506		494		577		398	
526		500		624		157	
530		415		487		242	
614		360		464		137	
575		274		511		737	
Appropriateness pattern attributes				Typicality pattern attributes			
R_x	R_y	C	θ	R_x	R_y	C	θ
32	63	531, 397	10.4	67	159	567, 386	38.1
$575 > 531 \Rightarrow$ ellipse is towards right				$464 < 567 \Rightarrow$ ellipse is towards left			

Table 6: Calculation sample of appropriateness and novelty patterns

Appropriateness and novelty values are calculated using the number of fixations which are located in the related patterns. For appropriateness, number of fixations of a target product which are located in the appropriateness pattern (Figure 28-top) is divided by total number of fixations. For novelty, number of fixations of a target product which are 'not' located in the typicality pattern (Figure 28-bottom) is divided by total number of fixations.

$A = \frac{N_A}{N_T} = \frac{5}{15} = 0.33$ (Greater the number more appropriate the design is)

$N = \frac{N_N}{N_T} = \frac{3}{15} = 0.20$ (Greater the number more novel the design is)

In the example, 5 fixations of the target product are located in the appropriateness area while 3 fixations are not included in the typicality area.

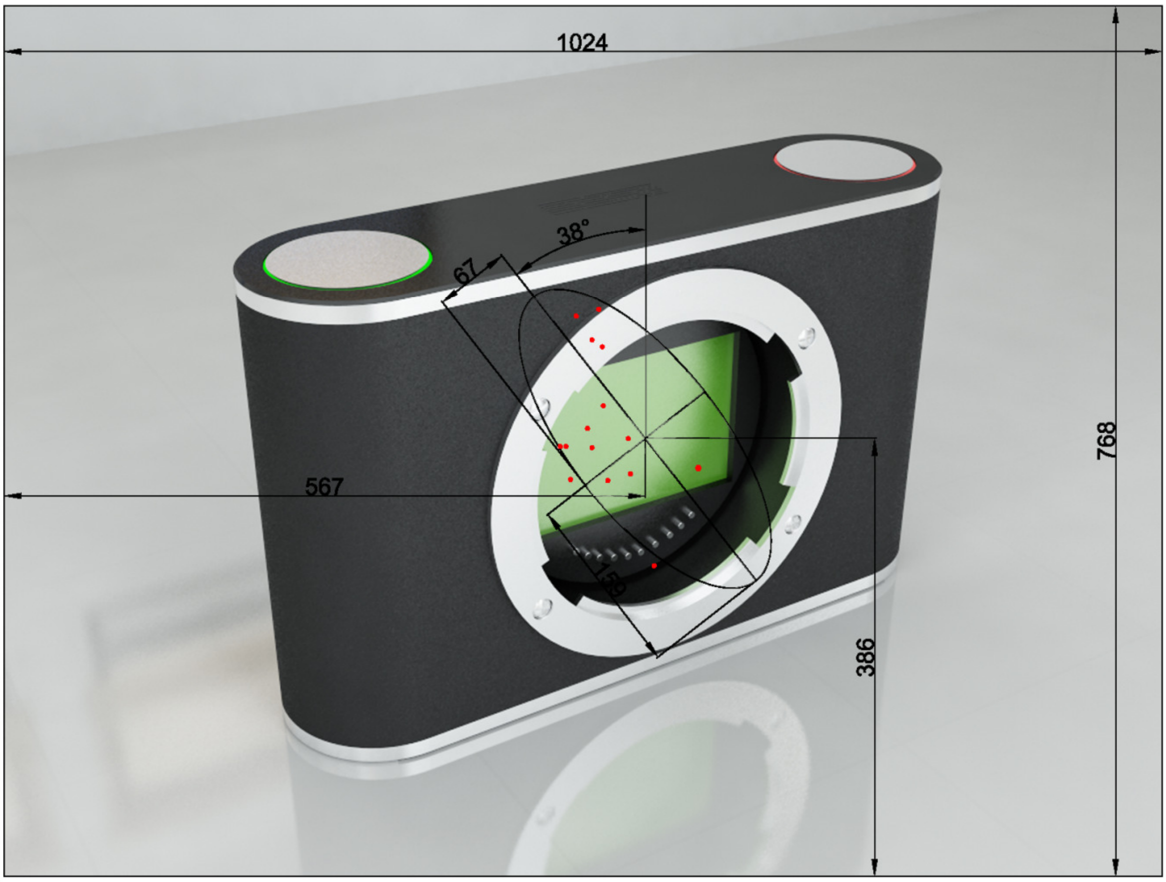


Figure 28: Top: Appropriateness pattern; Bottom: Typicality pattern in order to use in calculating the novelty of the target product. The pattern is in the same size as input image which is 1024 by 768 pixels.

Chapter 4: Experimental framework

4.1. Eye-tracking experiments

4.2. Preference of beauty

4.3. Preference of appropriateness

4.4. Preference of novelty

4.5. Aesthetic equation

4.1. Eye-tracking experiments

Four eye-tracking experiments were conducted in order to examine the proposed methodology and overall 180 human subjects participated. The main aim of the examination is comparing the results which are measured through involuntary responses with the declared preference. The procedure and the result of each experiment are discussed in this section.

4.1.1. Pilot experiment

The first eye-tracking experiment was done in order to make a quick evaluation of conducting eye-tracking, procedures, the methodology and data analysis. Therefore, a limited number of stimuli were chosen.

4.1.1.1. Method

Two tasks were designed in order to examine non-functional and functional aspects of aesthetics. The first task which is called 'selection task' employs simple geometric figures with no clue of functionality. Therefore, the judgment is purely based on the beauty of the design. Because it is difficult to rate a simple figure, sets of figures are used in order to make a comparison between them. The first image comprises two figures and the second image includes four figures which are alphabetically labelled (see Figure 29).

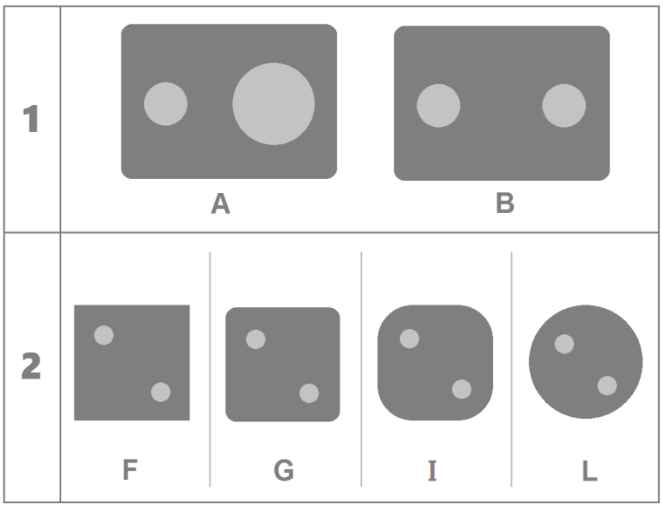


Figure 29: Image 1 and 2 which were used in the selection task

The images in selection task deliver different levels of proportion. In image 1, the difference is between the shapes in which figure 'A' has lower proportion compared to figure 'B' because the size of one circle is larger than the other. In image 2 the forms have changed while the shapes inside remain unchanged. In order to keep the task simple, other elements such as colour and texture were not applied to the stimuli. The second task (which is called 'rating task') uses the images of the real products. In this case two different cameras were selected which offer different form designs (see Figure 30).

Figure 30: Camera images were used in the rating task (Left: Cam 1, Right: Cam 2)

4.1.1.2. Conduct of experiment

50 students (age 19-29, 21 female, 29 male) participated in the experiment which was conducted in the school of psychology eye-tracking lab at the University of Glasgow (see Figure 31).

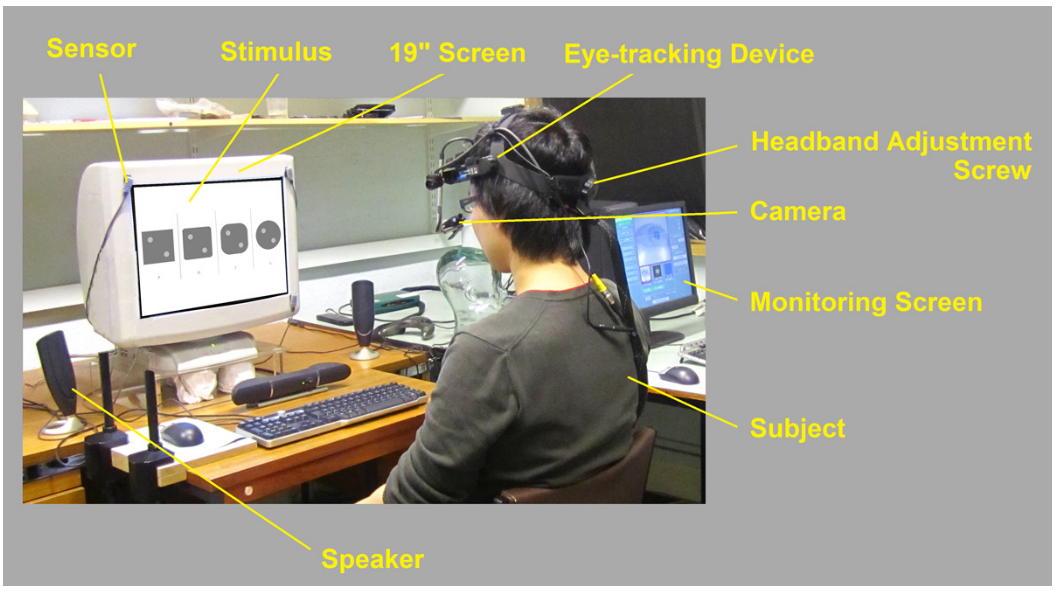


Figure 31: Conducting the experiment with subjects in eye-tracking lab

Each participant is given an information sheet (see Appendix 2) in order to clarify the procedure of the experiment and a consent form (see Appendix 3). They sit in front of the screen and the eye-tracking headband is set on their head and the position of the camera is adjusted. After calibration process the images is shown. First the images of selection task plus one warm-up image is shown. The purpose of the warm-up image is to eliminate any mistake caused by unfamiliarity with the procedure. The subjects do the same task for warm-up image but the data will not be counted in the analysis. In the selection task each image is shown for an unlimited time until the participant is able to choose one of the figures. Therefore, total time of observation refers to the time in which a subject is able to express the judgment. They are asked to select A or B in image 1 and F, G, I or L in image 2 by saying the related letter. Once they say a letter, the next image is shown by pressing SPACE button on the operator PC. After the selection task, the images in the rating task are shown. This time subjects are asked to rate the image from 1 to 5 depending on the level of pleasantness of the appearance. Same as the selection task the next image is shown once they say a number between 1 and 5.

4.1.1.3. Data analysis

The output data is saved as 'EDF' file. In order to access the text format data the EDF file is converted to ASCII file using EDF2ASC application which is provided with the eye-tracking software package. The ASCII files can be recorded in different style depending on eye-tracking firmware. In order to make the ASCII file in a standard format 'ActivePerl' software is used. The software includes a '.pl' file (prefilter.pl) and a '.bat' file. In the '.bat file' a following command is written for each trial:

```
Perl prefilter.pl [current file name].asc > [new file name].asc
```

By running the bat file, the ASCII file will be converted into a new file with the standard format. The new standard ASCII files are saved as '.asc' which contain all information about the eye-tracking event. However, in order to implement the defined methodology, only three types of data are required: duration, coordinate, and number of fixations plus the trial ID in order to identify the trial related fixations. Therefore, the new ASCII files are filtered using 'AscFilter' software. The 'AscFilter' software interface is composed of 8 different sections: input/output file, data message, items of interest, eye channel, blinks, events, time set, and pupil size include/exclude (see Figure 32).

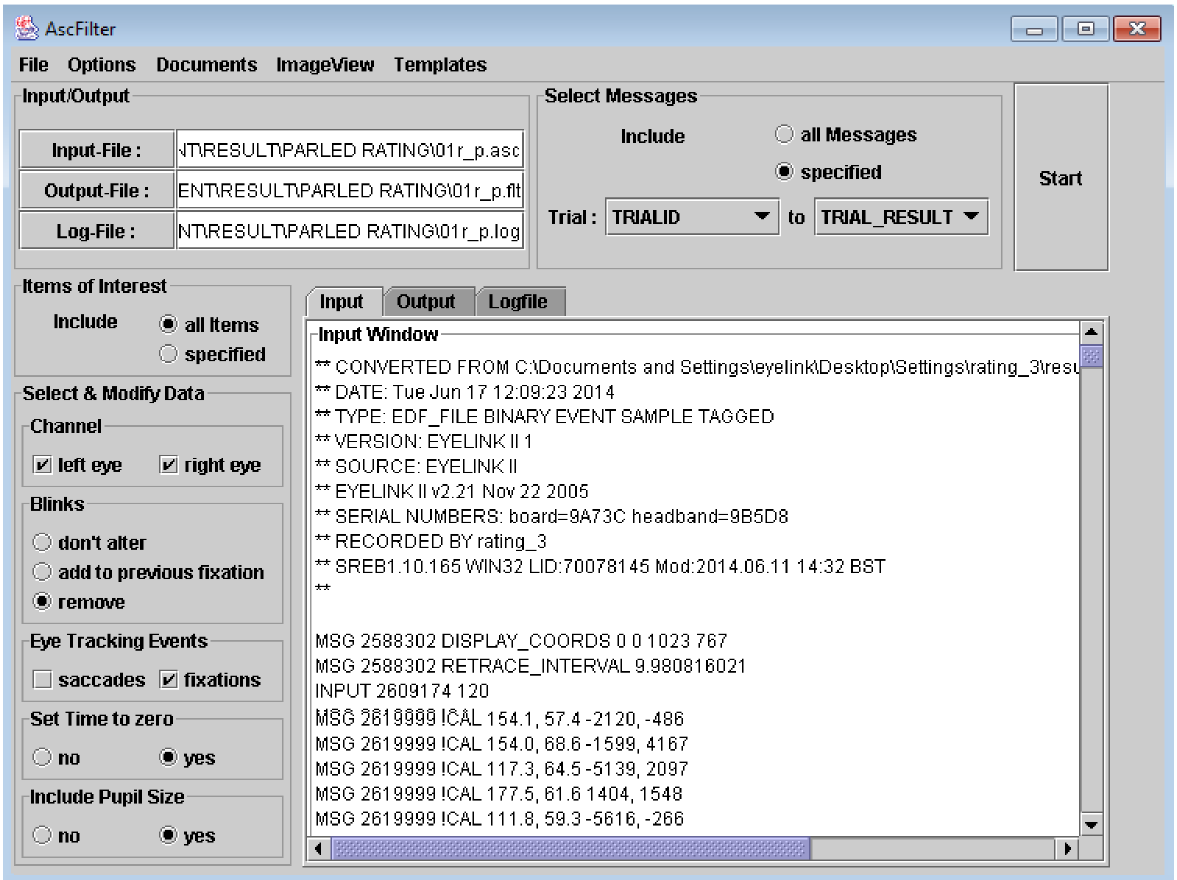


Figure 32: The interface of AscFilter software which is used to filter the ASCII data in order to generate a file which only contains the desired data to make the further analysis

In input section, the target file which is '.asc' is chosen. In data message section the desired data is selected. By choosing specified option a new window will open which shows all types of data which are recorded in the ASCII file and can be ticked or unticked (see Figure 33).

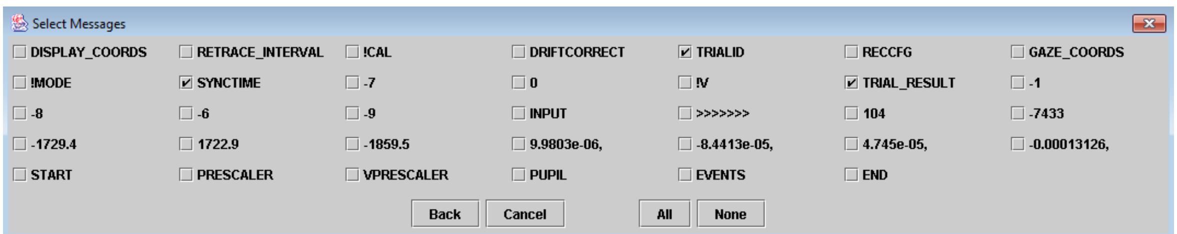


Figure 33: Different data included in ASCII file can be chosen.

The desired data in this experiment are 'SYNCTIME', 'TRAILID', and 'TRIAL_RESULT' which are ticked in Figure 33. SYNCTIME shows the start and end time for each trial. Although it is not directly used in data analysis, it has to be selected in order to show the fixations in the output data. TRIALID shows the image file name (e.g. 01.bmp). TRIAL_RESULT shows the fixations duration and coordinates on each trial. After choosing the relevant data the window is closed by clicking on 'Back' button on the menu. In the message area the Trial is chosen from TRIALID to TRIAL_RESULT which covers all the relevant events. In items of interest section, the desired trials will be selected. For example if 10 images are used in the experiment, all or some of them can be selected in order to use their data. In case of using warm-up image, the trial can be exempted by unchecking its related ID in the menu. The eye channel section specifies the data of which eye (left or right or both) is required. Because in the experiment a dominant eye is used both left and right eye are checked in order to include all the data. Blink is assumed as a noise in this study and it is selected to be removed. Saccade is not included in this study. Therefore, in the event section, only the eye-tracking fixation is chosen. By selection the fixation another window will open which shows the options for choosing the minimum duration of fixation and also out of range fixations (see Figure 34). The minimum duration is selected to 80 milliseconds because shorter fixations are normally caused by false saccade rather than intended eye fixation. The out of range fixations are also selected to be removed because these fixations are not in the defined 1024x768 pixels area of the image which are not counted in the data analysis.

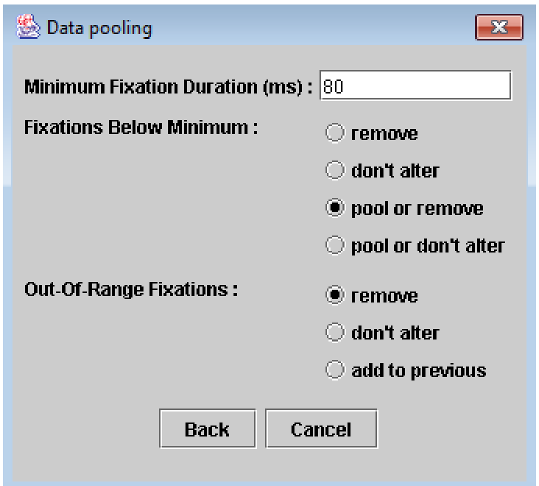


Figure 34: Minimum fixation duration is chosen to 80 and below that is removed. The out of range fixations are also removed from the data.

The time is then selected to set to zero for each trial. Otherwise, in data the time starts from zero for the first trial and continue to the last which makes large numbers in millisecond. The applied eye tracker can also measure the pupil size which is not relevant to the defined methodology. Therefore, it can be excluded from the data by choosing ‘no’ option.

Now ‘AscFilter’ software is ready to generate the filtered ASCII files by clicking Start button. The new filtered data is shown in AscFilter software interface (see Figure 35).

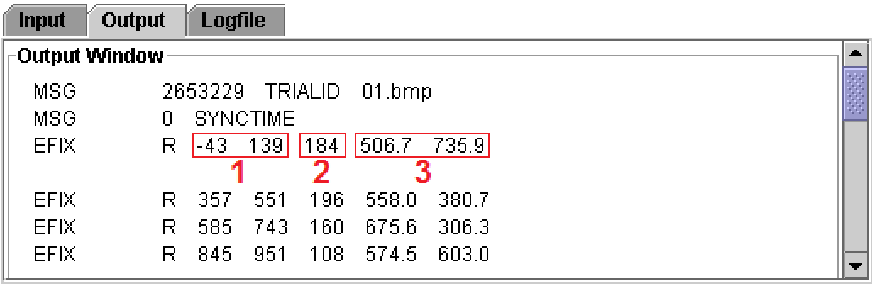


Figure 35: Filtered data in AscFilter software interface. 1: SYNCTIME 2: Fixation duration (in millisecond) 3: Fixation coordinates (x, y) based on 1024x768 input data

The new files will save as ‘.flt’ file instead of ‘.asc’. New FLT files can be opened in Microsoft Excel as an imported file. The data set then will be optimised with relevant cells in Excel (see Figure 36).

	A	B	C	D	E	F	G	H
1	MSG	9004	TRIALID	02.bmp				
2	MSG	0	SYNCTIME					
3	EFIX	R	-35	115	152	511	736.5	
4	EFIX	R	161	311	152	488.8	473.5	
5	EFIX	R	337	607	272	456	388	
6	EFIX	R	629	899	272	519.9	378.4	
7	EFIX	R	1029	1183	156	497.6	352.6	
8	EFIX	R	1305	1699	396	459.9	328.1	
9	EFIX	R	1721	1875	156	483.2	323.2	
10	EFIX	R	1885	2003	120	475.6	314.9	
11	EFIX	R	2025	2243	220	463.3	360.1	

Figure 36: The FLT file imported in Microsoft Excel

The aesthetic qualities are required to be calculated for each trial. Therefore, all the fixation data for all the subjects (in this experiment 50 subjects participated) of each trial are copied into one column in Excel. The columns contain duration and coordinates of fixations (see Figure 37).

	A	B	C	D
1	IMAGE 02			
2	FIXATION	X	Y	
3	160	239.7	404.9	
4	132	601.4	427.9	
5	252	741.6	409.8	
6	324	288.9	380.6	
7	244	181.5	365.6	
8	160	285.2	349.7	
9	100	691.8	393.4	
10	304	689.6	369.1	

Figure 37: The list of fixation duration and coordinates from all 50 subjects for each trial

Using a relevant Excel command for each equation, the aesthetic qualities are calculated. Pureness can be calculated as a percentage. Because the minimum number of fixation is 2, 200 can be divided by number of fixations divided by number of subjects (because pureness is quantitative) in order to achieve the pureness percentage (2x100). Proportion can be calculated in the unit of inverse of second. Therefore, 1000 is divided by the standard deviation of the fixation duration. Contrast is simply product of invers of pureness (divided by number of subjects) and proportion. Standard contrast is the contrast divided by total time which is calculated by sum of all the fixations (A3 to A1000 are the related rows which contain fixation duration in millisecond) (see Table 7).

Quality	Excel command
Pureness (%)	**=200/(COUNT(A3:A1000)/50)**
Proportion (s^{-1})	**=1000/STDEV(A3:A1000)**
Contrast (ms)	**=(COUNT(A3:A1000)/50)*STDEV(A3:A1000)**
S-Contrast	**=(COUNT(A3:A1000)*STDEV(A3:A1000))/SUM(A3:A1000)**

Table 7: Excel commends in order to calculated the qualities of beauty

4.1.1.4. Result

For selection task, the canvas is divided by the areas that contain each figure. For instance in image 1, if the ‘x’ coordinates of the fixation are less than 512 it belongs to figure ‘A’ otherwise it is in the figure ‘B’ area. The commands were used in excel to distinguish figure A and B in image 1 and figure F, G, I, and L in image 2. Therefore, the ‘x’ coordinate of image 1 which contains 2 figures is divided by two and the image 2 which contains 4 images is divided by 4 and relevant commands were applied (see Table 8).

Image		Excel command
1	A (copied in A related column)	IF B3<512,B3,” “
	B (copied in B related column)	IF B3>512,B3,” “
2	F (copied in F related column)	IF B3<256,B3,” “
	G (copied in G related column)	IF(AND(B3>256,B3<512),B3,” “
	I (copied in I related column)	IF(AND(B3>512,B3<768),B3,” “
	L (copied in L related column)	IF B3>768,B3,” “

Table 8: Excel commands to differentiate figures in one image

Table 9 shows the calculation of each quality for each trial using the commands:

Trial	1		2				3	4
Figure	**A**	**B**	**F**	**G**	**H**	**I**	**Cam 1**	**Cam 2**
Contrast	971	808	512	481	453	386	1768	1489
Pureness	29.3%	30.6%	51.8%	50.5%	49%	54.6%	14.4%	14.3%
Proportion	7.02	8.10	7.54	8.24	9.00	9.48	7.84	9.36
S-Contrast	0.57	0.53	0.71	0.64	0.56	0.48	0.67	0.59
Preference	42%	58%	4%	30%	50%	16%	51%	61%

Table 9: The result of the pilot experiment (see figure 29)

As can be seen from Table 9, for all the figures, the preference is higher when the standard contrast is close to 0.5 and not below that. This is where the proportion is high but still maintains a certain amount of contrast. As can be seen, contrast is higher in real product images compared to the simple geometrical shapes due to their higher level of detail.

4.1.1.5. Discussion

The result of the pilot experiment shows that the pattern which was observed in subjective experiments (see **section 3.2**) has repeated again. The highest preference is given when the proportion is high but contrast in not too low which occurs when the measured standard contrast (contrast divided by total time of observation) is close to 0.5 and not lower. When the standard contrast is lower than 0.5 the design is not preferred even if the proportion is high. In order to confirm the result, the second experiment which employs greater number of stimuli is conducted.

4.1.2. Second experiment

More trials were used in the second experiment in order to evaluate the consistency of the results obtained in the pilot experiment.

4.1.2.1. Method:

Same as the pilot experiment, two tasks were designed: selection and rating tasks. In selection task two or more figures in one image were shown in order to make a comparison and choosing the best one by subjects. Each figure represents a product with a brand name. 10 images were used plus one warm-up image in which each figure is alphabetically labelled (see Figure 38). Image 1 represents mobile phones with the same overall size and different screen sizes in order to simply assess the aspect ratio preference in this kind of product. Image 2 contains the exact same figures in terms of shape while the colour is different. In figure ‘A’ the colour contrast is much higher. This image is aimed to assess the preference of higher and lower contrasted colours. Image 3 provides three figures with more subtle difference. Figure ‘A’ has higher pureness compared to figure ‘B’ and ‘C’ and figure ‘B’ has better proportion compared to figure ‘C’. Image 4 is aimed to evaluate the role of form and shape when they swap their places. Image 5 offers two different controllers mostly in terms of pureness. Figure ‘B’ has much higher pureness in shape and colour. Image 6 represents contour of phones which the change is in the corners from sharp to curved one in order to address which curve is more pleasing for this kind of product. Image 7 shows the back design of two cameras with the exact design of the shape while the form is slightly different. Figure ‘A’ was created based on the exact design of the real camera and figure ‘B’ is redesigned to be simpler. This comparison shows whether the simple form is preferred or not. Image 8 represents the interface design of three popular mobile operating systems in order to measure the aesthetic qualities of well-known graphic designs. Image 9 is aimed to compare applied organic form versus geometric form for the same functionality. Image 10 shows two cameras from same manufacturer which have slight difference in pureness and contrast. Same image has been used in rating task but showing the cameras in perspective in order to evaluate how the viewing angle of a product can change the preference.

In the rating task, 12 pair images of real products were selected from different categories from small to large plus one warm-up image. 2 images of wrist watch, 4 cameras, 2 chairs, 2 sport cars and 2 trucks with different designs were selected (see Figure 39). The images were shown in a certain order. First, one series of different products and second, the next series were shown to the participants. Image 1 and 7 show two wrist watches which are different in terms of amount of applied details. Image 2 and 8 show two cameras which are used in the selection task. This time the viewing angle is different in order to compare the difference between the aesthetic qualities and the preference. Image 3 and 9 show two chairs with two different design styles (more classic and more modern designs). Image 4 and 10 show two cameras which are designed in order to evaluate the role of form design while the shapes are kept the same. Image 5 and 11 show two sport cars with very different designs. One is classic and the other is modern. Image 6 and 12 show two trucks with the same aim as the sport car. One is closer to traditional truck design and the other is more unique.

4.1.2.2. Conduct of experiment

Same as the pilot experiment, 50 subjects from different countries (mostly students with ages between 20 and 30) participated in the experiment (16 female and 34 male). In the selection task they were asked to verbally express their preferred design by saying the related letter while they were looking at the image and immediately after selecting the preferred figure, the next image was being shown. The rating images were shown after the selection task. This time they are asked to rate the images verbally by saying a number between 1 and 10 depending on how much they like the design. This approach makes the whole process simpler and it avoids any distraction and provides faster data collection. The range of rating score changed from 1 to 5, to 1 to 10 in order to give the subjects more freedom and flexibility.

4.1.2.3. Data analysis

The same approach as pilot experiment was used in data analysis. Defined measuring equations were formulated in Microsoft Excel and final results were calculated by entering the fixations in the related columns.

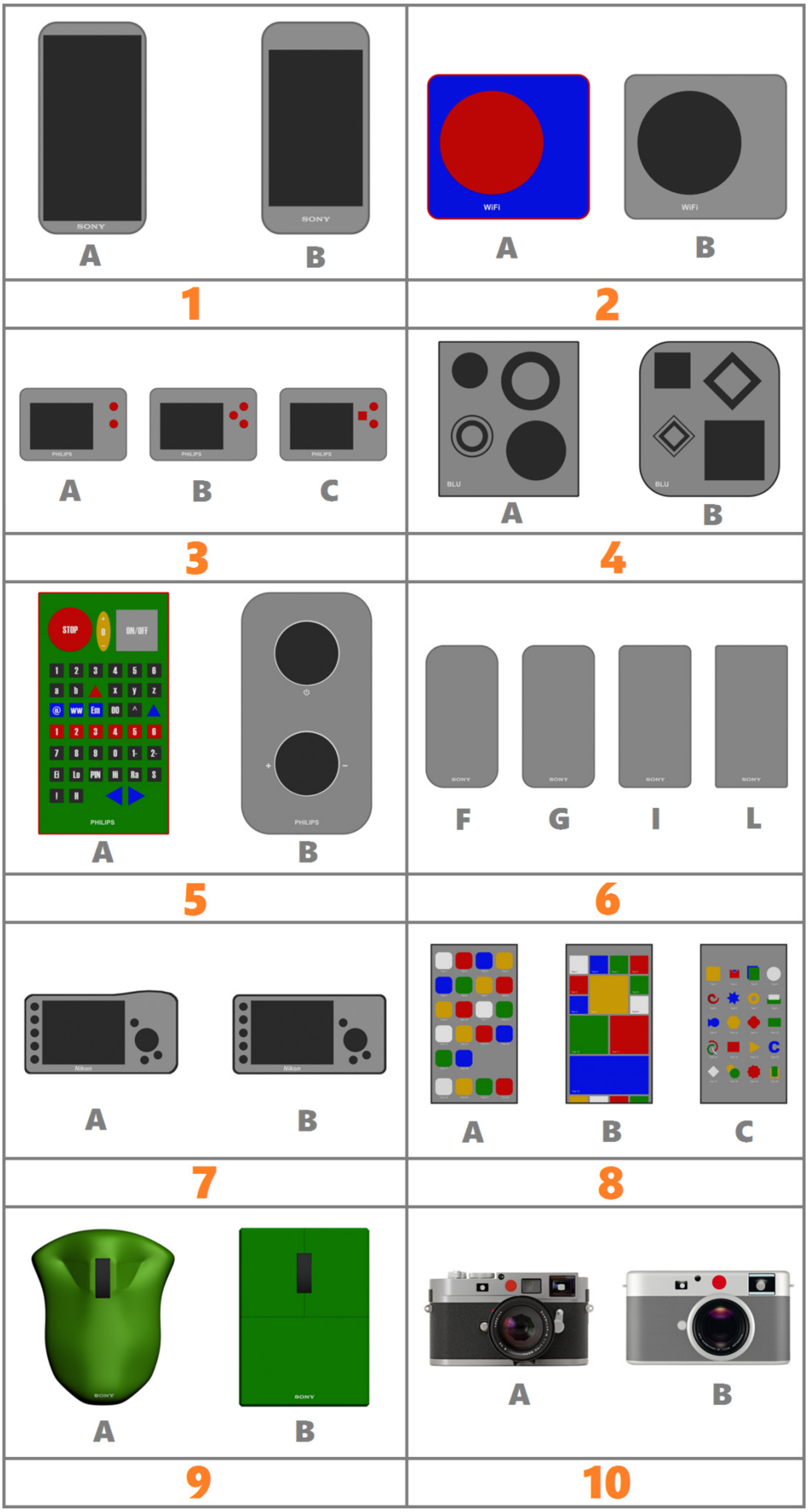


Figure 38: The images were used in the selection task

Figure 39: The images were used in the rating task

4.1.2.4. Result

Table 10 shows the result of calculating the qualities of aesthetics and the declared preference of the subjects for each stimulus (total number of stimuli is 36). The preference value in the selection task is shared between the stimuli. For instance if 2 figures are in one image, if one has 40% preference the other one has 60%. In the rating task the preference is out of 10 which are multiplied by 10 in order to set a percentage value for each image. The images with letters (A, B, etc.) indicate the stimuli used in the selection task and the images without an alphabet show the stimuli used in the rating task. The images of the same products are placed next to each other to make the comparison easier.

Stimulus	Contrast	Pureness	Proportion	S-Contrast	Preference
01-A	501	36.2	11.02	0.45	54
01-B	511	39.2	9.90	0.44	46
02-A	568	37.2	9.48	0.49	54
02-B	387	47.6	10.84	0.43	46
03-A	365	62.5	8.76	0.47	14
03-B	422	43.7	10.86	0.51	64
03-C	497	46.5	8.66	0.52	22
04-A	553	32.5	11.14	0.44	58
04-B	583	33.4	10.26	0.41	42
05-A	689	30.1	9.64	0.59	28
05-B	418	41.7	11.48	0.51	72
06-F	282	67.1	10.58	0.43	20
06-G	430	39.1	11.90	0.47	40
06-I	470	45.5	9.36	0.44	30
06-L	238	82.6	10.18	0.40	10
07-A	607	31.2	10.58	0.44	50
07-B	488	39.7	10.32	0.44	50
08-A	536	48.3	7.72	0.51	44
08-B	470	44.6	9.54	0.47	28
08-C	582	48.3	7.10	0.56	28
09-A	714	31.1	9.02	0.56	62
09-B	574	46.5	7.50	0.43	38
10-A	537	33.4	11.14	0.49	50
10-B	383	47.6	10.96	0.49	50
01	1452	17.8	7.74	0.48	64
07	1713	16.1	7.26	0.53	65
02	1565	13.2	9.68	0.43	61
08	1529	15.0	8.74	0.45	61
03	1512	16.7	7.92	0.48	57
09	1656	17.3	6.98	0.52	64
04	1600	15.4	8.14	0.47	48
10	1569	15.8	8.08	0.48	49
05	1561	16.5	7.74	0.48	54
11	1214	18.8	8.78	0.52	85
06	1423	16.0	8.80	0.46	60
12	1562	15.9	8.02	0.48	61

Table 10: The result of selection task and rating task in the second experiment, stimuli with alphabet are in selection task and without alphabet are in rating task, in the rating task the pair images are provided next to each other in order to make the comparison easier.

4.1.2.5. Discussion

As can be seen from Table 10, in all the images with the standard contrast closer to 0.5 and not lower, the preference is higher. In image 1 the contrast of figure ‘B’ is slightly higher than figure ‘A’ while the proportion is higher in figure ‘A’ and pureness is higher in figure ‘B’. The standard contrast of figure ‘A’ by a little margin is higher than figure ‘B’. Finally the preference of figure ‘A’ is higher by 8%. In image 2 the contrast of figure ‘A’ is higher due to its colour difference while the proportion is higher in figure ‘B’ because of the colour resemblance. Once again the preferred design is the one which has standard contrast closer to 0.5. In image 3 the same pattern which was revealed in the subjective experiment (see **Section 3.2**) is repeated. The design with higher proportion and maintaining a certain amount of contrast is the preferred one which also has the closest standard contrast to 0.5. In image 4, figure ‘A’ is the most preferred one with 16% difference. As can be seen figure ‘A’ has higher proportion and pureness compared to figure ‘B’. In image 5, figure ‘B’ which has higher proportion and contrast is the preferred design. The standard contrast of figure ‘B’ is also closer to the preferred number. In image 6, the preference matches the standard contrast. Again the most preferred design has the highest proportion. In image 7, figure ‘A’ and ‘B’ have the same preference. The difference between the designs is very subtle and the standard contrast is also showing the exact same number. In image 8, figure ‘A’ has highest preference. While figure ‘B’ and ‘C’ have the same amount of interest one has a standard contrast lower than 0.5 and the other higher than 0.5. This shows that the preference and the standard contrast may have a kind of inverted-U relationship. In image 9 the organic form generated higher contrast and the standard contrast is more than 0.5 and closer to 0.5 compared to figure ‘B’. In image 10 the difference between the designs makes them to have the same preference while the standard contrast also shows the same number. In the rating task, images 1 and 7, 2 and 8, 4 and 10, and 6 and 12 have very close preference and the standard contrasts also show close numbers. In images 3 and 9, and 5 and 11 both standard contrasts have 0.02 differences with 0.5 while the one which is higher than 0.5 is the preferred design. It shows that even with higher proportion, and close to 0.5 the standard contrasts lower than 0.5 are less preferred. As can be seen from the result the methodology consistently produces the numbers which match the physical properties of the trials.

4.1.3. Third experiment

The third experiment was conducted to measure the qualities of attractiveness as well as qualities of beauty in order to achieve the final aesthetic equation.

4.1.3.1. Method:

Same as previous experiments, two tasks were designed: selection and rating. In the selection task 24 simple images were designed based on the metrics by applying difference between nature (NA), dimensions (DI), and location (LO) of the elements (form (FO), shape (SH), colour (CO), and texture (TE)) in proportion (PR) and pureness (PU) and their combination (see Table 11).

	PR	PU	NA	DI	LO	FO	SH	CO	TE
M01	x		x			x	x		
M02	x			x			x		
M03	x			x		x			
M04	x				x		x		
M05	x		x					x	
M06	x		x			x			
M07		x			x		x		
M08		x	x					x	x
M09	x			x	x		x		
M10	x	x	x				x		
M11		x	x			x			
M12		x	x					x	
M13	x		x				x		
M14	x		x					x	
M15	x	x	x				x		
M16	x		x				x		
M17	x		x						x
M18	x			x	x		x		
M19	x	x	x	x	x	x	x	x	
M20	x		x		x		x		
M21	x		x			x			
M22	x		x	x			x		
M23		x	x						x
M24	x	x		x			x		

Table 11: Metrics table is used in order to generate different stimuli for the selection task

In each image two figures were designed based on offering 'high' and 'low' quality of each metric. Therefore, 48 figures were designed (see Figure 40). In two previous experiments the figures in selection task were alphabetically labelled which generated some fixations around the related alphabet which is not counted because those fixations are not relevant to the design. In order to eliminate those fixations, this time no alphabet is added to the designs. Instead, the participants were asked to choose the left or the right design (only two figures in each image). In the rating task only one product was selected in order to apply the attractiveness measurement method. Therefore, 24 images of different chairs were chosen. The chairs offer very different design styles from classic to modern (see Figure 41). As discussed in **section 3.5.2.4** a pattern is needed to measure the qualities of attractiveness. Therefore, all the trials must be in the same scale and location in order to make the comparison accurate. To comply with this method, all the chairs were modelled and rendered in 3Ds Max® with the same scale and placed in the same location in the virtual space according to the 'centre point' of the design (see Figure 42).

Figure 40: Images used in the selection task which were designed based on metrics table

Figure 41: Chair images were used in the rating task with same scale and location

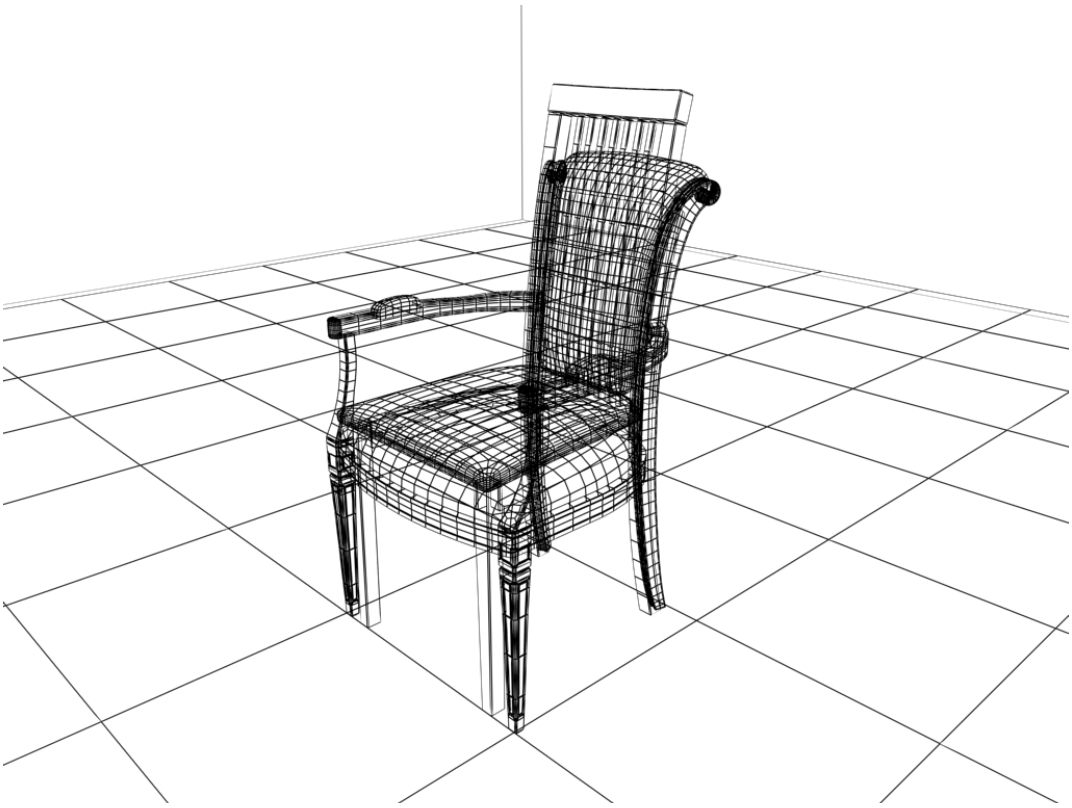


Figure 42: The chairs in rating task were modelled in the same scale and positioned in same the location

4.1.3.2. Conduct of experiment

50 design students attended in the experiment. In the selection task they were asked to choose the preferred figure by saying ‘left’ or ‘right’ word as their choice. Their choices then were written in the answer sheet by the experimenter. In the rating task, they rate the chairs depending on how much they liked it from 1 to 10 (1 for the least pleasant and 10 for the most pleasant). The numbers also were noted in front of each stimulus in the answer sheet by the experimenter.

4.1.3.3. Data analysis

Using the same method which was used in the pilot and the second experiment, the qualities of beauty were calculated for each trial. In order to measure appropriateness and novelty the related templates were created. To measure novelty, all the coordinates of fixations of all the trials were copied into two columns in Excel as *x* and *y* coordinates (see Figure 37 as an example of excel file). Then using the Excel commands, the properties of the elliptical template were calculated (see Table 12).

Variable	Excel command
R_x	**=STDEV(B3:B1000)**
R_y	**=STDEV(C3:C1000)**
C_x	**=AVERAGE(B3:B1000)**
C_y	**=AVERAGE(C3:C1000)**
θ	**=(DEGREES(ASIN(MIN(B3:B1000)/STDEV(B3:B1000))))+ (DEGREES(ASIN(STDEV(C3:C1000)/MIN(C3:C1000))))/2**

Table 12: Excel commands in order to calculate the variables of patterns of appropriateness and novelty

To measure appropriateness the same variables are calculated for the most preferred design. The variables for the elliptical template of novelty and appropriateness are given (see Table 13). The *x* coordinates are between 0 and 1024, and *y* coordinates are between 0 and 768 based on the resolution of the trials which is 1024 by 768 pixels.

Variable	For appropriateness	For novelty
R_x	124	120
R_y	234	202
C_x	566	539
C_y	416	404
θ	30 °	26 °
Direction	Right	Right

Table 13: Result of calculating appropriateness and novelty template variables

Using the variables, the templates were generated in Auto CAD software in 1024 by 768 pixels rectangle which matches the trial size. Then the CAD file exported as a bitmap image and inside the ellipse was coloured in black (see Figure 43).

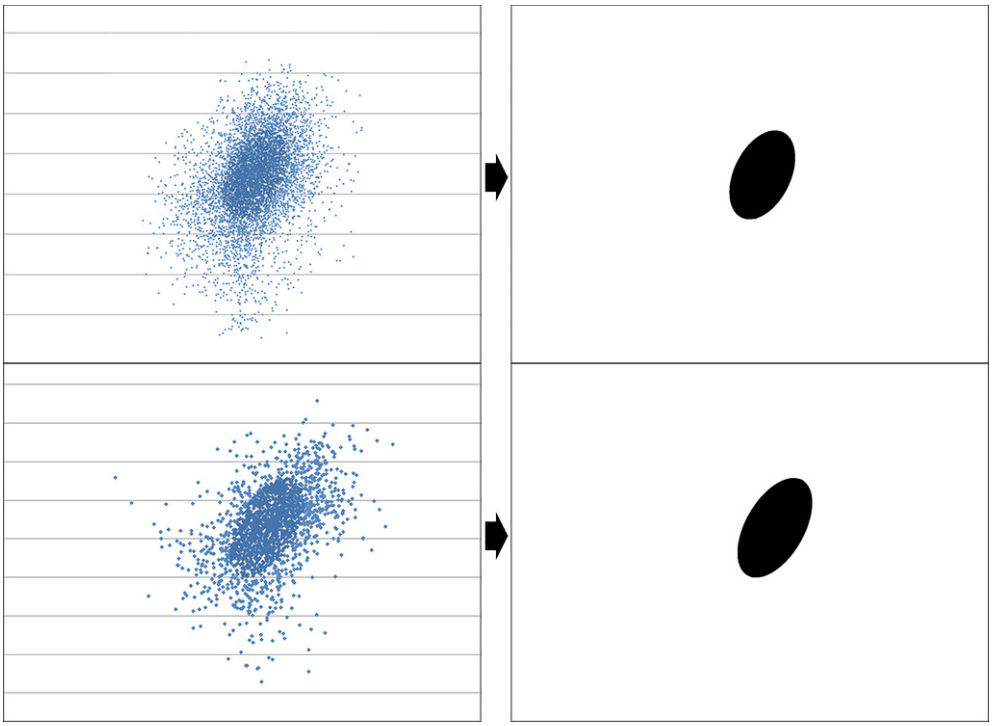


Figure 43: Novelty (top) and appropriateness (down) templates are generated for the trials in the rating task based on the concentration of the distribution of fixations on the stimuli

By selecting the templates in 'AscFilter' software, the fixations of each trial are associated with black or white word which indicates whether the fixation is located in the black ellipse or not. In order to setup the template in the software, a bitmap file of the template is generated. Then the script file for each trial is made as '.txt' file using the following command:

```
Crap [trial file name].bmp 3000 image name.bmp [template file name].bmp
```

For example:

```
Crap 01.bmp 3000 image name.bmp template_n.bmp
```

The script file contains the command for all the trials. The script file is then added to AscFilter software by using ‘Select Masterscripts’ in the option menu then choosing ‘Add’ option and selecting the script file (see Figure 44).

Figure 44: The menu of selecting the script file as a template in AscFilter software

This time the FLT files, produced by AscFilter software, contain ‘black’ and ‘white’ words for each fixation indicating that fixation is located in the defined ellipse (black) or out of the ellipse (white). Same as before, the FLT file is imported in Excel (see Figure 45).

	A	B	C	D	E	F	G	H	I	J
289	MSG	3349	TRIALID	20.bmp						
290	MSG	0	SYNCTIME							
291	EFIX	R	-35	135	172	512	729.7	63	white	
292	EFIX	R	181	347	168	546.9	399.1	63	white	
293	EFIX	R	425	531	108	598.5	299.2	63	white	
294	EFIX	R	693	971	280	591.9	258.9	0	black	
295	EFIX	R	1225	1375	152	642.1	231.6	63	white	
296	EFIX	R	1429	1699	272	626.5	237.6	63	white	
297	EFIX	R	1725	1891	168	562.3	315.7	63	white	
298	EFIX	R	1977	2119	144	545.9	389.4	63	white	
299	EFIX	R	2289	2443	156	593.2	403.8	0	black	
300	EFIX	R	2541	2763	224	444.1	332.2	63	white	

Figure 45: The FLT file imported in Microsoft Excel. Using the template each fixation is associated with black and white word which shows whether the fixation is located in the defined ellipse or not.

Then the black and white fixations are separated using 'IF' command in Excel and are saved as a separate file. Using the related Excel commands for appropriateness and novelty formula, both qualities are calculated. In order to measure novelty the 'white' fixations (out of typicality area) and to quantify appropriateness 'black' fixations are counted (see Table 14).

Variables	Excel command	
	Appropriateness	Novelty
Related fixations	=IF(I5="black",I5," ")	=IF(I5="white",I5," ")
Value (%)	=COUNT((J3:J1000)/COUNT(F3:F1000))*100	COUNT((K3:K1000)/COUNT(M3:M1000))*100

Table 14: Excel commands in calculating the qualities of attractiveness

J column contains the black fixations for appropriateness and F column contains all the fixations on related trial. K column contains the white fixations for novelty and M column contains all the fixations on related trial. By multiplying the result by 100, the value of both qualities is calculated in percentage.

4.1.3.4. Result

Table 15 shows the result of the qualities of beauty for the selection task. Because only simple figures without any indication of function are used in the selection task, the preference is only based on the beauty (attractiveness does not exist in absence of a known function). Therefore, the preference in selection task can be assumed as the value of beauty.

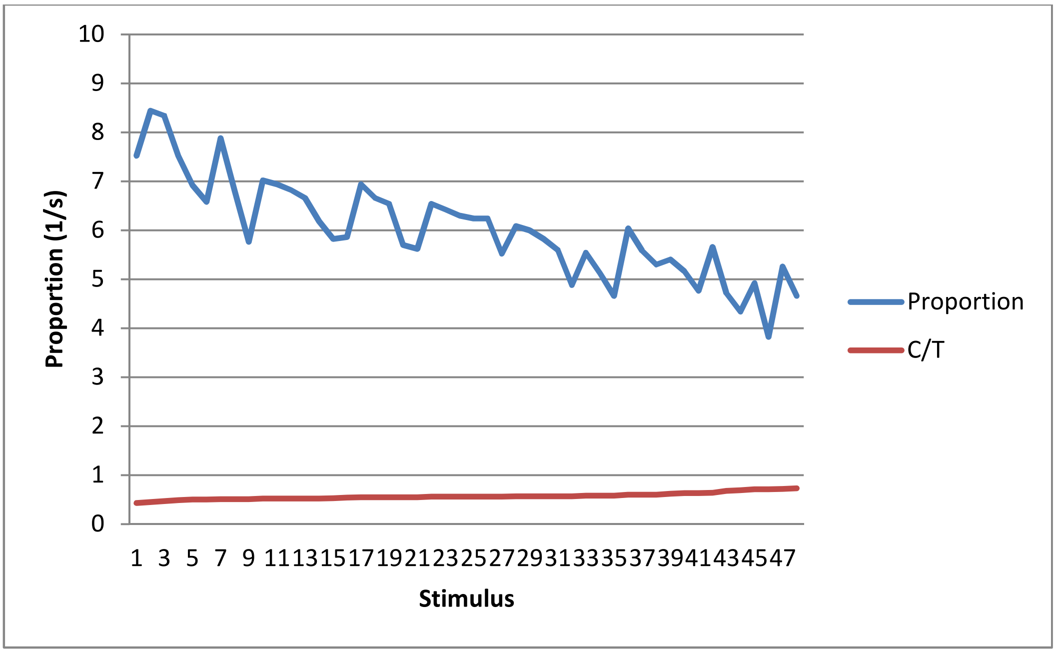
Figure No.	Figure	Contrast (ms)	Pureness (%)	Proportion (s^{-1})	S-Contrast	Preference (%)
1	Left	652	51.0	6.00	0.524	72
	Right	761	60.6	4.34	0.554	28
2	Left	516	60.2	6.42	0.584	38
	Right	479	60.2	6.94	0.563	62
3	Left	549	65.4	5.58	0.599	44
	Right	581	59.2	5.82	0.567	56
4	Left	574	62.9	5.54	0.583	78
	Right	632	67.1	4.72	0.680	22
5	Left	429	71.4	6.54	0.570	14

	Right	**465**	**63.3**	**6.80**	**0.555**	**86**
6	**Left**	**423**	**82.0**	**5.76**	**0.618**	**86**
	Right	**484**	**80.0**	**5.16**	**0.662**	**14**
7	**Left**	**288**	**83.3**	**8.34**	**0.404**	**42**
	Right	**542**	**63.3**	**5.82**	**0.531**	**54**
8	**Left**	**621**	**69.0**	**4.66**	**0.413**	**48**
	Right	**546**	**96.2**	**3.82**	**0.722**	**52**
9	**Left**	**516**	**69.0**	**5.62**	**0.549**	**80**
	Right	**527**	**74.1**	**5.12**	**0.583**	**20**
10	**Left**	**270**	**87.7**	**8.44**	**0.450**	**48**
	Right	**567**	**65.4**	**5.40**	**0.767**	**52**
11	**Left**	**406**	**84.0**	**5.86**	**0.616**	**52**
	Right	**450**	**80.6**	**5.52**	**0.656**	**48**
12	**Left**	**527**	**54.6**	**6.94**	**0.545**	**50**
	Right	**439**	**65.8**	**6.92**	**0.499**	**50**
13	**Left**	**500**	**71.4**	**5.60**	**0.572**	**78**
	Right	**290**	**91.7**	**7.52**	**0.440**	**22**
14	**Left**	**311**	**85.5**	**7.52**	**0.489**	**40**
	Right	**517**	**79.4**	**4.88**	**0.563**	**60**
15	**Left**	**541**	**56.5**	**6.54**	**0.554**	**94**
	Right	**488**	**87.7**	**4.66**	**0.734**	**6**
16	**Left**	**521**	**78.1**	**4.92**	**0.749**	**12**
	Right	**431**	**70.4**	**6.58**	**0.525**	**88**
17	**Left**	**446**	**56.8**	**7.88**	**0.568**	**78**
	Right	**440**	**66.7**	**6.82**	**0.586**	**22**
18	**Left**	**549**	**54.6**	**6.66**	**0.549**	**58**
	Right	**608**	**54.1**	**6.08**	**0.574**	**42**
19	**Left**	**405**	**74.1**	**6.66**	**0.586**	**66**
	Right	**635**	**59.5**	**5.30**	**0.698**	**34**
20	**Left**	**592**	**55.9**	**6.04**	**0.751**	**46**
	Right	**548**	**58.5**	**6.24**	**0.593**	**54**
21	**Left**	**601**	**58.5**	**5.70**	**0.550**	**64**
	Right	**722**	**58.1**	**4.76**	**0.630**	**36**
22	**Left**	**459**	**69.9**	**6.24**	**0.564**	**88**
	Right	**452**	**78.1**	**5.66**	**0.643**	**12**
23	**Left**	**597**	**53.2**	**6.30**	**0.609**	**38**
	Right	**416**	**68.5**	**7.02**	**0.515**	**62**
24	**Left**	**402**	**94.3**	**5.26**	**0.604**	**16**
	Right	**452**	**71.4**	**6.18**	**0.534**	**84**

Table 15: The result of the selection task in the third eye-tracking experiment (see figure 40)

4.2. Preference of beauty

As can be seen from Table 15, the same pattern has repeated. The preference is higher when the proportion is high and the certain amount of contrast is maintained. In other words, the preference is higher when the standard contrast is closer to 0.5 and not lower. When the standard contrast is lower than 0.5, the design is not preferred even the proportion is high. Moreover, the standard contrast increases when proportion drops (see Graph 1).



Graph 1: The result of the selection task shows the standard contrast increases when proportion decreases.

Therefore, the maximum beauty occurs when the contrast is half of the total time (T) (see Equation 10).

$$\lambda = \frac{contrast}{T} = \frac{1}{2} \Rightarrow contrast = \frac{T}{2} \quad \textbf{(10)}$$

The preference in the selection task is recorded based on the comparison between two figures in one image. In order to assess the preference of each figure compared to all other figures, another experiment was conducted in which 12 figures were shown to 82 subjects from design students. The participants were asked to rank the figures from 1 to 12 from least beautiful to most beautiful using an answer sheet (see Appendix 4). Figure 46 shows the figures which were used in the test.

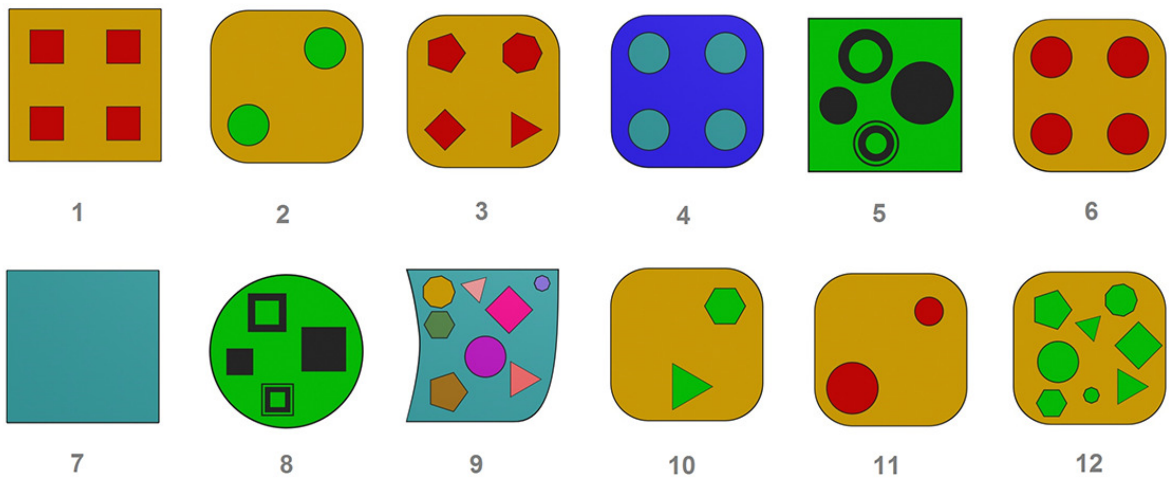


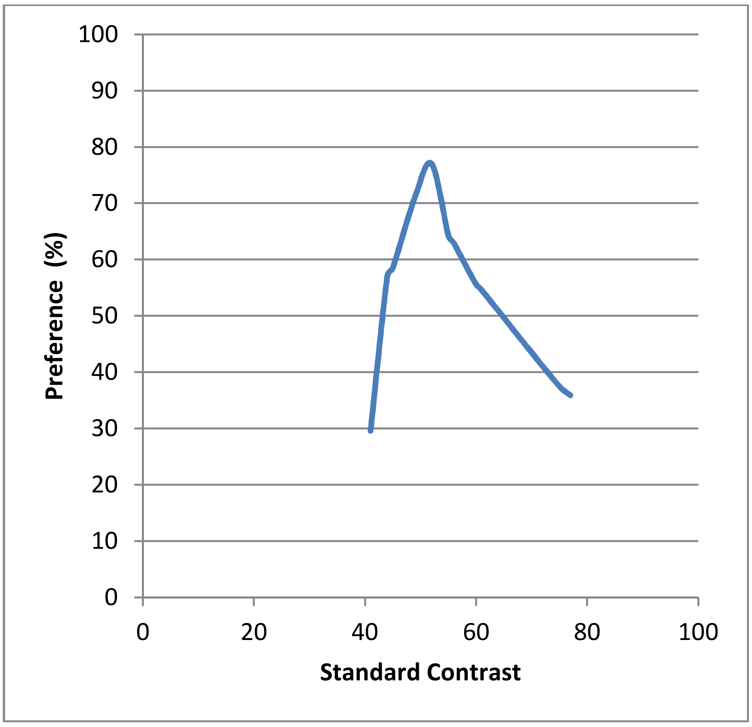
Figure 46: The figures were used in the test in order to study the preference of beauty

The figures were selected based on the various range of standard contrasts (λ) from the lowest value (0.40) to the highest (0.77) which are given via the third eye-tracking experiment. All 24 figures were not included in the experiment for two reasons: first, to make the ranking task more manageable and second, to avoid repeating figures with the same value of standard contrast (which is the main variable of measuring beauty). Each figure is rated based on the allocated rank then divided by 12 which is the maximum possible rate. The rate is then multiplied by 100 to make a preference in percentage and compared with the standard contrast (see Table 16).

Fig.	1	2	3	4	5	6	7	8	9	10	11	12
Pref.	57.0	58.5	37.5	71.1	77	62.9	54.6	64.3	43.5	29.6	55.6	35.9
λ	0.44	0.45	0.75	0.49	0.52	0.56	0.61	0.55	0.70	0.40	0.60	0.77

Table 16: The result of test which indicates the preference of beauty

As can be seen from Table 16, the result shows higher preference for standard contrasts closer to 0.5. By normalising the result the graph of preference against standard contrast is given (see Graph 2).



Graph 2: Preference against standard contrast (multiplied by 100)

As can be seen from the Graph 2, the preference and standard contrast below 0.5 and over 0.5 have different relationships. Therefore, two equations which fit the results, one for standard contrast (λ) below 0.5 and one for over 0.5, were created as the beauty formula (see Equation 11, 12).

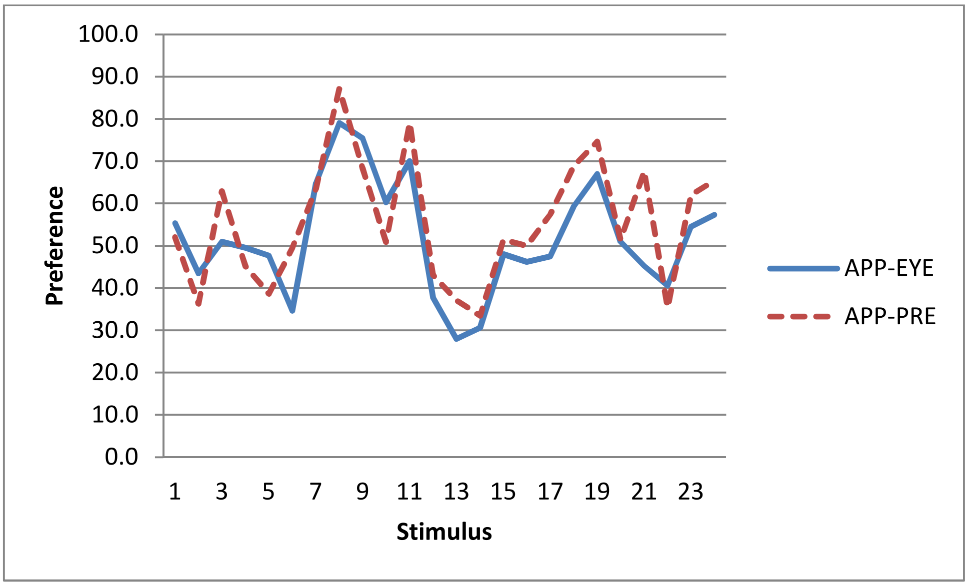
$$beauty = 35\lambda - \frac{100}{3}\lambda^2 - 8.37 \;\; , \;\; \lambda < 0.50 \qquad \textbf{(11)}$$

$$beauty = \frac{100}{19}\lambda^2 - 9\lambda + 4.18 \;\; , \;\; 0.50 \le \lambda \qquad \textbf{(12)}$$

Using the Equations 11 and 12, the beauty value will be a number between 0 and 1 which can be multiplied by 100 in order to express the beauty in percentage.

4.3. Preference of appropriateness

Applying the appropriateness template, the value was calculated for each trial using the data from 50 subjects participating in the eye-tracking experiment. In order to compare the data from eye-tracking and declared preference of appropriateness, the images of chairs in the rating task were shown to further 45 subjects and they were asked to rate each design from 1 to 10 in terms of appropriateness: 1 for least appropriate design and 10 for most appropriate design using an answer sheet (see Appendix 5). The result of applying the measurement method then was compared with the declared preference (see Graph 3).

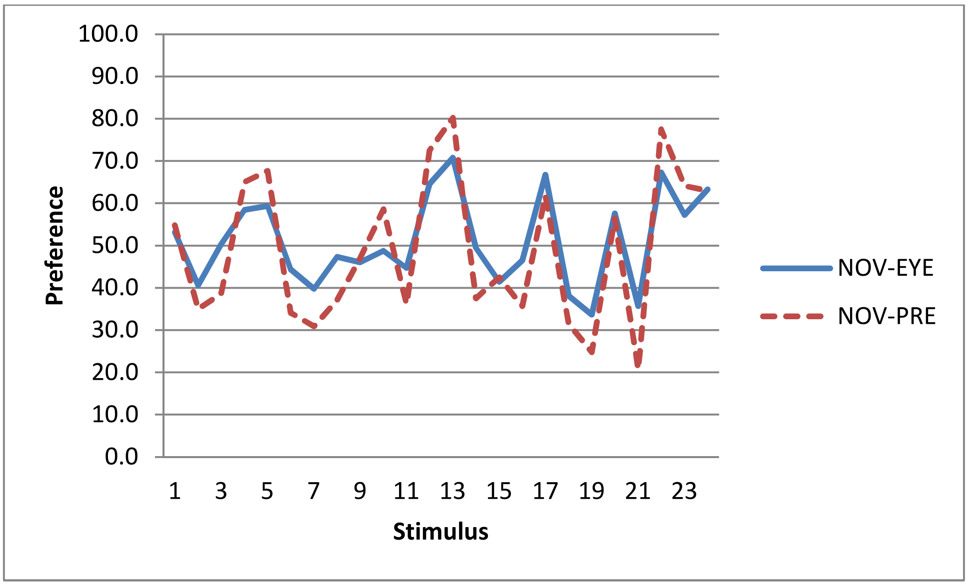


Graph 3: Appropriateness measured using eye-tracking data and proposed method (APP-EYE) against the declared preference (APP-PRE) (see figure 41)

As can be seen from Graph 3, the result of proposed method to measure the appropriateness has been able to predict the declared preference with a good match.

4.4. Preference of novelty

Using the novelty template, the value of novelty was calculated for each trial. In order to compare the novelty data extracted from eye-tracking experiment, and the declared preference, the chair images were shown to a further 45 subjects (excluding the subjects who attended in rating the appropriateness) and they were asked to rate each chair in terms of novelty from 1 to 10: 1 for least novel and 10 for most novel design using answer sheet (see Appendix 6). The result of this test was then compared with the data calculated via the proposed methodology of measuring novelty using eye-tracking data (see Graph 4).



Graph 4: Novelty measured using eye-tracking data and proposed method (NOV-EYE) against the declared preference (NOV-PRE)

As Graph 4 shows, the outcome of the proposed method has a good match with the declared preference which means the method has been able to estimate the novelty of the designs close to subjective interpretation.

4.5. Aesthetic equation

Using the beauty formula (Equation 11, 12), the beauty value for each chair is calculated. Appropriateness and novelty are also measured for each design. Table 17 shows the quantified values for each stimulus and the declared preference.

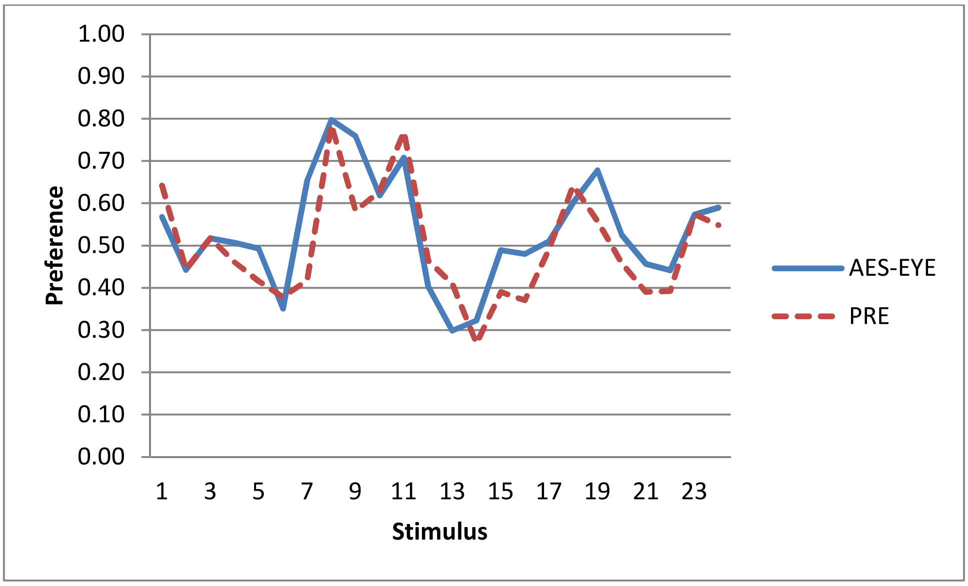
Chair No.	Beauty	Appropriateness	Novelty	Preference
1	70.2	55.4	53.1	64.2
2	67.5	43.5	40.6	44.4
3	51.3	50.9	50.3	51.8
4	53.3	49.5	58.5	46.0
5	67.5	47.6	59.3	41.6
6	42.8	34.6	44.3	37.8
7	67.5	64.8	39.7	41.8
8	64.8	79.0	47.3	78.6
9	47.6	75.4	46.0	58.2
10	82.2	60.2	48.8	62.8
11	64.8	70.0	44.6	77.0
12	79.1	37.7	64.5	46.4
13	67.5	27.9	70.7	41.0
14	88.8	30.6	49.4	26.8
15	73.1	48.0	41.4	39.0
16	88.8	46.3	46.5	37.0
17	85.5	47.4	66.8	49.2
18	76.0	59.4	38.1	64.2
19	92.3	67.0	33.6	55.8
20	64.8	50.9	57.6	45.8
21	59.9	45.2	35.7	39.0
22	85.5	40.6	67.3	39.2
23	88.8	54.5	57.3	57.4
24	62.3	57.3	63.3	54.8

Table 17: The result of the eye-tracking experiment using the methods of calculating beauty, appropriateness and novelty with the declared preference for each trial, the unit of each quality and the preference is in percentage (see figure 41).

Given the declared preference is the final aesthetic value; the preference is a function of beauty, appropriateness, and novelty. This function defines the final aesthetic formula for a chair as the applied stimulus. Using exponential function, if N is a value of novelty, B is a value of beauty and A is a value of appropriateness, the aesthetic equation is created as shown in Equation 13.

$$aesthetic = Ae^{NB} - e^{NBA} + 1 \tag{13}$$

All the values are a number between 1 and 0. Using the Equation 13, the aesthetic is calculated for each trial. The result of the formula and the declared preference is then compared (see Graph 5).



Graph 5: Aesthetic measured using eye-tracking data and proposed equation (AES-EYE) against the declared preference (PRE) for each chair in the rating task

As can be seen from Graph 5, the proposed equation generates a result which has a good match with the declared preference. In other words, the model appears to be capable of predicting the aesthetic preference by monitoring the eye behaviour. However, the level of influence of attractiveness in aesthetic preference may depend on the function of the product. In other words, the aesthetic equation may differ for different products. Therefore, the fourth eye-tracking experiment for a different product was conducted which will be explained in the next chapter.

Chapter 5: **Practical framework**

5.1. The case study of the methodology

5.2. Applying methodology to design process

5.1. The case study of the methodology

A case study was conducted as an example of the methodology application. The case study aims to objectively evaluate three hypotheses: first, designers are biased in judging their own work; second, the quality of presenting the design affects the qualities of aesthetics and the final preference; and third, by using the quantification methodology the experiment verifies if the level of influence of attractiveness in final aesthetic preference is dependent on the function. Therefore, a fourth eye-tracking experiment was conducted in order to use the aesthetic quantification methodology in evaluating the hypotheses.

5.1.1. Method of the experiment

The experiment contains two stages:

- Designing a product as a simple sketch then generating refined and 3D model of the sketches.
- Evaluating the aesthetic judgment using the proposed method by two groups: one group consist of the designers of the sample product and a control group consist of people who did not participate in the design task.

The sample product must have the following features:

1. The allocated time to the design task is limited. Therefore, the sample product must be simple with a clear and understandable function.

2. The sample product must offer sufficient physical detail. In other words, it must not be too simple.

3. The dimension of the product must not exceed a certain number in order to keep the designs in true scale which is required to generate the patterns to measure the qualities of attractiveness.

4. In order to make the task simple, only one view is designed. Therefore, the structure of the product must be more concentrated in one view. In other words, one certain view of the product must be more substantial.

5.1.2. Conducting the experiment

As discussed, the experiment consists of two stages: designing task and the aesthetic evaluation test.

5.1.2.1. Designing task

According to the required features of the sample product, a multifunctional controller device with following functions and criteria was chosen:

Function: This controller is meant to be used during an academic presentation.

Features: Laser pointer, changing and controlling the slides, slide notes (text only) appearing on the screen, it has to be a handheld device.

14 design students (3 female, 11 male) were asked to design the sample product. Each student was given an answer sheet in order to draw the final sketch in the specified area (see Appendix 7). The following rules were asked from participants:

1. Design only the front view.

2. The design must be in true scale (1:1).

3. Maximum size is 80x160mm and minimum size is 40x80mm.

4. All types of user interface are allowed except touchscreen.

5. The design must be fully rendered and represent the real model.

6. The final design must be created on this paper only in the specified area.

7. Aesthetics, user interface, and ergonomics are the main factors.

The task allowed time was 45 minutes. All the participants were able to finish their final sketch within the allocated time. Therefore, 14 sketches were made by participants (see Figure 47).

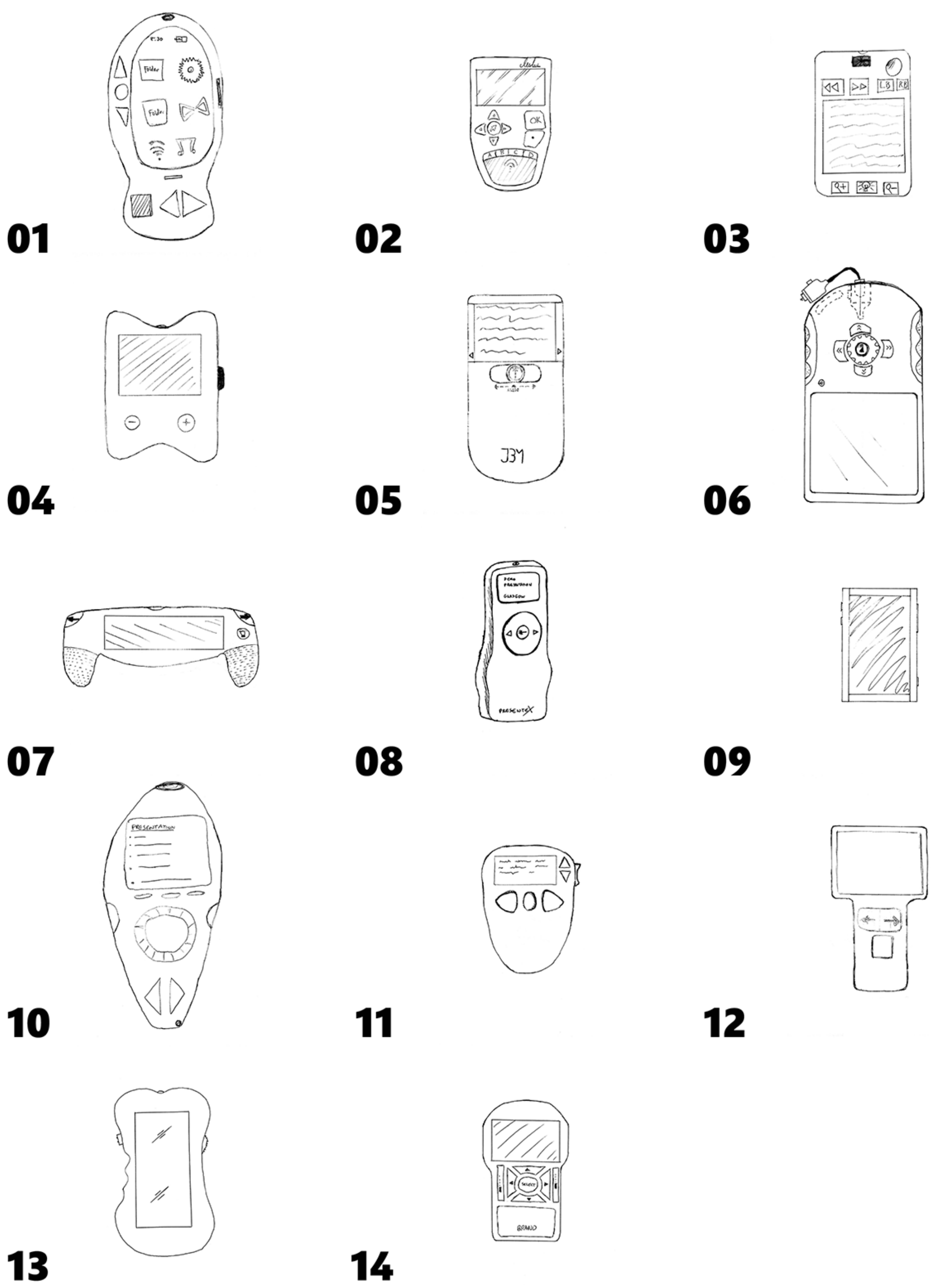


Figure 47: The sketches of the sample product in the design task

Each design was scanned and placed in the same location with the same scale. In order to evaluate the influence of the quality of sketch in aesthetic judgment, each sketch was refined so that the sketch lines were aligned, and symmetry and other details were improved. Therefore, 14 refined sketches were generated in line with the details of the original designs (see Figure 48).

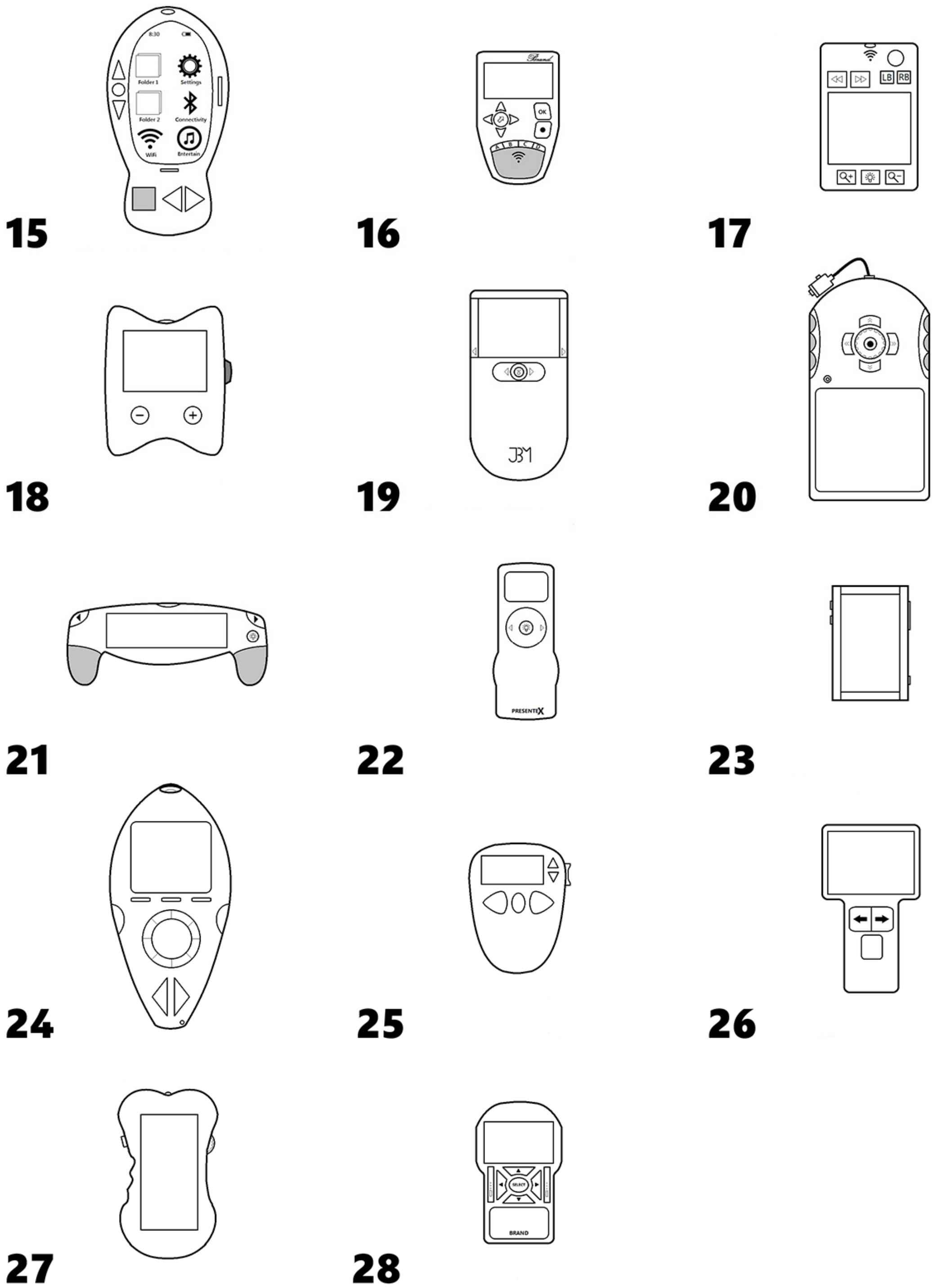


Figure 48: Refined sketches of the sample product in the design task

After generating the refined version of the sketches, the next step is to design the 3D model of the designs in order to produce the perspective view. Therefore, each sketch was modelled in CAD using the exact dimensions and rendered in 3Ds Max software. All the details including the graphics were added to the 3D model. Because no colour was presented in the original sketches, the same colour was applied to all the 3D designs (see Figure 49).

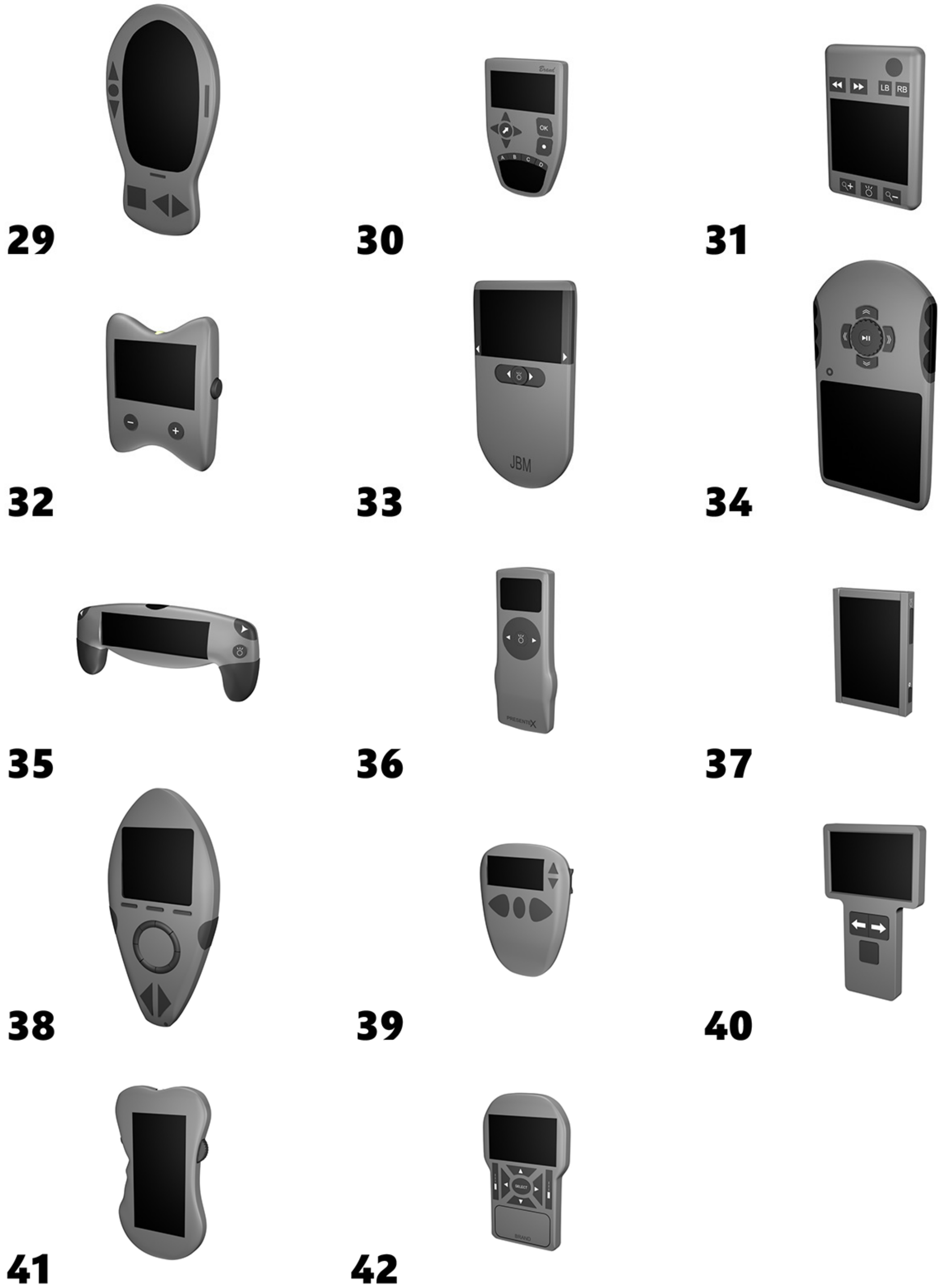


Figure 49: 3D models of the sample product in perspective view

In order to keep the 3D models simple, 4 colours were used in all the designs: Black for screen, light grey for the body, dark grey for buttons and brand graphic, and white for buttons graphic. All details were made in line with the original sketches and no extra detail was added to the models. Therefore, 3 groups of designs were generated: original sketch, refined sketch, and 3D model in perspective view.

5.1.2.2. Aesthetic evaluation test

The fourth eye-tracking experiment was conducted in which 30 subjects attended including the designers of the sample product and people who did not attend in the designing task. 42 images including 14 original sketches, 14 refined sketches, and 14 3D models plus one warm-up image were used as stimuli in the experiment. The same approach as previous experiments was used in conducting the experiment. Participants were asked to look at each image and rate it from 1 to 10 depending on level of aesthetic preference. First the original sketches were shown following by refined sketches and 3D models.

5.1.3. Data analysis

Using the proposed methodology, beauty, appropriateness, and novelty were measured for all 42 figures. The declared preference for each figure was also recorded. Moreover, the designs were shown to a further 30 subjects and they were asked to rank the 3D designs in terms of appropriateness from most appropriate to the least appropriate. In order to measure the qualities of attractiveness, the template for each set of designs was generated separately due to different nature of the sketches, refined sketches, and the 3D designs. Table 18 shows the specifications of each template.

Spec	Original Sketch		Refined Sketch		3D Design	
	A	N	A	N	A	N
Cx	521	520	523	526	504	516
Cy	365	364	364	377	385	378
Rx	27	72	41	75	44	73
Ry	145	127	134	121	134	112
Min (x)	438	183	377.4	213	226.9	161.6
Min (y)	14.1	2.7	105.8	1.1	26.1	11.7
Degree	7.4	12.7	55.3	10.8	16.9	19.5
Direction	Left	Right	Right	Right	Right	Right

Table 18: The specification of the ellipses as a template of measuring appropriateness (A) and novelty (N)

Figure 50 shows the templates were used in quantifying the qualities of attractiveness.

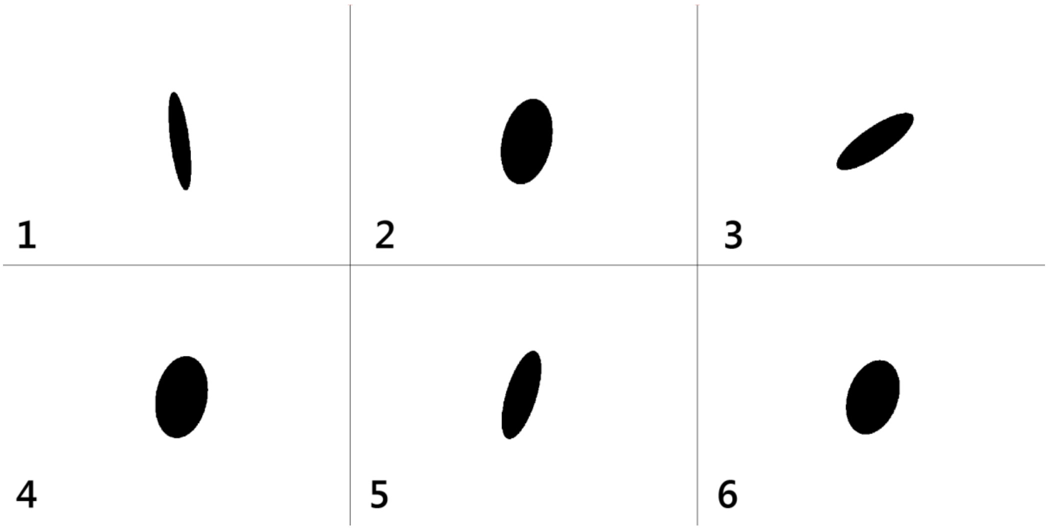


Figure 50: The templates were used in quantifying appropriateness and novelty of the designs. 1: Original sketches (A), 2: Original sketches (N), 3: Refined sketches (A), 4: Refined sketches (N), 5: 3D Designs (A), 6: 3D Designs (N)

Using AscFilter software, Number of fixations in black area for appropriateness and number of fixations in white area for novelty for each image were recorded (see Figure 51).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
IMAGE 01	1	3	2	3	4	0	0	1	3	2	6	3	3	5	3	5	4	4	3	3	7	4	10	0	2	6	0	3	3	1	94
IMAGE 02	5	3	6	1	4	0	1	3	1	3	3	2	4	4	3	3	1	3	2	2	5	3	4	4	4	4	5	1	2	5	91
IMAGE 03	3	1	4	4	4	0	2	1	0	2	2	1	2	2	4	8	3	5	2	4	3	3	0	5	4	6	1	3	2	1	82
IMAGE 04	3	8	3	3	3	0	1	4	0	4	4	1	3	4	4	7	4	3	2	6	3	2	0	5	4	5	3	4	3	2	98
IMAGE 05	7	1	2	6	5	0	2	6	1	4	4	3	1	7	3	2	0	7	4	6	0	2	8	10	4	3	0	1	1	2	102
IMAGE 06	6	5	6	2	5	0	3	2	0	2	13	2	0	3	2	5	2	2	3	0	0	1	3	4	1	2	4	3	3	2	86
IMAGE 07	1	3	1	1	2	0	2	2	0	1	2	0	0	3	0	2	2	1	1	1	0	0	2	2	1	2	1	1	4	1	39
IMAGE 08	1	3	2	2	4	3	10	4	2	0	5	3	1	1	3	5	4	3	4	4	10	2	4	2	1	2	6	4	5	3	103
IMAGE 09	1	2	4	1	5	3	2	2	2	4	1	2	1	3	0	2	3	4	2	2	2	3	1	3	3	3	1	2	4	3	71
IMAGE 10	0	2	2	0	5	3	4	7	2	4	4	2	1	6	1	6	1	5	1	6	7	1	1	7	3	4	1	2	4	4	96
IMAGE 11	2	2	4	1	3	3	1	4	3	3	3	3	1	4	2	6	2	3	4	7	6	2	3	9	2	3	0	1	2	2	91
IMAGE 12	5	6	2	3	6	3	1	5	3	5	2	3	2	5	1	4	4	7	4	6	12	5	9	7	3	7	2	3	5	3	133
IMAGE 13	2	1	3	2	3	0	2	1	2	1	3	0	0	3	0	4	1	1	2	4	4	2	4	5	2	1	1	2	4	4	64
IMAGE 14	7	4	2	6	10	2	4	4	1	3	7	2	4	4	7	9	4	5	2	5	6	7	7	4	6	7	3	2	3	13	150
IMAGE 15	8	2	4	4	9	2	2	9	3	2	3	0	4	5	4	5	2	1	3	6	6	0	2	2	3	1	6	5	5	1	109
IMAGE 16	7	6	4	4	7	5	2	5	2	6	0	4	1	8	5	6	3	5	4	3	7	1	10	5	5	8	4	2	4	4	137

Figure 51: Number of fixations in appropriateness area for each image showing in Microsoft Excel

By dividing the sum of the number of fixations by total number of fixations, appropriateness and novelty are measured. The beauty of each image was also evaluated using the proposed equations (Equation 11, 12).

5.1.4. Result

Table 19 shows the beauty, appropriateness, and novelty value plus declared preference for all 42 designs in percentage:

Stimulus	Beauty	Appropriateness	Novelty	Preference
01	12.9	23.0	58.2	34.0
02	74.8	24.2	39.1	50.7
03	66.9	24.1	63.2	52.0
04	49.5	33.2	51.9	50.0
05	56.7	33.9	49.2	49.3
06	45.4	21.7	73.5	47.7
07	46.4	12.3	76.9	50.3
08	62.9	33.9	59.6	55.3
09	58.0	23.0	63.4	50.0
10	23.3	29.9	62.3	40.3
11	63.2	30.5	45.3	47.7
12	74.5	53.2	22.8	47.0
13	60.5	20.3	62.7	50.0
14	83.0	47.0	30.4	54.3
15	98.8	22.6	56.7	61.0
16	99.0	39.6	33.5	61.0
17	99.4	12.7	61.2	62.3
18	73.3	30.5	46.5	49.0
19	80.7	33.7	43.1	53.0
20	94.2	7.0	64.2	54.7
21	75.9	13.5	73.7	53.7
22	73.8	36.9	40.3	55.3
23	84.8	19.1	65.1	54.3
24	74.0	27.2	48.2	49.3
25	67.4	39.5	41.6	47.7
26	71.4	47.5	25.6	49.0
27	62.3	26.7	57.3	49.3
28	73.4	41.6	32.6	53.3
29	80.8	23.1	70.1	58.0
30	95.6	54.5	36.8	63.7
31	93.2	49.2	50.4	64.3
32	78.2	37.1	53.7	54.7
33	95.7	38.6	57.5	60.7
34	83.4	26.7	68.8	56.0
35	76.1	18.1	76.0	56.7

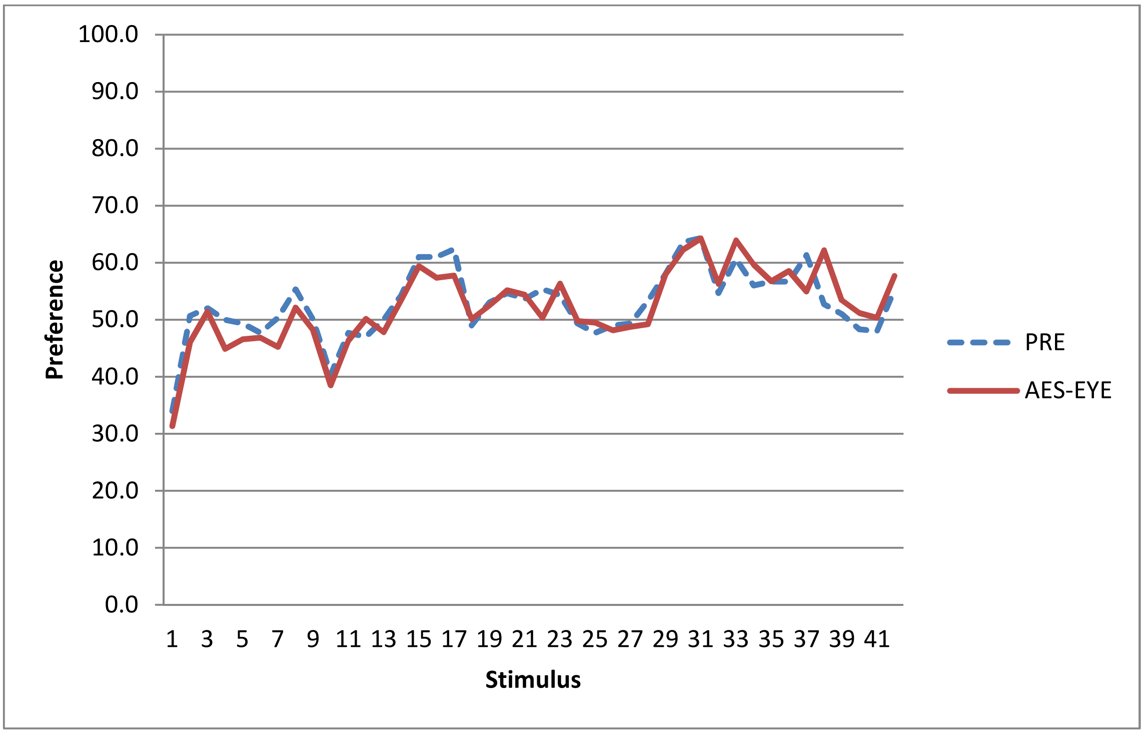
36	77.3	56.7	41.6	56.7
37	86.8	27.1	50.9	61.3
38	74.1	53.8	58.7	52.7
39	69.2	53.2	38.0	51.0
40	63.3	58.5	31.7	48.3
41	62.1	33.8	55.1	48.0
42	79.6	60.2	33.3	55.3

Table 19: The result of the eye-tracking experiment using the methods of calculating beauty, appropriateness and novelty with the declared preference for each trial, the unit of each quality and the preference is in percentage.

As can be seen from Table 19, this time appropriateness, novelty, and beauty have equal weight in the final preference. Therefore, the aesthetic is calculated using Equation 14.

$$aesthetic = \frac{A+N+B}{3} \tag{14}$$

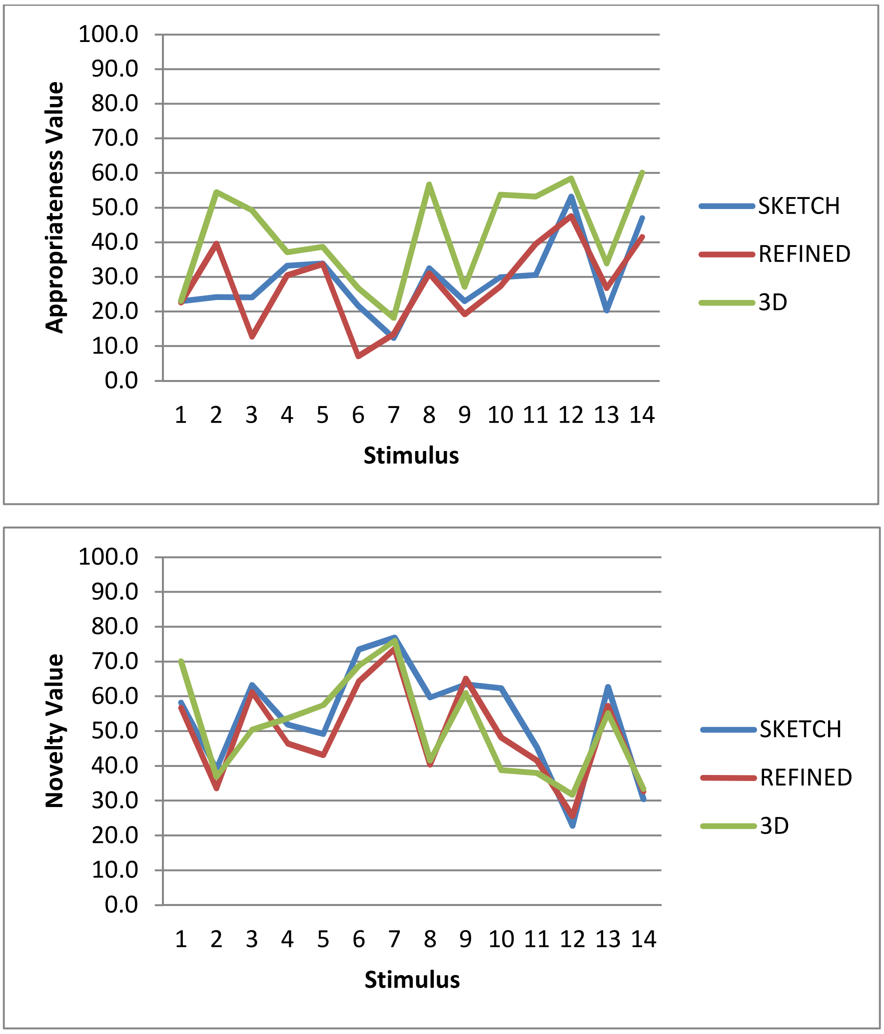
Graph 6 shows the comparison between aesthetic measured using Equation 14 and the declared preference.



Graph 6: Aesthetic measured using the proposed method (AES-EYE) versus the declared preference (PRE)

As can be seen from Graph 6, the result of the method is close to the declared preference for all 42 images. For the first 14 images, the overall aesthetic measured value is slightly lower than the declared preference. For the second 14 images which are the refined sketches, the preference and the value are closer, and for the 3D designs, the preference is lower than the measured value which shows the designers' biased interest in their own work.

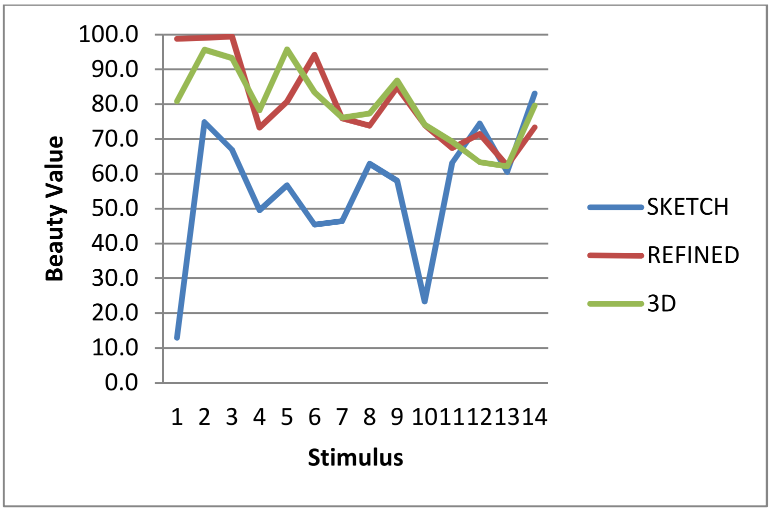
Graph 7 shows the appropriateness and novelty measured for original sketches, refined sketches, and the 3D designs.



Graph 7: Appropriateness (top) and novelty (bottom) measured using the method for each set of stimuli

As can be seen from graph 7, the method has generated relatively consistent result for all three sets of stimuli while appropriateness of 3D designs is noticeably higher than the sketches.

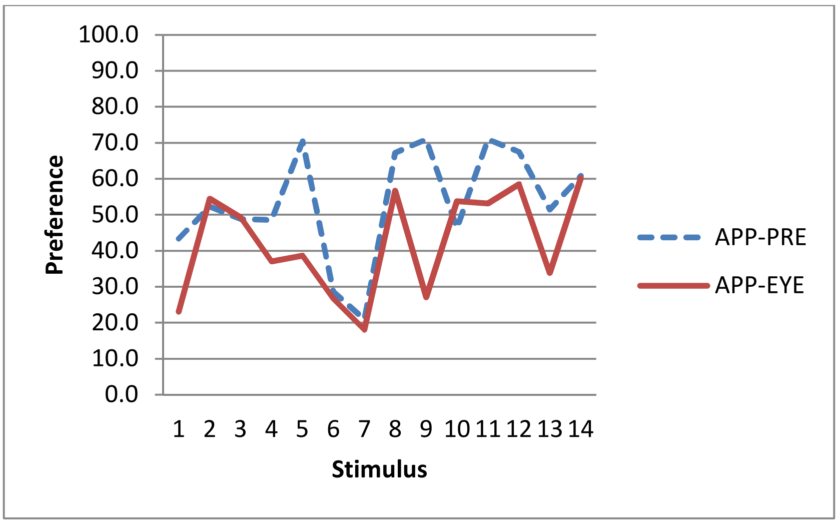
Graph 8 shows the beauty value measured for original sketches, refined sketches, and the 3D designs.



Graph 8: Beauty value measured for each set of stimuli

As Graph 8 shows, although the result is relatively consistent for each set of stimuli, the beauty of original sketches is considerably lower than the refined sketches and the 3D designs (it is expected because beauty is affected by the qualities (such as symmetry) which are difficult to control by hand drawing).

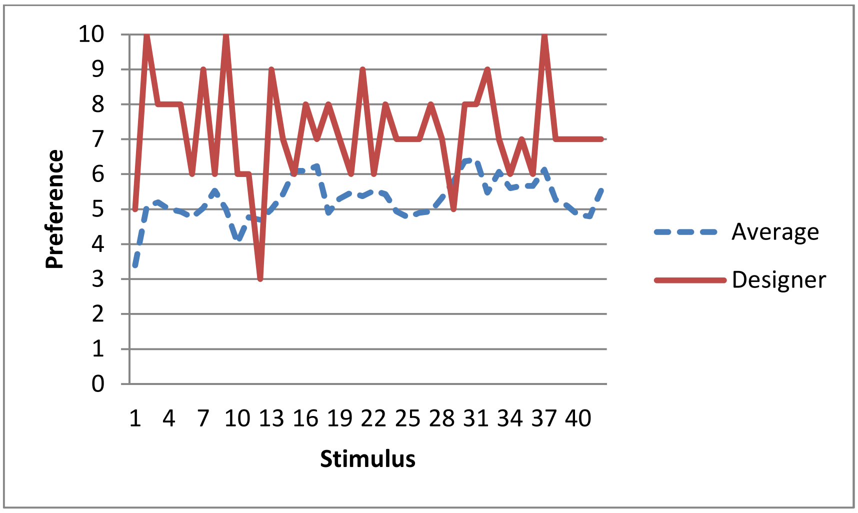
Graph 9 shows the measured appropriateness compared to declared judgment of appropriateness.



Graph 9: Measured appropriateness (APP-EYE) value compared to declared preference of appropriateness (APP-PRE)

As can be seen from graph 9, except for two designs, the measured appropriateness is close to the declared judgment of appropriateness.

Graph 10 shows the average preference of each design compared to the designer's judgment.



Graph 10: The average preference compared to designer's score (out of 10)

As can be seen from Graph 10, the average score of the designers is about 20% higher than the average which indicates that the designers are biased towards their own work.

Table 20 shows the average response for the original sketches, the refined sketches, and the 3D models in percentage (the original score scale is out of 10).

Design	Original sketches	Refined sketches	3D Designs
Average Declared Score	48.5	53.8	56.2
Average Measured Score	46.4	52.8	57.8
Average Designer's Score	71.7	72.5	71.7

Table 20: The average preference of three types of design presentation

As can be seen from Table 20, the quality of presenting the design clearly changes the final preference. 3D model has higher score compared to refined sketch and refined sketch has higher score compared to the original sketch in which the variance between refined sketch and original sketch is higher than refined sketch compared to 3D design. On the other hand, average designer's score has met lower increase among refined sketches and 3D designs which confirms they are biased about their own work. It has been also reflected in the average measured score so that the average declared score for the original sketches is 2.1% higher than the average measured score. The average measured score for the refined sketches is 1% lower than the declared preference but 1.6% higher for the 3D designs.

5.1.5. Discussion

The 4th eye-tracking experiment revealed several facts: first, the measuring methodology generates consistent result regardless of the quality of how the design is presented. Second, although all three qualities of aesthetics are effective in the final preference, the influence of each quality is dependent on the function of a product. Therefore, the aesthetic measuring equation varies for different products (see Equation 13, 14). Third, the quality of presenting the design influences the preference in which better quality improves the final judgment. Fourth, designers are biased towards their own work. This not only is reflected in each score, it is also shown in the average score of each set of stimuli so that even the quality of presenting the refined sketches and 3D designs are noticeably higher than the original sketches, the average score has met lower increase. This may also occur due to the difference between designers and non-designers view in which the designers see more information of their designs compared to non-designers (Menezes & Lawson, 2006) which they may expect to see in the 3D models. By comparing the measured score with the declared preference it is shown that the average declared score compared to the measured score is higher for the original sketches and lower for the 3D designs. This reflects the high scores in the original sketches given by the designers which are effective in the average score. **However, the measured scores confirm that their involuntary response is not affected by their biased opinion. This shows that the methodology is capable of objective quantification which ignores subjective responses.**

5.2. Applying methodology to design process

After generating the product aesthetic quantification methodology, it is required to apply the method to the design process. As discussed in **section 2.5**, metrics can be employed in designing the aesthetic in order to enhance the visual qualities of the product. This process has two stages: first, developing measured metrics, and second, developing an instruction of using the metrics effectively. The instruction then is used in a sample design process in order to illustrate how the method can potentially enhance the aesthetic qualities.

5.2.1. Developing measured metrics

This section will discuss how to generate and measure the effective metrics in order to use in the design process.

5.2.1.1. Generating metrics

As discussed, metrics are generated by combining the properties of design elements and the aesthetic qualities. One or more properties can be combined with one or more aesthetic qualities to produce a metric.

1. Beauty metrics: By manipulating the design elements, pureness and proportion can change. The examples of how pureness and proportion increase in different design elements has been provided (see Appendix 8).

In order to generate a metric template, a standard coding table is defined. Table 21 shows the metric code when the properties of design elements and beauty qualities are combined to increase or decrease the quality value.

Variable	PU	PR	Value	NA	DI	LO	FO	SH	CO	TE
Code	W		X	Y			Z			
	1	2	+,-	3	4	5	6	7	8	9

Table 21: Metric code table

Each metric is allocated a code as follows:

$MAW_1X_1Y_1Z_1\_W_2X_2Y_2Z_2\_\ldots\_W_NX_NY_NZ_N$ (for analytical metric)

$MCW_1X_1Y_1Z_{1\ldots N}\_W_2X_2Y_2Z_{2\ldots N}\_\ldots\_W_NX_NY_NZ_{N1\ldots NN}$ (for compositional metric)

For instance, MC2+37_2-367_1+38 means that the compositional proportion increases in nature of the shape and compositional proportion decreases between nature of shape and form and compositional pureness increases in nature of the colour. The analytical metric evaluates each element with its own qualities: for instance, the proportion of the shape in terms of its aspect ratio.

Table 22 shows the examples of combining the properties of the design elements and the qualities of beauty which is done via 9 variables (Table 21).

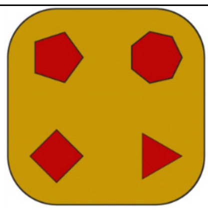
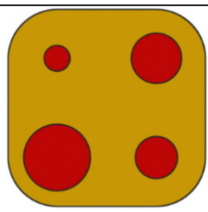
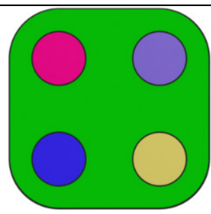
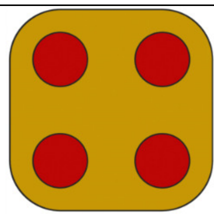
Design	Target design	1	2	3
Metric	-	MC2+37_2-47	MC1-38_2+37	MC2+37
Figure				
λ	0.74	0.58	0.54	0.51
Beauty	40%	73%	85%	95%

Table 22: The example of generating metrics and their beauty value

As can be seen from Table 22, different combination of beauty qualities and properties of design elements as metrics can change the beauty of the design. In Design 1, the proportion of the shape in terms of nature has increased while the proportion has dropped in terms of dimension. In Design 2, the proportion of shape in terms of nature has improved. However, the pureness of colour has decreased because more variety of colours has been used. In Design 3, the proportion of the shape in terms of nature has increased.

2. Attractiveness metrics: The metrics of the qualities of attractiveness can be developed based on the main function of the target product and its physical properties. Because the qualities of attractiveness are relative, the related metrics are determined relative to the other products in the same category. For example, a chair is divided into three sections to evaluate the effectiveness of each part in the final preference. The chairs are divided into back, seat, and support with the design elements of form, material, and dimension (see Table 23).

Part \ Element	Form	Material	Dimension
Back	**M1**	**M2**	**M3**
Seat	**M4**	**M5**	**M6**
Support	**M7**	**M8**	**M9**

Table 23: The example of generating metrics for a chair

5.2.1.2. Measuring the metrics

1. Beauty metrics: Using the quantification methodology, each metric can be measured for different qualities. Figure 52 shows the changes in beauty value when different metrics are applied (beauty value for 48 figures are measured). As can be seen from Figure 52, the highest discrepancy in beauty value is related to the proportion in nature following by proportion in location and dimension. The value has higher change when two or more properties change. Proportion in colour saturation caused the slight change compared to colour variety in pureness as well as texture which means pureness in colour and texture is more effective, while proportion in shape and form is more influencing the beauty. Moreover, the designs with high pureness and low proportion have lowest value of beauty in which by only decreasing the pureness, the beauty value is dramatically improved.

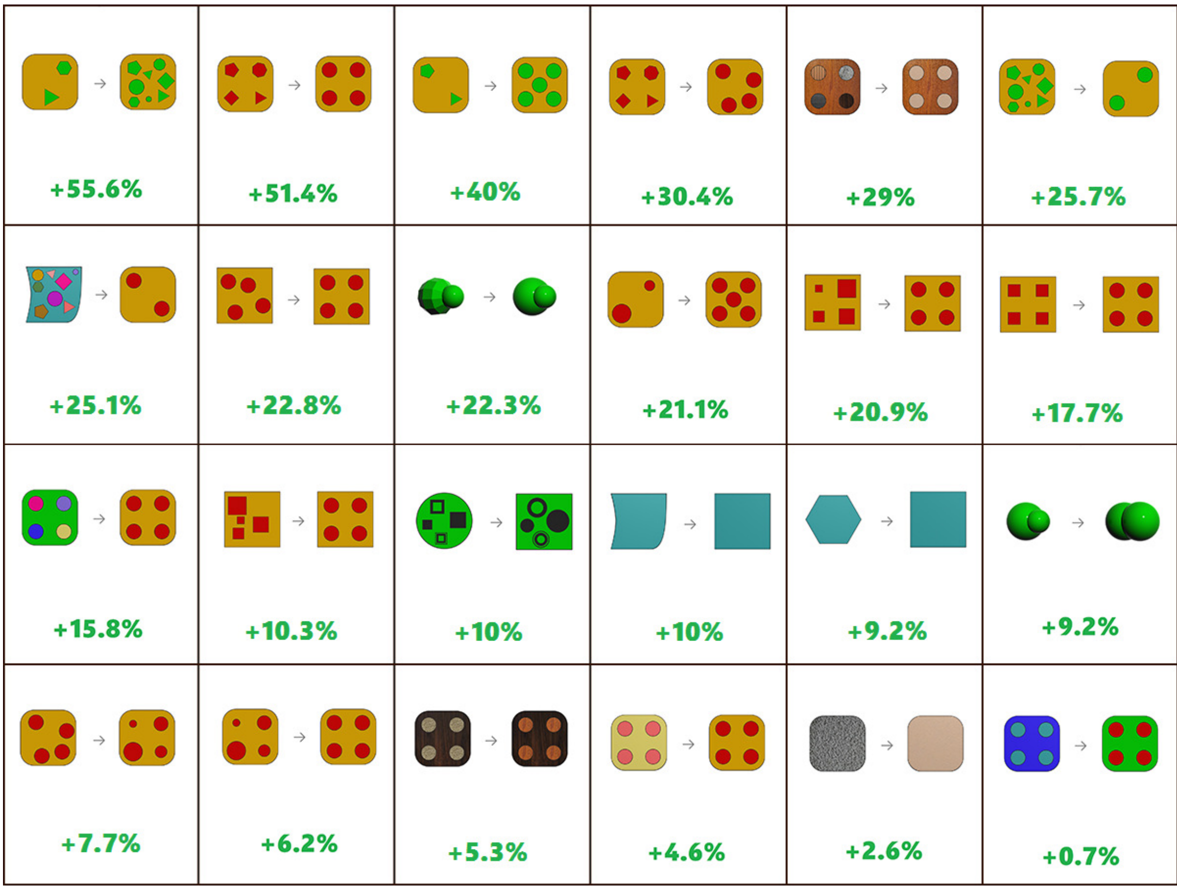


Figure 52: The change in beauty value for different metrics

2. Attractiveness metrics: Using the quantifying methodology, appropriateness and novelty are measured for each stimulus. The defined metrics are then added to each measured value. Therefore, the value of the qualities of attractiveness is allocated to each metric. The metrics are evaluated for appropriateness and novelty. Figure 53 shows the chairs which are divided into two groups based on the measured appropriateness value over and below 55% which is the mean of the values. The chairs are placed in order according to the appropriateness value. By looking at Figure 53, the immediate observation indicates that the chairs with better ergonomics and comfort have higher value of appropriateness. By evaluating defined chair parts, it is revealed that the back and support height is highly effective compared to seat size and comfort in the appropriateness value in which taller back and support are preferred as an appropriate design (see Figure 54). By contrast, the form of chair's support has not affected the appropriateness value (see Figure 55).

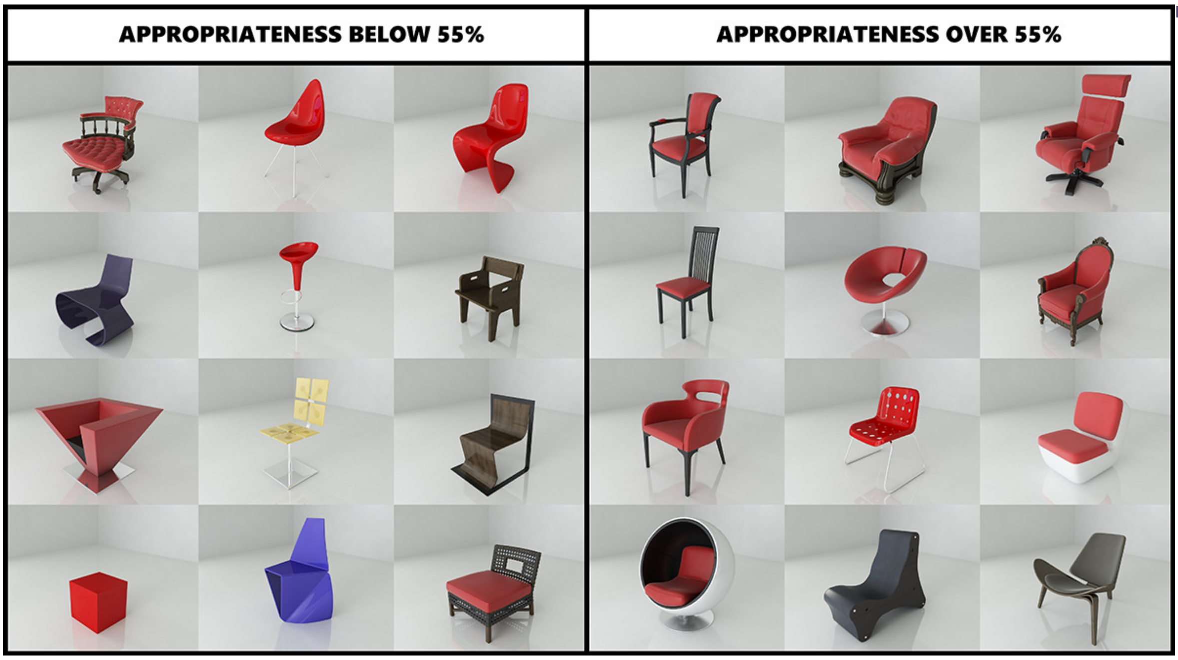


Figure 53: Chairs are divided into two groups based on the appropriateness value

Figure 54: The chair with taller back and support has higher appropriateness preference

Figure 55: The chair with different supports while the appropriateness value is similar

Figure 56 shows how appropriateness value increases in different chairs.

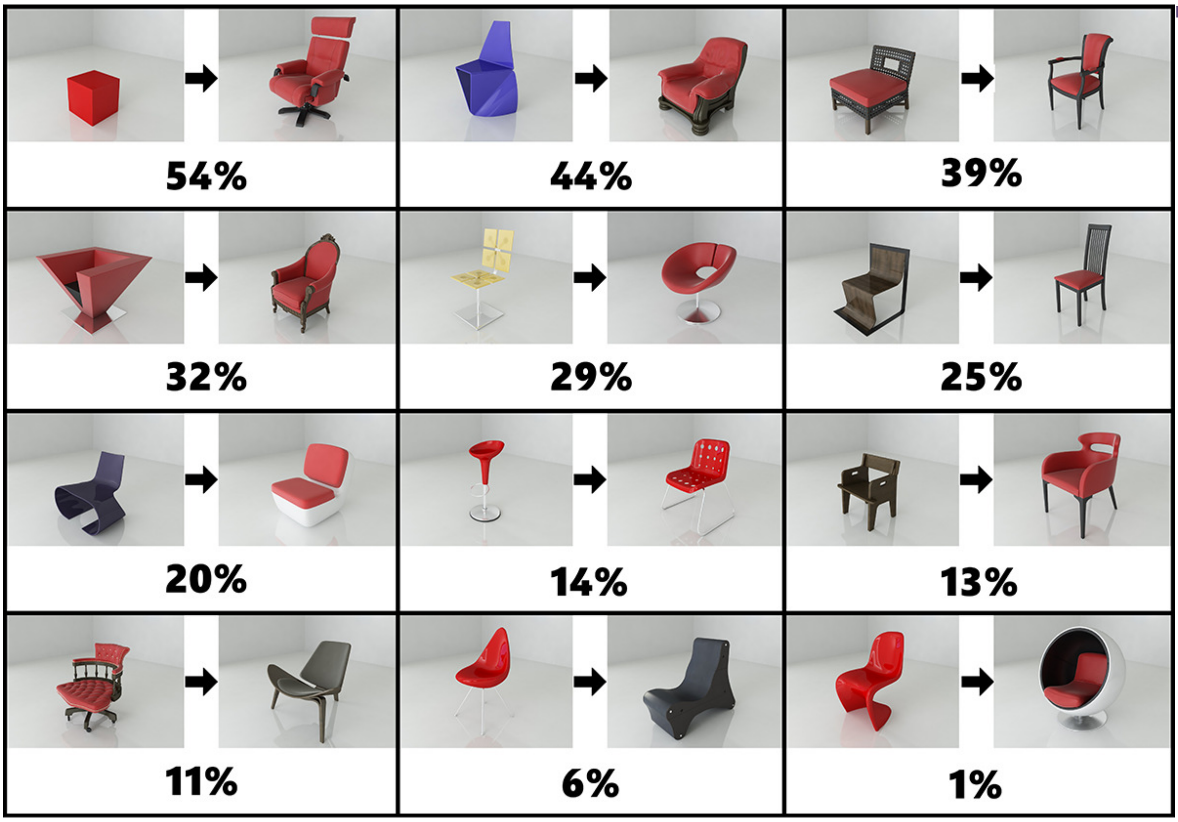


Figure 56: The appropriateness value increases when different metrics are applied

Figure 57 shows two classifications of the chairs according to the values of novelty over and below 50% (mean of the values). 12 designs have novelty value of over 50% and 12 designs have novelty value of below 50%.

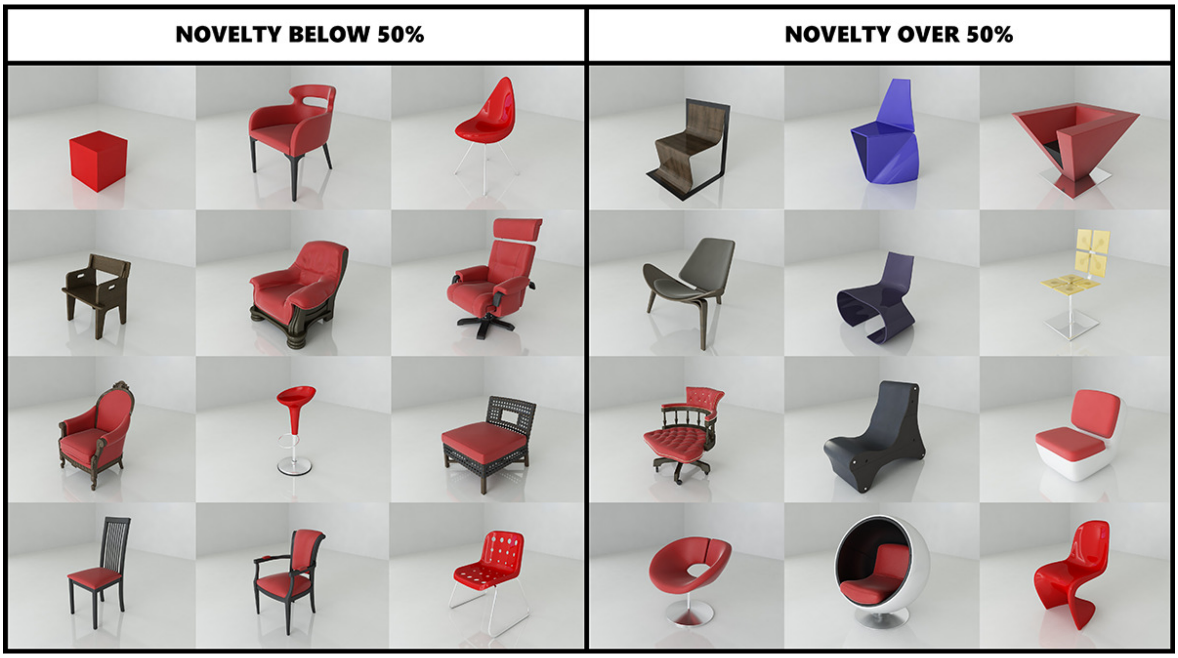


Figure 57: Chairs are divided into two groups based on the novelty value

As can be seen from Figure 57, the chairs which have employed more atypical elements are perceived as more novel designs. The figure shows that back, seat and support of the more novel designs are merged together as one form. Using three legs as support, using classical element in an office chair, and using transparent material for back and seat with spider fitting are the observable features of more novel designs.

Figure 58 shows how novelty value increases when different design elements are applied.

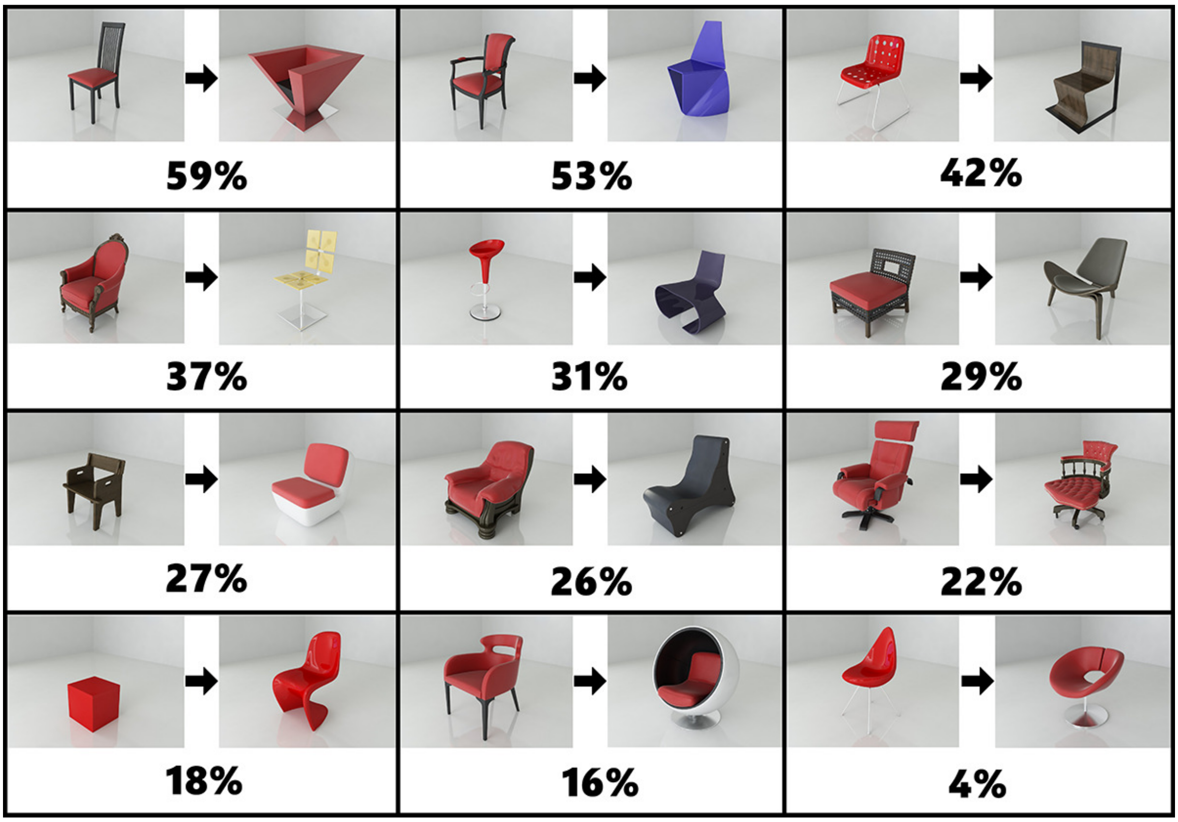


Figure 58: The novelty value increases when different metrics are applied

As can be seen from appropriateness and novelty values of the chairs, metrics M3, M5, M9 are high effective metrics in appropriateness and metrics M1, M4, and M7 are highly effective in novelty.

The next example is the controller device. The 3D models are divided into two groups in terms of level of appropriateness value over and below 42% (the mean) (see Figure 59) and in terms of level of novelty value over and below 51% (the mean) (see Figure 60).

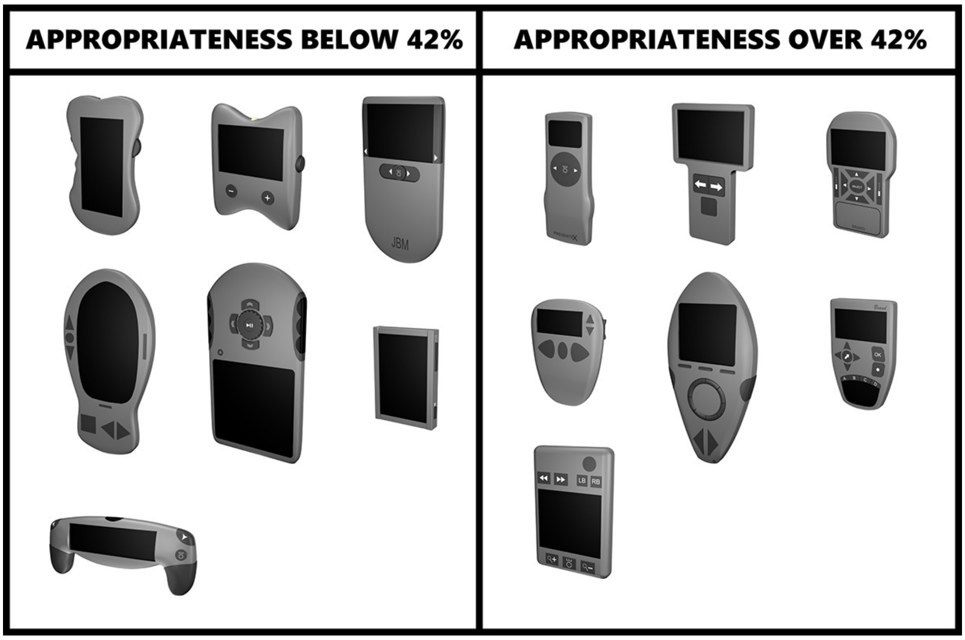


Figure 59: Controllers are divided into two groups based on the appropriateness value

As can be seen from Figure 59, the more appropriate designs have more logical interface and more comfortable in hand due to the form and size. As can be seen, design 29 has irregular shape of the screen. Designs 37 and 41 do not have any keys on the front face, and designs 32, 33, and 34 seem awkward to use single handy. This shows that in this kind of product the appropriateness depends on ease of use and the comfort of the device in hand (see Figure 50 for design numbers).

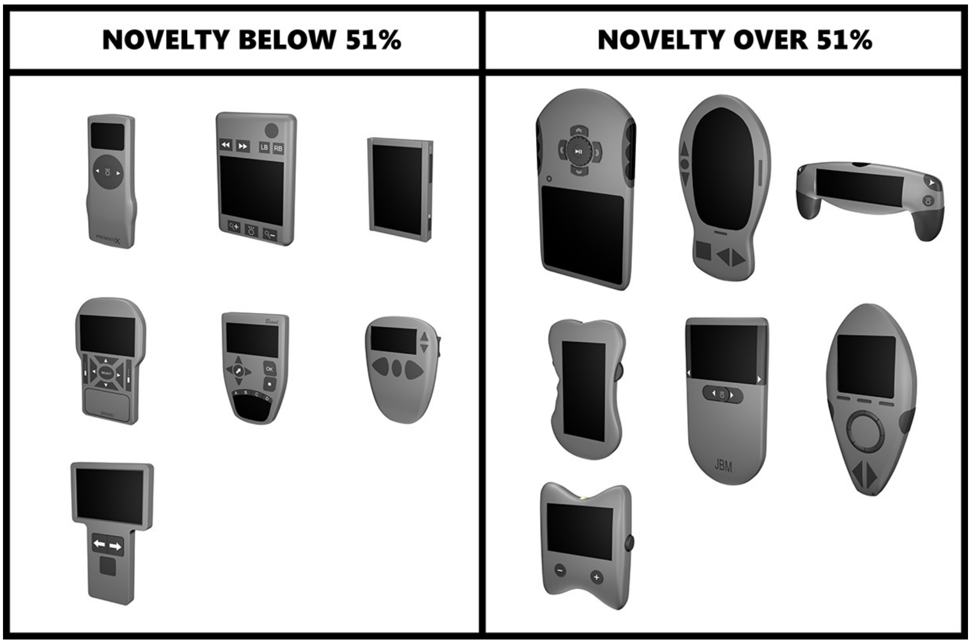


Figure 60: Controllers are divided into two groups based on the novelty value

As can be seen from Figure 60, most of the designs with novelty over the mean value have appropriateness below the mean value which confirms opposing nature of novelty and appropriateness. As the figure shows, novel designs have more irregular shape and interface.

Figure 61 shows the controllers based on the beauty value in two groups below and over 79% (the mean value of the beauty).

Figure 61: Controllers are divided into two groups based on the beauty value

As Figure 61 shows, the designs with higher value of beauty have better proportion between the screen and the body shape.

5.2.2. Using the metrics

After generating and measuring the metrics, it is required to apply them to the design using a standard instruction.

5.2.2.1. Instruction of applying the metrics

As discussed in **section 2.5**, the qualities of attractiveness determine the type of the design elements and the qualities of beauty define the relationship between the properties of the elements. Each metric can be applied to the design in order to enhance the qualities of aesthetic. Therefore, each measured metric is allocated an instruction for manipulating the design elements. This instruction is described for beauty and attractiveness metrics:

1. Beauty metrics: The condition of the target design in terms of proportion and pureness values before applying the metric is essential in increasing or decreasing the beauty value of the design. Therefore, contrast of the target design is categorised into very high (over 600 ms), high (500 to 600 ms), medium (450 to 500 ms), low (400 to 450 ms) and very low (below 400 ms). The target design contrast category (Very high to very low), metrics code, effectiveness in beauty value, and instruction of applying the metrics have been provided (see Appendix 9).

The level of contrast was divided into 5 levels. In order to evaluate the physical properties of each level, the sample of metrics are categorised according to the level of contrast which can be seen in Figure 62.

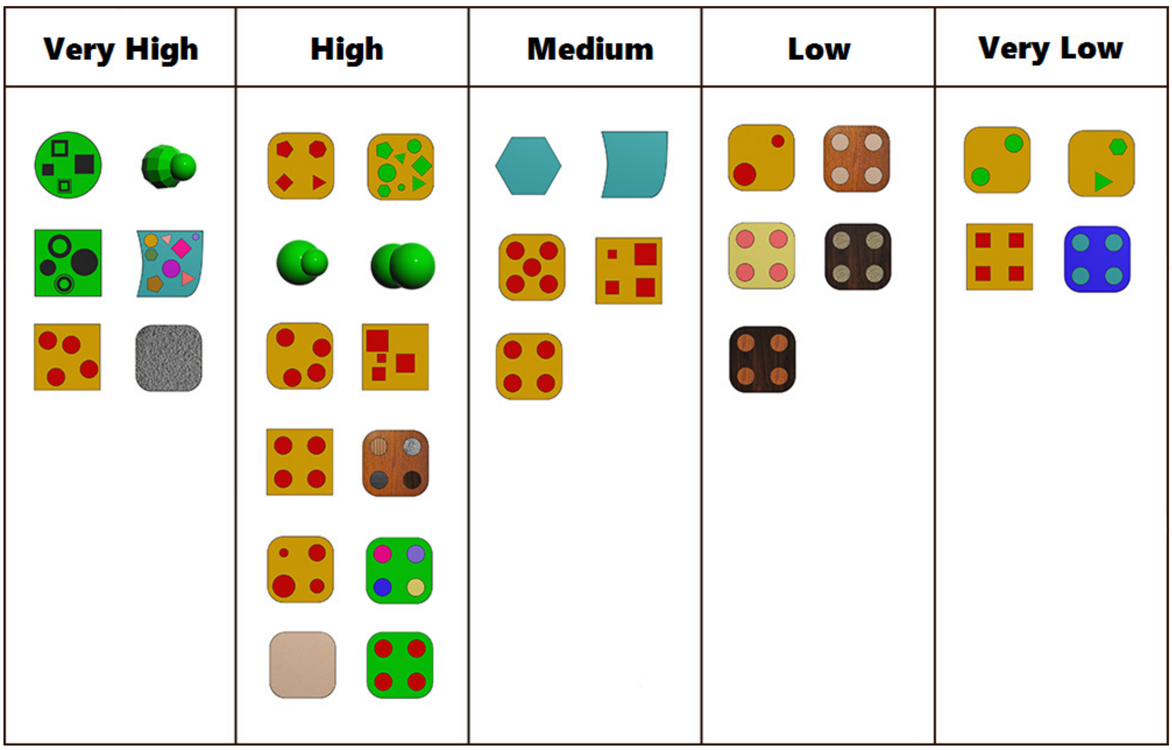


Figure 62: The categorised samples of designs in terms of level of contrast

As can be seen from Figure 61, the images with 2 shapes, or images with high proportion in colour or similarity between shape and form have very low contrast. The beauty value varies in different levels of contrast. Table 24 shows the mean, lowest, and highest beauty value for each contrast number of the measured metrics.

Contrast Level	Very High	High	Medium	Low	Very Low
Mean of Beauty Value	65.5%	68.1%	66.1%	75.2%	57.8%
Lowest Beauty Value	39.9%	38.9%	41.0%	62.8%	32.9%
Highest Beauty Value	90.9%	88.5%	87.5%	94.1%	77.4%

Table 24: Level of contrast against beauty value

As can be seen from Table 24, the highest value of beauty is related to Low contrast which means high proportion and pureness. Very low contrast has the lowest beauty value and very high, high, and medium levels have similar value of beauty. This occurs because very low contrast normally causes standard contrast to be below 0.5 while low contrast provides standard contrast over and close to 0.5 which is the preferred number. As the table shows, all contrast levels can provide range of beauty values from low to high. This table particularly indicates which design has more potential for improvement in terms of beauty value according to the level of contrast.

Using the instruction table (Appendix 9), the metrics can be applied to the design process. The measured beauty metrics are used to enhance the beauty value via following steps:

1. Identifying the level of contrast of current design using Figure 61.

2. Identifying the condition of the design elements using the instruction table provided (Appendix 9).

3. Applying the relevant metric using the instruction provided (Appendix 8, 9).

2. Attractiveness metrics: The physical properties of each chair design which are effective in the value of appropriateness and novelty are provided in a table as an instruction for applying defined metrics in designing a chair (see Appendix

10 for appropriateness and Appendix 11 for novelty). Figure 63 shows the example of calculating the metrics M3, M6, and M9 which determine the dimensions of chair's back, chair's seat, and chair's support respectively.

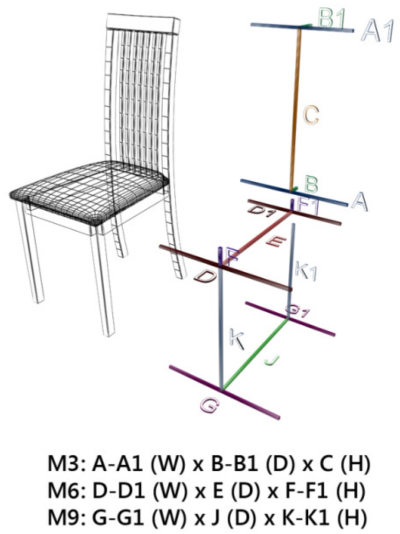


Figure 63: Example of calculating metrics M3, M6, and M9 (dimensions)

As discussed, the metrics of the attractiveness qualities are generated for each function separately. In this example metrics of appropriateness and novelty are made for a chair design. Using tables provided (Appendix 10, 11), 9 defined metrics can be applied to the design of a chair in order to enhance the appropriateness and novelty values. Therefore, the method of applying attractiveness metrics can be summarised in following stages:

1. Calculating the qualities of attractiveness using the proposed methodology.

2. Identifying the metrics of the target design and generating metrics table.

3. Applying the effective metrics to the design (e.g. Appendix 10 for appropriateness and Appendix 11 for novelty).

5.2.2.2. Sample designs

Sample designs are provided in order to illustrate the result of applying the metrics to redesign the target product.

1. Enhancing beauty: Metric 'MC2+36' is applied to chair 6 in order to enhance the beauty by making similarity in nature for different parts of the form design (see Figure 64). This change can potentially increase the beauty by 22% according to the metrics table.

Figure 64: Sample of applying metrics to a chair in order to increase the beauty. Target chair (left) and redesigned chair (right)

2. Enhancing appropriateness and novelty: While the beauty metrics can be applied to any object, the attractiveness metrics must be defined for each function. As discussed, three metrics are more effective in appropriateness of a chair and three other metrics are more effective in measured novelty of a chair (see Table 25).

High effective metrics in appropriateness	High effective metrics in novelty
M3, M5, M9	M1, M4, M7

Table 25: Highly effective metrics in appropriateness and novelty value of a chair

As the metrics showed in chair design, the size of back and support, and the material of seat are effective in the final appropriateness value. Chair 4 is selected as an example of a novel design. In order to make the design more appropriate, the relevant metrics are applied. Metric M5 shows the changes of material from plastic to high density sponge plus fabric. Metric M3 suggests 40% taller back. Metrics M9 has not significantly changed. By applying metrics M3 and M5 as high effective metrics, chair 4 has been redesigned (see Figure 65).

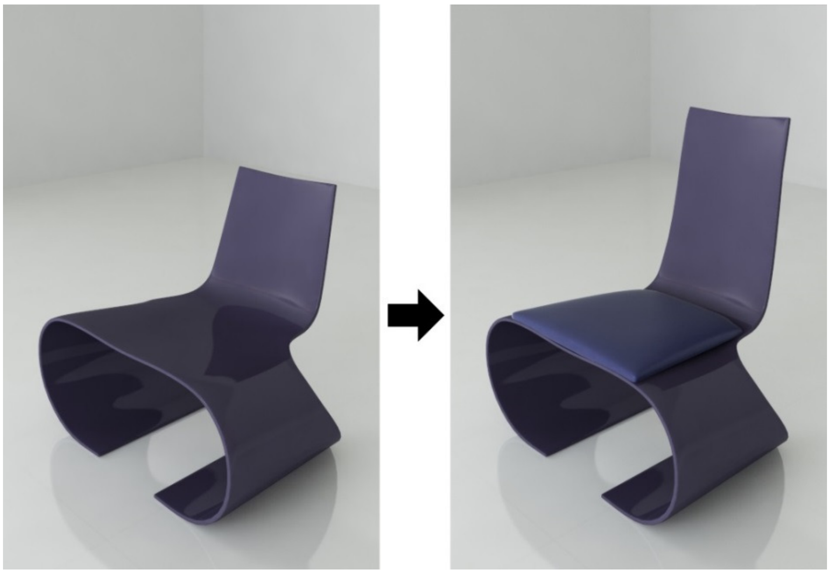


Figure 65: Sample of applying metrics to a chair in order to increase the appropriateness. Target chair (left) and redesigned chair (right)

Although this change does not affect the entire design, it can potentially increase the appropriateness by 25% according to the metrics table. This shows how applying the metrics can improve the efficiency of the redesigning process which saves time and produces the designs with higher aesthetic value.

Chair 21 is selected as an appropriate and typical design. In order to enhance the novelty, the high effective metrics in novelty (M1, M4, and M7) are applied to the design (see Figure 66).

Figure 66: Sample of applying metrics to a chair in order to increase the novelty. Target chair (left) and redesigned chair (right)

As can be seen from Figure 66, the form of back, seat, and support has changed to be less typical. This change can potentially increase the novelty of the design up to 50% according to the metrics table. As can be seen from design samples (Figure 64, 65, 66), applying the identified metrics can improve the aesthetic qualities. Those three examples illustrate how applying the defined metrics can enhance the qualities of aesthetics and consequently increase the preference.

Defining more metrics will increase the number of potential improvements. Moreover, the ability to create a higher level of aesthetic in design process will improve when the method is more utilised. In fact, it determines whether the designer is moving in the right direction or not.

The above examples show the application of each quality to a sample design separately. The final examples show designs of a chair and also a controller device when all the qualities of aesthetics are applied (see Figure 67, 68).

Figure 67: Sample of a chair design when all the qualities of aesthetics are maintained.

Figure 68: Sample of a controller design when all the qualities of aesthetics are maintained.

As can be seen from Figure 67, beauty is maintained by using similar elements in the structure of the chair (MC2+36 and MC2+46), fewer details (MC1+57), and two different colours (MC2-38). Appropriateness is maintained by using right material (M2, M5), dimensions (M3, M6), and form (M1, M4) of the back and the seat which provide comfort. Novelty is maintained by applying less typical elements in design of the support (M7, M8, and M9).

Table 26 shows the example metrics for the controller device.

Part \ Element	Form	Dimension
Body	M1	M2
Screen	M3	M4
Buttons	M5	M6

Table 26: The example of generating metrics for the controller device

As Figure 68 shows, the overall body design is comfortable to use (M1, M2), the interface layout is simple and logical (M5, M6), and the screen size is not too big or too small (M4) and rectangular shape (M3). These are the key points in enhancing the appropriateness of the controller. The body and the screen design are different from all the samples in order to maintain the novelty (M1, M3). Beauty is maintained by increasing the similarity between the shape's nature (MC2+37), location (MC2+57), and size (MC2+47), fewer details (MC1+57), and difference between colours used in the body design (MC2-38).

The above examples are an illustration of the aesthetic design by applying relevant metrics.

Next chapter will discuss analytical evaluation of the design methodology and verification of the defined hypotheses.

Chapter 6: Discussion

6.1. Analytical evaluation

6.2. Proof of hypotheses

6.1. Analytical evaluation

The fundamentals, empirical experience, and the instruction of applying the proposed methodology were discussed in previous chapters. In this section more observed results in addition to the main outcome, and the strengths and weaknesses of the method will be discussed.

6.1.1. Subsidiary analysis

This section discusses the additional statistics and results extracted from the conducted experiments.

6.1.1.1. Statistics

Table 27 shows the statistics for each eye-tracking experiment.

Experiment>	Pilot	2nd	3rd	4th	Total/Average
Number of images	4	22	48	42	116
Number of stimuli	8	36	72	42	158
Number of participants	50	50	50	30	180
Total number of clusters	400	1800	3600	1260	7060
Total number of fixations	2835	13186	19845	12629	48495
Total duration of fixations	12 min	54 min	80 min	58 min	204 min
Average fixations per image	14	12	8	10	11
Average duration of each fixation	253 ms	244 ms	236 ms	273 ms	251 ms
Average observation time per image	3.6 sec	2.9 sec	2.0 sec	2.7 sec	2.8 sec

Table 27: Statistics of the eye-tracking experiments

As can be seen from Table 27, 180 individuals have attended 4 eye-tracking experiments in which 158 stimuli in 116 images have been used. The average fixation time is ¼ of a second which indicates the time between saccades on average. The average observation time shows that each image has been observed for about 3 seconds. It shows that people on average require about 3 seconds before they can express their preference of a design.

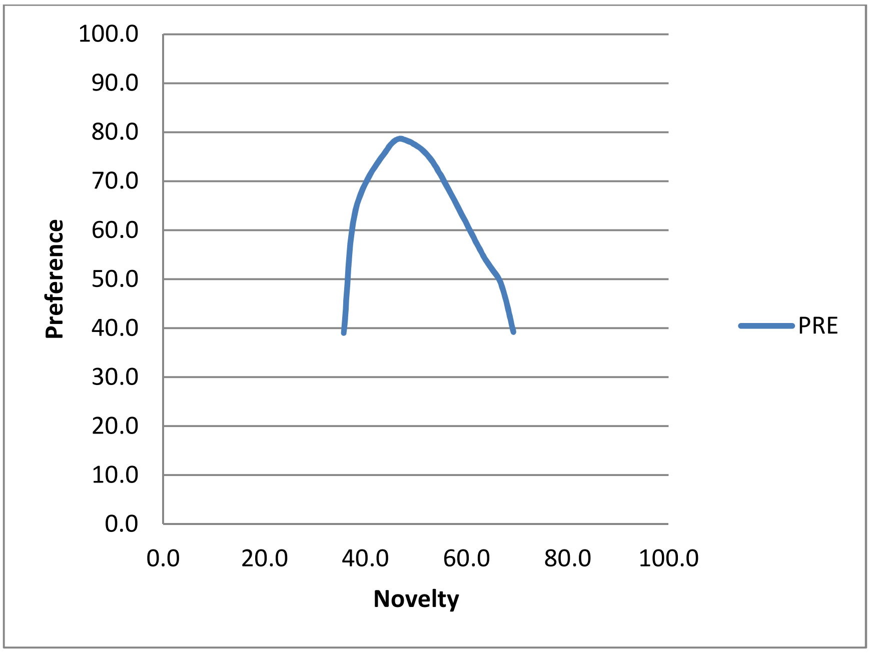
6.1.1.2. Technical definition of visual beauty

Using the result of the experiments and defined equations, beauty can now be defined technically. Therefore, the visual beauty is defined as follows:

‘Maximum beauty is observed when the erratic of eye movement multiplied by number of eye fixations equals half of the total time of the observation’.

6.1.1.3. Novelty and preference

As mentioned in **sections 1.2.3.2, 1.4.2.2,** and **2.4.2**, it is claimed that novelty has inverted-u relationship with preference in which maximum preference lays somewhere in between the least and most novel design. Using the data from the experiments, this relationship was evaluated. Graph 11 shows the novelty and preference comparison for 8 chairs.

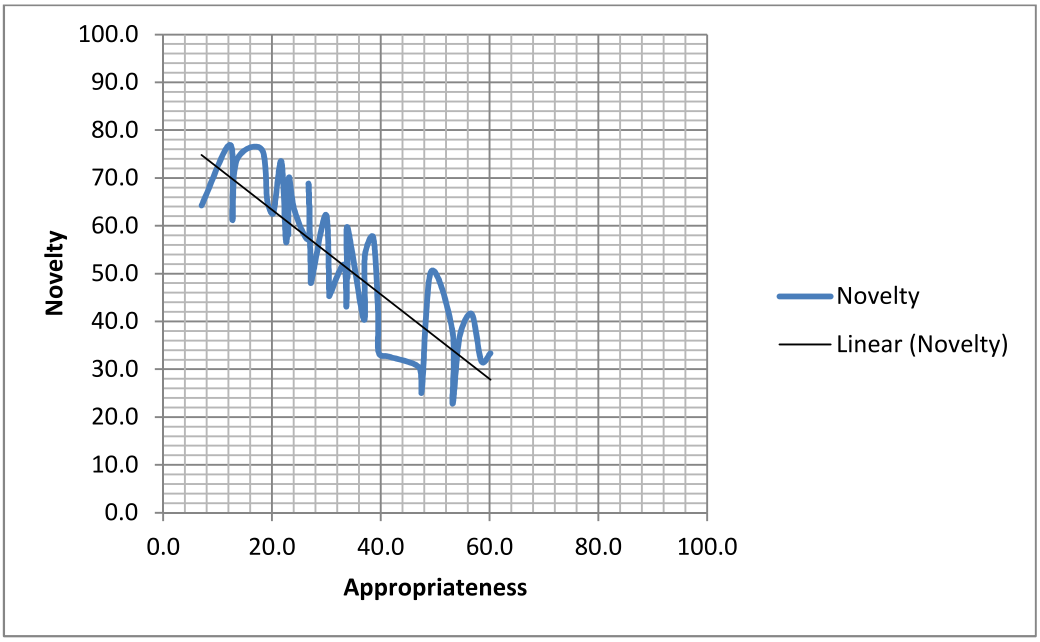


Graph 11: Novelty and preference (PRE) comparison

As can be seen from Graph 11, the result somehow confirms that maximum preference is where the novelty is about 50% and it is lower when novelty is very low or very high.

6.1.1.4. Interaction of appropriateness and novelty

As already discussed, appropriateness and novelty are opposing qualities. The result of the experiments confirms this theory (see Graph 12).



Graph 12: Interaction of appropriateness and novelty of the controllers

As Graph 12 shows, the appropriateness is low when the novelty is high and while overall appropriateness increases, novelty value drops. In a given scenario, if a product is shown to two subjects with different knowledge of the product, each one reacts to the product in a different way. However, the proposed method works based on comparing the products and not the subjects.

6.1.1.5. Determining the attractiveness value

Some of the designs can be identified as the most attractive designs (the designs which maintain both appropriateness and novelty higher than the mean value). By looking at Figure 52, and 56, chairs number 1, 9, 17, 23, and 24 have both novelty and appropriateness value higher than the mean. But in order to determine the order of their attractiveness (the most attractive to the least attractive) the transition between appropriateness and novelty must be evaluated. This approach is summarised into three stages:

1. Identifying the values of appropriateness and novelty using the proposed methodology.

2. Arranging the samples in terms of maximum to minimum difference in the values.

3. Studying the transitions between appropriateness and novelty alternatively.

The first and second stages have been already discussed in chapter 5 (see Figures 55 and 57). The third stage begins with the design with lowest appropriateness (chair 14) and the transition to highest appropriateness (chair 8). Then chair 8 is compared with the transition to a more novel design which is chair 10. Then chair 10 transition in terms of novelty ends with chair 23. Because chair 23 is already a transition to a novel design (from chair 2) the process stops in this stage. The process is continued with the second least appropriate design which is chair 22 until all the chairs are evaluated. Table 28 shows the transition for each design (stage 2) and Table 29 shows this process for all the chairs. Final effect is calculated using mean of the effect values.

No.	Appropriateness			Novelty		
	Chair No.	Chair No.	Effect	Chair No.	Chair No.	Effect
01	14	8	54%	21	13	59%
02	22	11	44%	19	22	53%
03	2	19	39%	7	12	42%
04	13	18	32%	18	5	37%
05	5	9	29%	6	4	31%
06	12	21	25%	2	23	29%
07	4	24	20%	16	24	27%
08	6	7	14%	11	17	26%
09	16	3	13%	8	10	22%
10	10	23	11%	14	20	18%
11	15	17	6%	3	1	16%
12	20	1	1%	15	9	4%

Table 28: Example of changes in qualities of attractiveness in chairs

Chair	A	N	A	N	A	N	A	Final	Effect
14	8	10	23					23	29%
22	11	17						17	35%
2	19	22	11	17				17	41%
13	18	5	9					9	33%
5	9							9	29%
12	21	13	18	5	9			9	36%
4	24							24	20%
6	7	12	21	13	18	5	9	9	34%
16	3	1						1	15%
10	23							23	11%
15	17							17	6%
20	1							1	1%

Table 29: Transition from appropriate to novel design

As can be seen from Table 29, the most repeated chair is chair 9 following by chair 17, 1, 23, and 24. The mean of effectiveness for each chair is calculated as 33%, 27%, 8%, 20%, and 20% respectively as attractiveness value. It shows the chair 9 is the most attractive design among the others (see Figure 69).

Chair	9	17	23	24	1
Attractiveness Value	33%	27%	20%	20%	8%

Figure 69: Most attractive chairs in order from left to right

6.1.1.6. Difference between beauty and attractiveness metrics

Beauty metrics are applicable to all fields of design including product and graphic design while attractiveness metrics are valid for a known or defined function. Beauty metrics are timeless and can be applied at any time while attractiveness metrics are valid for a limited time period. The update of the attractiveness metrics is required over time in order to keep the metrics effective and efficient while the frequency of the update is depending on how often the product is replaced with a newer version.

6.1.2. Detailed analysis

In this section the detailed outcome of the eye-tracking experiments will be discussed.

6.1.2.1. Applied stimuli

In the two latter eye-tracking experiments two different sets of stimuli were used in order to evaluate the methodology performance in various conditions. There are three main differences between these stimuli:

1. Familiar versus new: chair was used as a well-known product while the controller device is not functionally familiar compared to a chair.

2. Design: the chairs were created as complete 3D models while the controller devices were designed from the sketch.

3. Designer: the chairs were designed by the experimenter while the controller devices were designed by the subjects.

6.1.2.2. Outcome of experiments

Applying two inherently different stimuli has revealed some facts:

1. Judgment of appropriateness: by comparing Graph 3 and Graph 9, it is shown that the appropriateness value measured using eye-tracking data compared with the declared preference of appropriateness has a closer match for the chair compared to the controller device. It shows that for familiar products, the judgment of appropriateness is easier and less diverse compared to less familiar products. This is expected because appropriateness judgment is based on the knowledge of function.

2. Effectiveness of the quality of presenting the design on the qualities of aesthetic: by comparing Graph 7 and Graph 8, it is shown that novelty has met the minimum change in original sketch, refined sketch, and 3D designs compared to appropriateness and beauty. It shows that novelty is not highly affected by the quality of presenting the design. Graph 7 shows that appropriateness of 3D designs are higher compared to the sketches. The reason is that because 3D designs provide more data in terms of real way of usage and ergonomics, it can reveal the appropriateness quality more. Graph 8 shows that beauty is highly affected by the quality of sketch in which the original sketches have considerably lower beauty value. The reason is the fundamentals of beauty such as proportion which were improved in the refined sketches. As can be seen, the 3D designs have not added significant improvement in beauty value compared to refined sketches. The reason is the refined sketches have been already improved in terms of the effective qualities of beauty.

3. Biased judgment of design: one of the facts proved in the last experiment is how designers judge their own work. Significant difference between the average score and designers score indicates one of the issues in design process. The proposed quantification methodology is capable of revealing the true values of design aesthetics regardless of biased judgment of designers which can help them to be more objective about their own work. Using this method in educational environment can also train design students to avoid being trapped by their subjective preference in their design artwork.

4. Effectiveness of attractiveness: two latter experiments show that the effectiveness of aesthetic qualities on the final preference varies for different products. While for a chair appropriateness dominates the final preference, in controller device all qualities have equal effect. Because beauty is not affected by the function, the subjective and relative nature of attractiveness changes the weight of the effective qualities. In order to evaluate the effectiveness of aesthetic-function features on attractiveness qualities, four criteria were defined: internal and external complexity related to appropriateness, and variety and technology dependence related to novelty. Therefore, if the target product has simple internal or external design the appropriateness value will be zero (because that is a less effective factor due to its simplicity) otherwise it will be ***A***. Moreover, if the target product has a high variety of designs or low technology dependence, the novelty value will be zero (because there have been already variety of designs, novelty is less effective and low technology dependent products effectively have lower possibility of change, therefore, the novelty is less effective) otherwise it will be ***N***. Table 30 shows the defined criteria and related values, and calculation of the criteria for different products.

Criteria			Value		
High internal complexity			A		
Low internal complexity			0		
High external complexity			A		
Low internal complexity			0		
Low variety of designs			N		
High variety of designs			0		
High technology dependence			N		
Low technology dependence			0		
Product/Criteria	**Internal complexity**	**External complexity**	**Variety of similar designs**	**Technology dependence**	**Total**
Chair	A	A	0	0	2A
Controller	A	A	N	N	2A+2N
Water bottle	0	0	N	0	N
Car	A	A	0	N	2A+N
Bicycle	0	A	N	0	A+N
Television	A	0	0	N	A+N
Perfume bottle	0	0	0	0	0

Table 30: Effectiveness of attractiveness on different products

As can be seen from Table 30, for a chair, appropriateness has a high effectiveness value. For controller device both have equal weight. For a water bottle novelty is more effective and for a car appropriateness and novelty are both effective while novelty is less effective. For a bicycle and TV both criteria are effective. For a perfume bottle effect of attractiveness is very low and the final aesthetic judgment is dominated by beauty. Based on this calculation, share of each quality for different products can be estimated (see Figure 70).

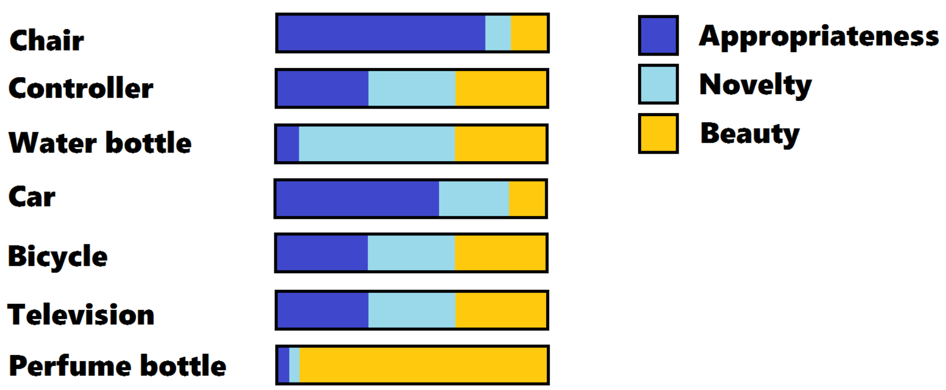


Figure 70: Estimation of effectiveness of each quality on final aesthetic preference

Using the model provided in Table 30, it is possible to predict the effectiveness of each quality on the final preference. For instance, to design a chair the most efficient way of increasing the consumer satisfaction from an aesthetic point of view, is to improve appropriateness. To design a perfume bottle, enhancing the beauty will improve the final preference. Four discussed criteria in determining the category of a product in terms of share of each effective quality have been identified based on the definition of the qualities of attractiveness. Appropriateness is a value which determines how much the design elements matches the function. What makes appropriateness effective is how much the function externally or internally is complex. For simple functions the appropriateness has already reached the optimum value and improving the value has lower effectiveness because it is already high enough. Novelty deals with variety of design elements with the same function. For designs which have an already high variety, the novelty has already reached the optimum. Technology dependence show that how much that variety can improve over time. For the products which are highly dependent on technology it is likely to change over time with completely new design elements which make the effectiveness of novelty higher than the products which have lower possibility of improvement over time due to their less dependence on progress of technology. This model provides two levels of values: high and low to generally show how each product can fit to a specific category. However, by increasing the level of values (e.g. adding medium level), number of categories will increase and the model will be able to predict the effectiveness of each aesthetic quality on a product more accurately. Moreover, this model shows that the attractiveness is effective when the variables related to 'appropriateness and novelty' have not reached the optimum level. Once these variables reach a certain level, the final preference is only affected by beauty. Therefore, attractiveness exists when people's knowledge about the possibilities of product function and design elements is limited or insufficient. On the other hand, absence of function removes the effect of attractiveness. Thus, attractiveness does not exist if the function is too well-known or not known at all. This shows that the maximum attractiveness effect is given somewhere in the middle (see Figure 71).

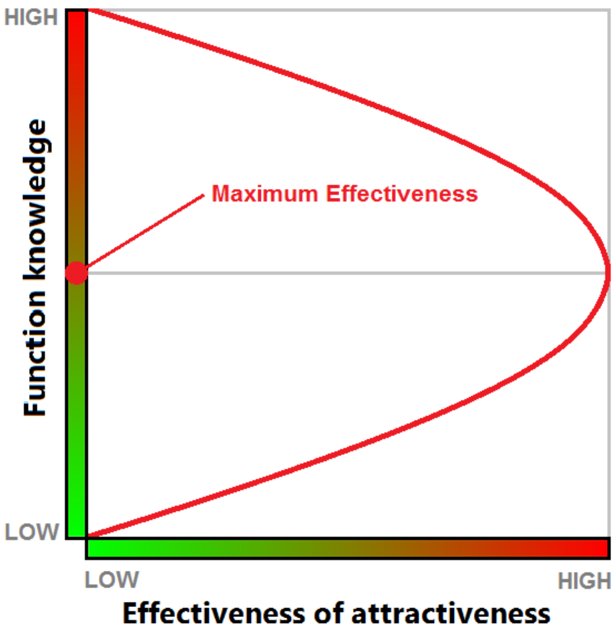


Figure 71: Estimation of relationship between Function knowledge and effectiveness of attractiveness

6.1.2.3. Design methodology evolution:

Measured metrics can be applied in order to enhance the aesthetic qualities. The aesthetic for the redesigned product can then be measured using the proposed quantification methodology in order to evaluate the effectiveness of metrics on final aesthetic judgment. The efficiency of the methodology improves when the method is repeatedly used:

1. By repeating the process, users gradually will be able to predict the approximate effect of the metrics.

2. Increasing number of measured metrics will improve the accuracy of the effective values.

3. Increasing number of metrics will expand the possibilities of effective enhancements to improve the aesthetic qualities.

4. The effectiveness of attractiveness qualities for different products can be estimated more accurately.

6.1.3. Performance analysis

This section discusses how the proposed methodology performs in comparison with previous methods.

6.1.3.1. How the method operates

The developed methodology has been built based on the fundamentals and theoretical foundations of aesthetic. It mixes the visual art principles with engineering and psychological analysis methods. Figure 72 summarises how the design methodology works via four distinct phases.

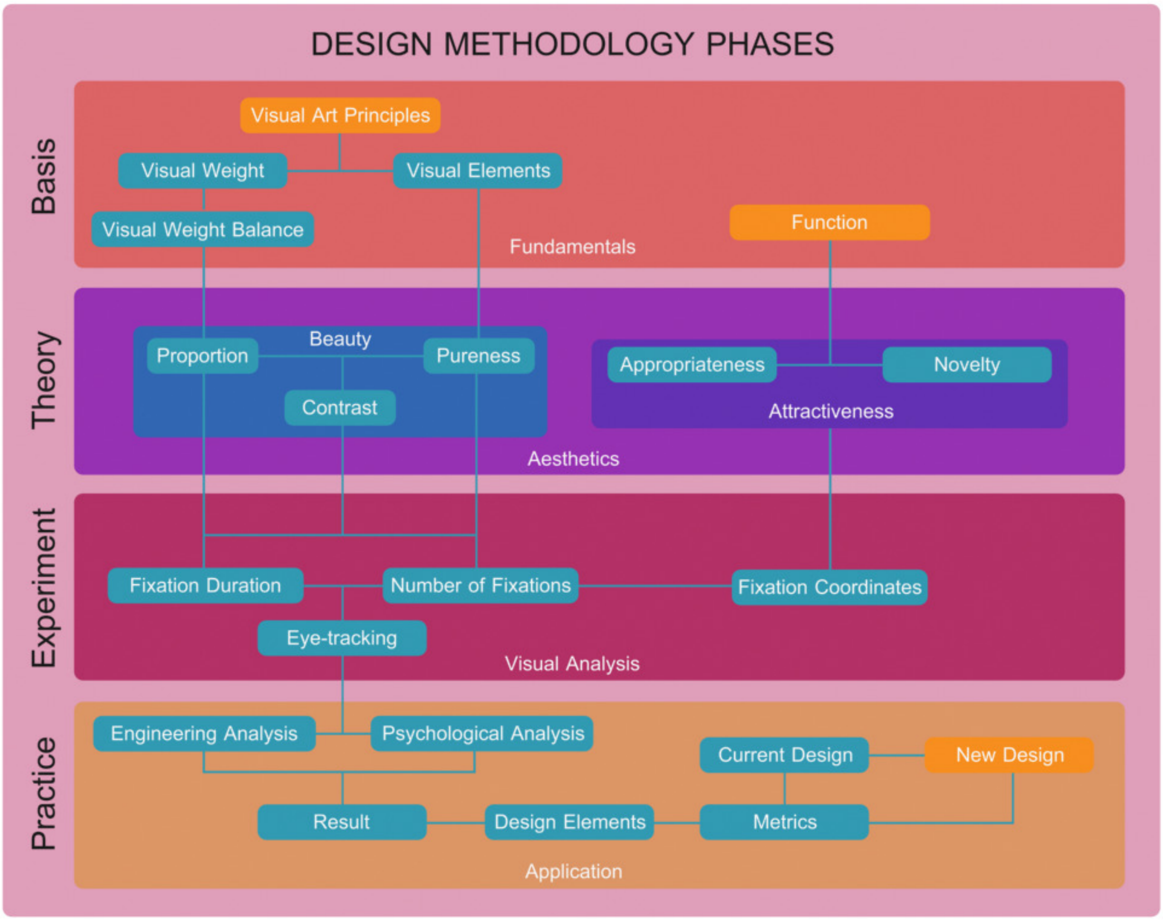


Figure 72: Design methodology phases

As can be seen from Figure 72, visual art principles and function lead to a new design through four phases of the design methodology. The 'basis' phase contains the fundamentals of aesthetics (visual art principles and function). The 'theory' phase includes defined qualities of aesthetics. Visual analysis is processed through the 'experiment' phase. Finally, the results of measured qualities of aesthetics and metrics are applied to the design process in the 'practice' phase.

6.1.3.2. Strengths of the method

There are a number of strengths in the proposed design methodology compared to other methods which are discussed as follows:

1. Relevant foundation: unlike other methods, the design methodology is constructed based on the fundamental aspects of visual aesthetic design which are visual art principles and function (Hekkert, 2006; Verma & Wood, 2001).

2. Aesthetic qualities: for the first time the aesthetic qualities have been clearly defined and the methodology has quantified the qualities.

3. Objectivity: unlike previous methods which are entirely based on subjective responses, the visual involuntary responses were measured and applied as an objective quantification of aesthetic qualities.

4. Efficiency: unlike many proposed methods, the design methodology has a simple measuring process and the result confirmed that it is accurate. Therefore, it can measure the qualities quickly and precisely.

5. Reliability: the constant outcome of the method confirmed that the result is reliable.

6. Applicability: the method is applicable to all fields of design and for all types of designers such as novice or professional.

7. Ease of use: the method's simple interface can be applied by anyone and no advanced skill is required in order to use the method.

8. Practicality: as the sample designs are provided, the method is practical and usable in real design processes.

9. Updatability: the metrics used in the method can be updated over time. Therefore, it is valid at all times.

10. Adaptability: the method can be adapted to any design environment from educational to professional design.

11. Flexibility: the method is not valid for a specific product only. It can be applied to all kinds of product whether a known familiar or a completely new product. Moreover, it is not limited to a certain stage of design and can be used from sketch to real prototype.

12. Universality: the method is not limited to certain people or area. It is comprehensive and can be applied by anyone at any place.

6.1.3.3. Weaknesses of the method

Despite a number of strengths, a few weaknesses of the method have been addressed which are discussed as follows:

1. Equipment dependent: eye-tracking is required to analyse the visual aesthetic qualities for a design.

2. Subject dependent: a number of subjects are required for the aesthetic analysis process.

3. Head-mounted video oculography limitations: although the applied eye-tracking device is a precise measuring tool, it has a few limitations which have been discovered during conducting the experiments:

-Eye shape and behaviour: for some eyes, the tracking is very difficult and sometime impossible. Small eyes and dark eyes are not easy to track. In addition, it can lose track of subjects who blink more than usual.

-Device weight and shape: although head-mounted eye-tracking is not a heavy device, the way it is held on head of subjects can get quite uncomfortable after a while. Therefore, it is better to keep the task duration short.

-Input data: the applied software only accepts the images with resolution of 1024x768. Although it is an acceptable quality, higher image resolution can improve the images and consequently give the subjects better visual impression.

-Saccade: It occasionally occurs that the eye movement of a subject is too limited. Therefore, the eye-tracking data is unusable.

6.1.3.4. Improving the method:

The practical model of applying metrics can be improved in order to enhance the efficiency and ease of use of the method:

1. Interface: user friendly interface can improve the usage of the method. Simple and logical order of instruction from beginning to the end, simplifying the process of applying metric in form of clear commands, and generating specified interfaces (based on the level of usage) for different target groups (novice or professional) are the potential solutions to improve the interface of the model.

2. Categorising the metrics: metrics have been categorised based on the aesthetic qualities into three groups. However, in order to improve the efficiency of using the metrics, more detailed categories can be defined: for instance, form-related metrics in enhancing beauty or seat-related metrics in improving the attractiveness of a chair.

3. Quick solutions: default suggestions can be defined based on the database of the metrics for a specific product. This can save time and consequently generate efficient solutions to improve the aesthetic: for instance, suggestions of different forms to be used for a specific part of a chair (see Figure 73).

Figure 73: Quick suggestions for the support design of the chair based on defined metric

Using metric MC2+36, two suggestions have been made for the support design of the current chair.

4. Software assistance: optimised software can be coded in order to apply the methodology more accurately and efficiently. The software can be used as a plugin or standalone application. The software can show the values for the aesthetic qualities as well as providing suggestions to improve the design for different design elements at different levels or for all the elements as an auto optimisation process (see Figure 74).

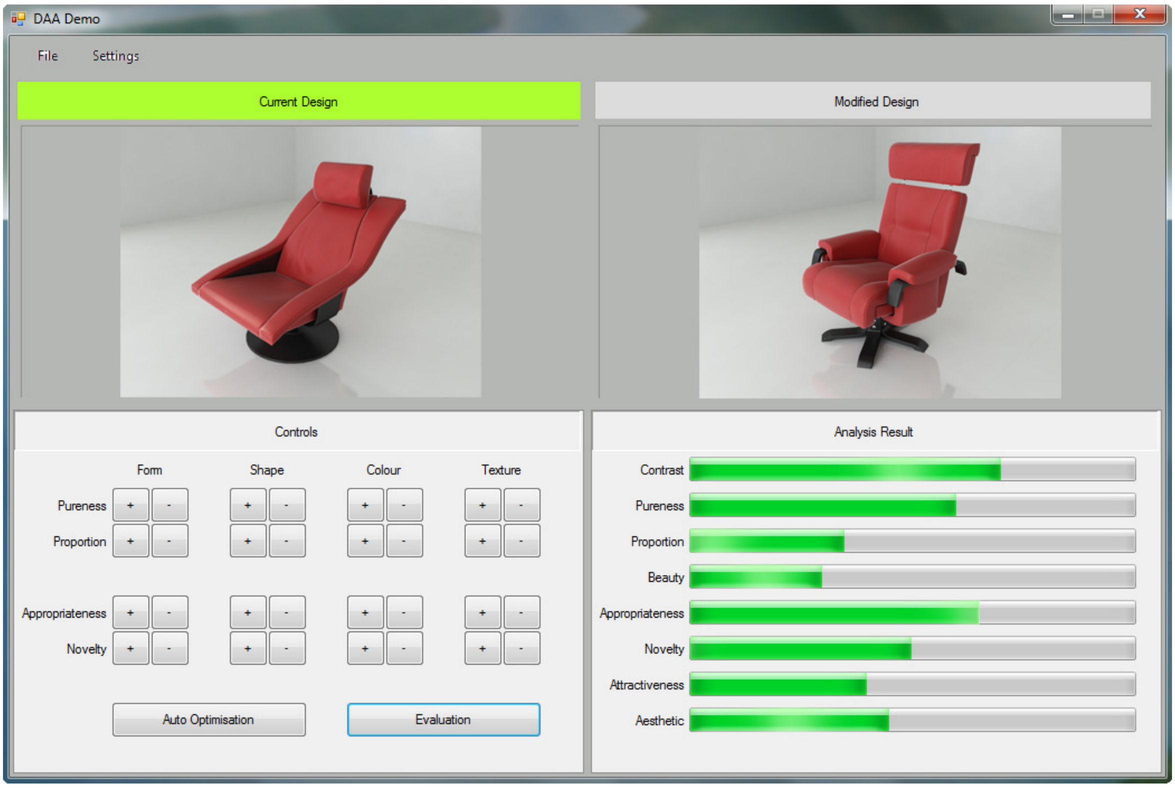


Figure 74: Possible interface of software-based methodology

6.2. Proof of hypothesis

6 hypotheses were defined at the beginning of the thesis (see **Section 1.6**). This section will discuss how each hypothesis is proven.

6.2.1. Hypothesis 1

Given the definition of the qualities of beauty; beauty is a certain balance between proportion, pureness, and contrast. In **section 4.2** it is proved that maximum beauty is achieved when the contrast equals half of total time. Because contrast is a function of proportion and pureness, then beauty is a certain balance between its qualities.

6.2.2. Hypothesis 2

Given the definition of the qualities of aesthetic; beauty, novelty, and attractiveness are major effective factors in the final aesthetic judgment. Equations 13 and 14 showed that the final aesthetic preference is affected by these three qualities of aesthetic.

6.2.3. Hypothesis 3

Aesthetic and its qualities can be quantified via a mathematical formula by analysis the eye movement. All the defined equations are based on eye-tracking data. Therefore, aesthetic qualities are quantified using mathematical equations and the extracted data from visual analysis.

6.2.4. Hypothesis 4

Level of influence of attractiveness in aesthetic preference is dependent upon the function. Difference between Equations 13 and 14 confirms that the effect of individual aesthetic qualities on final aesthetic judgement varies among different products and function.

6.2.5. Hypothesis 5

Designers are biased in judging their own design compared to other's work in which the declared preference does not match their involuntary response. The result of the experiment showed that the visual values extracted from eye-tracking data are relatively lower than the declared preference for original works of designers. The difference is negligible for refined sketches and higher for 3D designs. It shows that designers have tried to give their own work higher and the 3D designs lower score as a result of being biased towards their own work. Therefore, other than the declared preference which shows higher average score for designer's work, the method has proved that the involuntary response is not affected by their biased declared opinion/preference.

6.2.6. Hypothesis 6

The refinement of design sketch and rendering affects the qualities of aesthetics and the final preference. The average score given by subjects and also extracted data from eye-tracking analysis confirmed that higher quality of design sketch and rendering increases the overall aesthetic preference in which each aesthetic quality is affected differently.

Achievements and constraints of the conducted research will be discussed in conclusion in the next chapter.

Chapter 7: Conclusion

7.1. Achievements

7.2. Constraints

7.3. Method's applications

7.4. Research experience

7.5. Future studies

7.1. Achievements

Several significant achievements resulted from this research. In this section the main points will be discussed.

7.1.1. Theoretical achievements

This section explains the theoretical achievements which have been made through this research for the first time.

7.1.1.1. Comprehensive definitions of aesthetic qualities

By looking at the definitions of aesthetic qualities in books and journals, explanations are vague and often confused with beauty (Goldman, 1990). In this research the comprehensive and clear definition of aesthetic has been provided. For instance, visual beauty has been technically defined for the first time. These definitions can be used by other design researchers as a basis of related design aesthetic studies for both educational and professional target groups.

7.1.1.2. Establishing mathematical equations and measuring methods

Although some mathematical equations have been suggested to quantify properties of an image, this research has developed the aesthetic quantification method for the first time. The proposed equations in this research are based on the visual perceiving process of a stimulus rather than subjective interpretations of visual variable which have been often suggested by previous studies (Orsborn, Cagan, & Boatwright, 2009). These equations are not only used in aesthetic quantification process but can also explain the cogent reasons behind visual preference. For instance, the opposing nature of proportion and pureness against contrast, and appropriateness against novelty are reflected in the equations and measuring method. Moreover, the independent essence of beauty and attractiveness can be observed in which beauty is quantified using the duration and number of fixations while appropriateness and novelty is measured using the coordinates of fixations. This rational relationship can be used in order to reveal the scientific factors in aesthetic perceiving process for both educational and professional purposes.

7.1.2. Experimental achievements

This section explains several achievements which have been made by conducting the experiments through this research.

7.1.2.1. Measuring tool

Most of previous studies have applied subjective methods to measure the qualities of aesthetic (Yadav, Jain, Shukla, Avikal, & Mishra, 2013). Moreover, in aesthetic point of view, eye-tracking has been only used in order to find the area of interests on an image. In this research, eye-tracking was used as an objective measure to quantify aesthetic for the first time. This achievement can reveal new possibilities to utilise eye-tracking in related design experiments and studies for educational and professional purposes. Moreover, this method can reveal the new solutions in order to redesign and reengineer eye-tracking device in both hardware and software to be optimised for aesthetic measuring system which can increase the efficiency of the process of recording and analysis of data. The new optimised system can be directly used by designers in real time design task or by researchers to improve the design process.

7.1.2.2. Collaborative research

In design research, generally, engineering methods dominate the approach and results while art and psychology as significant determining factors have been mostly ignored. This approach has prevented the design research to generate reliable, valid, and relevant results (as discussed in the literature review). Unlike previous studies, this research is a result of technical collaboration between art, engineering, psychology, and computing sciences. This approach has not only provided the reliable and relevant results, it has established new potentials in mutual interactions between major design areas which can inspire design researchers in generating collaborative solutions and methods. Moreover, this collaborative approach can be highlighted in both engineering and art environments (educational and professional) to give engineers essence of art and to give artists essence of engineering. This can eventually lead to more practical solutions created by engineers and artists which can improve the overall quality of product design.

7.1.3. Practical achievements

The proposed quantification methodology provides real practical solutions in quantification and enhancing the aesthetic qualities.

7.1.3.1. Quantification:

The aesthetic qualities were practically quantified using the visual analysis data for the first time. This practical achievement can directly be used by anyone who aims to measure the beauty or attractiveness of an object or a design.

7.1.3.2. Aesthetic enhancement:

Measured metrics are used to improve the aesthetic in a design for the first time. These metrics are then generated by analysis of individual design elements which are quantified to enhance a specific quality. This practical methodology provides design solutions which can be directly used in designing or redesigning process:

-Using metrics in design process: by analysing the metrics, the optimum type of required design elements is revealed. For instance, measured metrics showed that using soft material in seat of a chair can dramatically improve the appropriateness and consequently the final satisfaction.

-Using metrics in redesigning process: the same approach which is used in design process can also be applied to redesigning a product. For instance, it was revealed that certain dimension of back of a chair can increase the appropriateness value. Therefore, a design with short back can be redesigned with taller back and the final preference will be improved.

-Supportive methodology: it is important to highlight that the proposed design methodology is not replacing the design task. The main goal is to help designers to be more efficient and create artworks with higher quality. This method generates the possibilities in design and redesign tasks in which a designer may not be aware of those potential solutions.

7.2. Constraints

This section will discuss the research constraints in achieving the defined goals.

7.2.1. Literature and tool constraints

The literature and tool constrains are related to the limitation of information sources and relevant tools with the aim of solving a specific issue which are discussed as follows:

7.2.1.1. Lack of art-based research

Art-based research has been widely ignored and most of the design studies are based on engineering methods. There are two possible reasons: first, artists are reluctant to conduct research (Crilly, Moultrie, & Clarkson, 2004). Second, design researchers have a limited knowledge of art (Khalighy, Green, Scheepers, & Whittet, 2014). Lack of art-based scientific studies makes difficulties to access the reliable and relevant data.

7.2.1.2. Limited design research information

Other than art research, generally, there are limited numbers of design research compared to the other areas. This constraint makes difficulties in generating new methods due to limited availability of relevant data in which many experiments are required to be done in order to reach the reliable outcome.

7.2.1.3. Lack of objective data

Most of previous design studies have applied subjective measures in their proposed methods. Therefore, objective data is limited which makes it difficult to verify the research outcome.

7.2.1.4. Limited measuring tools

Number of tools and equipment are accessible in engineering studies while the measuring tools are limited in design research. This makes difficulties in finding and applying objective methods.

7.2.2. Experimental constraints

Experimental constraints refer to the limitations of conducting required experiments which are discussed as follows:

7.2.2.1. Recruiting participants

In this research over 400 human subjects have attended all the experiments in which 180 of them participated in the eye-tracking experiments. Unlike the organised recruiting system which is provided by school of psychology, no similar system is accessible in school of engineering. Therefore, all the participants were recruited by email and direct negotiation. The experience of recruiting participants showed this is a difficult task and requires much time and effort.

7.2.2.2. Data analysis

Due to lack of specialised software, the process of data analysis took much time. As can be seen from Table 27, in 4 eye-tracking experiments over 7000 data clusters have been generated. This huge amount of data has been processed using Microsoft® Excel which required copying all data set into specified columns. This time consuming data analysis process can be done significantly quicker if specialised software is used.

7.2.2.3. Equipment quantity

Only one eye-tracking device was employed in the research. If larger quantity of eye-tracking equipment is used, the experiment process can be done faster by conducting more tests simultaneously.

7.3. Method's applications

There are three major applications for the proposed methodology which are discussed as follows:

7.3.1. Research applications

The proposed methodology can be used in design research across various disciplines which are discussed as follows:

7.3.1.1. Visual art

Visual art principles have been used in creating artworks for a long time. However, the quality of applying the principles has been subjectively judged and no objective measure is considered. The proposed design methodology can help researchers to invent more efficient principles and methods by examining the outcome objectively. Moreover, the quality of artworks in terms of beauty value can be measured for various areas of visual arts such as painting or sculpture. This can help to discover the secrets behind successful and famous artworks.

7.3.1.2. Engineering

The design methodology can be used by researchers in order to improve design process by evaluating the related issues more objectively. For instance, in the case study of this research, it was revealed that designers may be biased towards their own artwork. As objective criticism is essential in improving the design ability, the method can help researchers to eliminate subjective interpretation. It can also provide art basis for engineering design methods in order to improve their capabilities.

7.3.1.3. Psychology

Understanding beauty and attractiveness has been considered by psychology researchers for a long time: for instance, the reasons behind considering a face beautiful or attractive. The proposed methodology can help psychology researchers to measure these qualities and discover the real factors which influence people in interpreting the appearance of human, animal, plant, or an object.

7.3.2. Educational applications

Aesthetic has been one of the uncharted territories of design especially when enhancement methods are required. The proposed method can fill this gap and provides relevant instructions in understanding and enhancing the design aesthetic. Using this method potentially gives the engineering students better understanding of art principles and provides practical design solutions for students with the background of art.

7.3.3. Professional applications

The proposed design methodology can be used by professional designers which can potentially save cost and time. There are four major advantages which can benefit the company and designers:

1. Objective evaluation: the design method gives the designers the opportunity of objective judgment on their work. It shows to what extent their preference is close to or far from the average consumer's opinion.

2. Hidden design solutions: the design method can provide efficient solutions to a design task in which the designer may be unaware of them. These possibilities not only increase the ability of designer in generating an optimum design, it also can saves large amount of time and consequently reduce the costs.

3. Pre-examination: many companies expose their product to the test groups after the prototyping process in order to examine the consumer's response. The design method can reveal this response earlier which can save considerable cost and time.

4. CAD plugin: design methodology can be embedded to CAD software in order to measure and present the values of aesthetic quality while the design process is being done. This simultaneous evaluation enhances the efficacy of the design process and the outcome.

7.4. Research experience

Conducting design research, other than the main result, generates the experience of the research which reveals subsidiary outcomes. This outcome is summarised as follows which can be used for the future studies:

1. Design research requires human subjects. Recruiting subjects is time consuming which has to be considered in allocating research time. Each eye-tracking experiment took about one month from start to finish excluding the data analysis time.

2. Successful research requires effective tools. In this study eye-tracking has been used in which the outcome showed the tool is appropriate to achieve the defined goals. However, there are two main concerns: first, the required tool may not exist. If eye-tracking device was not invented, the research would need to employ a different tool which may not be effective as eye-tracking. Second, the required tool may not be accessible. If the tool exists but the access is not possible or very difficult, success of the research can be affected.

3. Comprehensive knowledge is required. A successful design research requires knowledge in art, engineering, psychology, and computing sciences. Ignoring one of these areas can lead to an invalid outcome.

4. Design is a complex skill (Lawson, 1997; Roozenburg & Eekels, 1995). Although the new methods can improve the process of design, the final outcome is affected by various disciplines. Therefore, new design methods must be constantly practiced until designers are able to use the methods skilfully.

5. People have various judgments. How designers perceive their design can be very different from how people judge the design. Therefore, novice designers must be trained to improve their objective view.

6. Research is never done. Although the short-term goals can be achieved in a certain period, various issues can emerge during the research process which requires conducting more research.

7.5. Future studies

This section discusses how this research and the proposed design methodology can be evolved in the future studies.

7.5.1. Further research

As discussed at the end of previous chapter, more research can be done in order to reveal further facts. These points can be summarised as follows:

1. Stimuli: 2D images as representation of a real product were used in the experiments. However, 3D model, prototype, and real product can be used for further evaluations and studying the response. This will require video recording and analysis the fixations on each frame.

2. Tracking eyes while designing: subjects can be asked to design while their eyes are being tracked. This can show how their eyes behave while designing and how the proposed method can be applied to this process.

3. Method practice: the method can be taught to designers in order to study the efficiency of the user interface and how the method works in real environment by professionals. This can help to improve the method's performance.

4. Further involuntary responses: other relevant involuntary responses such as pupil size and eye blink can be developed in order to study possible relationships with aesthetic preference.

5. Condition of experiment: the condition of the experiment such as design of the place including interior design, lighting condition, and quality of presenting the stimuli can affect the outcome of the experiment which is subject to further study.

6. Categorised evaluation: in this research the experiments have been conducted focusing on general target groups. However, the responses can be categorised in terms of gender, age, and educational and cultural background in order to reveal how these factors may affect the response and preference.

7. Context: different contexts were applied to the first subjective experiment to highlight the function of the product. However, in the eye-tracking experiments, the context was simplified or removed in order to eliminate any distraction. The context of a product may affect the preference which can be studies in further research. It can reveal the best possible way of presenting a product to a customer.

8. Viewing angle: a product can be seen from different angles. Different angles of a 3D object may offer different impressions. This variation may affect the final preference which can be evaluated by presenting the product in different views and quantifying the aesthetic qualities for each view. Two groups of subject are selected. For the first group each view is presented and subjects express their opinion for a single view separately. Second group will be presented by all views and their final preference is recorded. Therefore, two sets of data will be obtained. One contains the preference for each view and the other shows the overall views preference. Then, the relationship between the views and overall preference can be studied.

9. Long-term response: each stimulus is presented to subjects for a short time. However, observing the stimulus for a longer time may change the immediate response which can be studied by increasing the time of the experiment. This can show how increasing the time of observation can affect the final preference.

10. Multiple or single stimuli: presenting the images one by one or all together may change the overall response which can be studied in order to evaluate the best way of presenting a product to a consumer.

11. Different types of tracking: the head-mounted video oculography was used in the experiments. However, there are different types of video trackers such as remote eye-tracking. Remote eye-tracking does not require the headband which can be easier for conducting the experiments. However, the accuracy and the result must be evaluated.

12. Saccade: the start and end fixation and direction of eye movement can be studied in order to discover any relationship with aesthetic preference.

7.5.2. Practical solutions

Future practical solutions are divided into two groups: hardware and software which are discussed as follows:

7.5.2.1. Hardware solution

An optimised tool can be designed in order to conduct the eye-tracking measuring process. The required features can be defined as follows:

1. Portability: the whole system must be designed in a way to be portable and mobile in order to enhance the feasibility of usage and mobility of the system if required. Therefore the hardware must be optimised for mobile operation which requires efficient processor and battery.

2. Presenting the stimuli: high quality screen is recommended in order to increase the details of trials. The stimuli can also be presented using a virtual reality headset.

3. Tracker system: high-precision remote tracker system can be embedded to the system. This helps to process real-time eye-tracking (see Figure 75).

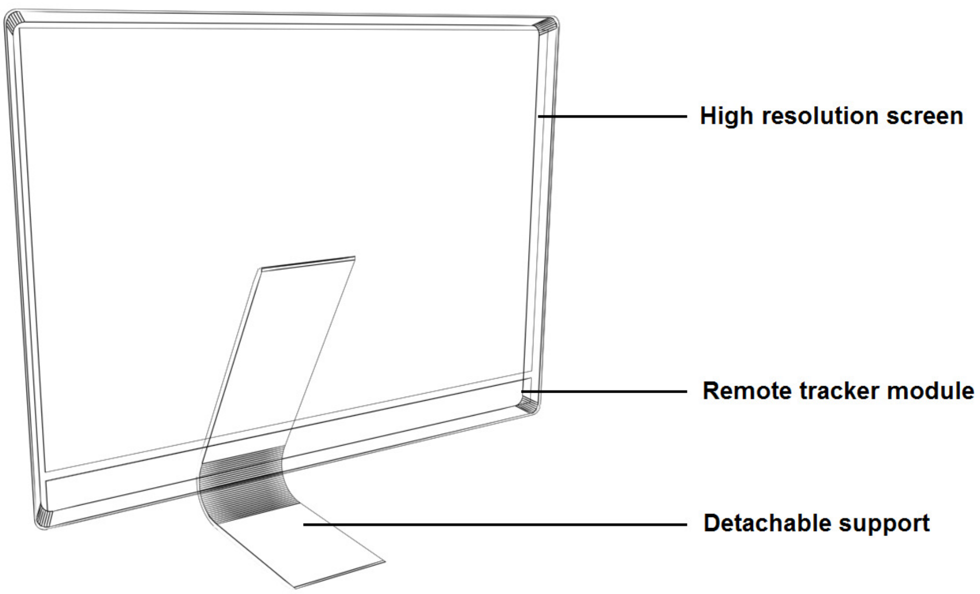


Figure 75: Embedding remote eye-tracker to the system

4. Connectivity: wireless connectivity can be applied to the system in order to provide remote controlling of tracking process and also connecting and synchronising the trackers if more than one is used (see Figure 76).

Figure 76: Several tracker systems can wirelessly work together

7.5.2.2. Software solution

Optimised software is required in order to enhance the efficiency and performance of the system. Possible required features are summarised as follows:

1. Algorithm: the methodology algorithm including the measuring procedures (quantification equations and producing the required templates) must be coded and used in the applied software.

2. Interface: An optimised, user-friendly, and sophisticated interface is required in order to improve the usability of the system. Other than indicating the values of each aesthetic quality, it can also provide the practical solutions to enhance the effective qualities. Moreover, it can provide 3D viewing and analysis of the stimuli with the possibility of evaluating a real 3D object.

3. Plugin or standalone: Other than optimised standalone software, it can also be designed as a CAD software plugin.

4. Updating: other than real-time producing the metrics and templates, the software can be updated by new templates and metrics online or offline.

7.5.3. Further suggestions

Further suggestions are provided in three categories: research, experiment, and practice which are discussed as follows:

7.5.3.1. Research

1. Visual art principles research: lack of comprehensive art-based research has made difficulty in access to relevant and valid data. For instance, the design elements and principles are still subjectively applied and no objective and clear definition has been provided. Therefore, codification of a comprehensive visual art principles database is suggested.

2. Applying art-based principles to engineering research: related studies such as developing solutions to enhance the aesthetics, requires relevant foundation of art principles. It is suggested that researchers apply those variables to their engineering methods in order to improve the outcome.

3. Collaboration of professional designers in related research: the false outcome of many design research is a result of ignoring the opinions of professional designers. It is suggested that designers be more involved in conducting related design research.

7.5.3.2. Experiment

1. Recruiting participants: as already discussed, design research requires human subjects. Therefore, it is suggested that an effective recruiting system is established which can save significant amount of time.

2. Tools database: conducting research may require an effective tool. Therefore, generating an accessible database of available tools in university across different colleges is suggested. Using this database not only can save time, it can reveal the possibilities of using relevant tools which can positively change the outcome of the research.

3. Ethics approval procedure: using human subject also requires ethical approval from the ethics committee. However, the procedure of applying for the approval such as making information and consent sheet is not provided. It is suggested that schools include those procedures in training courses for research students in order to save time.

7.5.3.3. Practice

1. Educational application: at the beginning the method can be examined in an educational environment. Design students are taught to use the method in their design activity. The result will help to enhance the method's performance by improving the interface and user instruction.

2. Marketing related studies: the method and further related research can be used in marketing studies such as improving the product presenting techniques including online purchase experience.

7.5.4. Future of the method

By repeating the experiments and the methodology for more products and designs and increasing the number of measured metrics, more precise relationship between design elements and the value of aesthetic qualities can be discovered and consequently the aesthetic algorithm for all products can be defined. This process can eventually determine the aesthetic value of a design using different variables and without applying eye-tracking measuring process.

Appendices

Appendix 1: Visual assessment answer sheet (196)

Appendix 2: Eye-tracking experiment information sheet (197)

Appendix 3: Eye-tracking experiment consent form (198)

Appendix 4: Beauty test answer sheet (199)

Appendix 5: Appropriateness test answer sheet (200)

Appendix 6: Novelty test answer sheet (201)

Appendix 7: Design task answer sheet (202)

Appendix 8: Instruction examples of increasing pureness and proportion in different elements (203)

Appendix 9: Instruction of applying beauty metrics and measured effect values (206)

Appendix 10: Appropriateness metrics in chair design and measured effect values (209)

Appendix 11: Novelty metrics in chair design and measured effect values (212)

Appendix 1

Visual assessment answer sheet

Visual Assessment

1. Please specify your gender: M F
2. Please specify your age:

3. Please rate (✓) the aesthetic of the object you see in the picture based on your own judgment from 1 to 10.

Less Pleasant	Pic #	1	2	3	4	5	6	7	8	9	10	More Pleasant
	1	1	2	3	4	5	6	7	8	9	10	
	2	1	2	3	4	5	6	7	8	9	10	
	3	1	2	3	4	5	6	7	8	9	10	
	4	1	2	3	4	5	6	7	8	9	10	
	5	1	2	3	4	5	6	7	8	9	10	
	6	1	2	3	4	5	6	7	8	9	10	
	7	1	2	3	4	5	6	7	8	9	10	
	8	1	2	3	4	5	6	7	8	9	10	
	9	1	2	3	4	5	6	7	8	9	10	

Appendix 2

Eye-tracking experiment information sheet

EXPERIMENT ON
EYE MOVEMENT AND AESTHETIC PREFERENCE

INFORMATION SHEET

Dear participant,
Thank you very much for taking part in this experiment which should take no longer than 20 minutes to complete. Throughout this experiment, your eye movements will be monitored while looking at various pictures (40 images altogether). During the experiment, you will be sitting in front of a computer screen on which the pictures are presented. In order to track your eye movements, you will be asked to wear a headband with various infrared cameras attached (Figure 1). The experimenter will set up the headband for you, ensuring that it will not cause any discomfort during the experiment.

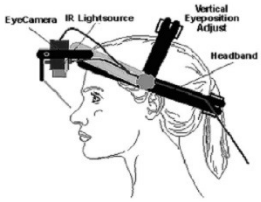


Figure 1: Eye-tracking device to be worn throughout the experiment

The tasks:
There will be two groups of pictures, each associated with a different task. In the first task, you will look at a picture for several seconds, after which you will see a 5-point rating scale ranging from **1** (not very pleasant) to **5** (very pleasent). Your task is to rate how pleasant the previous image was for you, by typing the corresponding number into the computer keyboard in front of you (Figure 2).

Figure 2: A sample of task 1

The second group of pictures comprises arrays of various figures (labelled A, B, C. ..), and you will be asked to choose one figure that you like most by verbally expressing the relevant label (Figure 3).

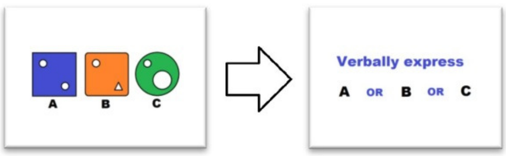


Figure 3: A sample of task 2

Note that there are no 'right' or 'wrong' answers to either of the tasks – i.e., we are only interested in your aesthetic judgements.

The procedure:
At the beginning of the experiment, and once half way through (if necessary), we will run through a brief calibration procedure during which you have to look at a fixation point that jumps to various positions on the screen (this is to ensure an accurate measurement of your eye-movements). During the experiment, please try to avoid strong head or body movements as this may compromise the measurement accuracy. Should you have any further questions, please do not hesitate to ask.

Thank you very much,

Appendix 3

Eye-tracking experiment consent form

EYE-TRACKING EXPERIMENT **CONSENT FORM**

OFFICIAL USE ONLY: **CODE ____**

- I have read and understood the procedures of this eye-tracking experiment, as provided in the information sheet.
- I understand that my participation is voluntary. I can withdraw my consent to participate at any time without penalty, in which case my data will not enter any further analysis.
- I understand that my data will be treated confidentially and not be associated with any personally identifying information.
- At the close of the experiment, the experimenter will provide me with their contact details for future inquiries.

With my signature below, I give my consent to take part in this experiment:

Date ___________________ Participant's signature __________________________________

Name in BLOCK letters ____ Age _______

Experimenter's signature ________________________

Appendix 4

Beauty test answer sheet

Please rank the images from **1** to **12** from most beautiful to least beautiful on your own judgment of the appearance: Gender: M ☐ F ☐ Age: ____

MOST BEAUTIFUL													LEAST BEAUTIFUL

Appendix 5

Appropriateness test answer sheet

Gender: M ❑ F ❑ Age: ____

Please rate the chairs in terms of **Appropriateness** of the design and the function from **1** to **10**.

	No.	1	2	3	4	5	6	7	8	9	10	
Least Appropriate	1	1	2	3	4	5	6	7	8	9	10	Most Appropriate
	2	1	2	3	4	5	6	7	8	9	10	
	3	1	2	3	4	5	6	7	8	9	10	
	4	1	2	3	4	5	6	7	8	9	10	
	5	1	2	3	4	5	6	7	8	9	10	
	6	1	2	3	4	5	6	7	8	9	10	
	7	1	2	3	4	5	6	7	8	9	10	
	8	1	2	3	4	5	6	7	8	9	10	
	9	1	2	3	4	5	6	7	8	9	10	
	10	1	2	3	4	5	6	7	8	9	10	
	11	1	2	3	4	5	6	7	8	9	10	
	12	1	2	3	4	5	6	7	8	9	10	
	13	1	2	3	4	5	6	7	8	9	10	
	14	1	2	3	4	5	6	7	8	9	10	
	15	1	2	3	4	5	6	7	8	9	10	
	16	1	2	3	4	5	6	7	8	9	10	
	17	1	2	3	4	5	6	7	8	9	10	
	18	1	2	3	4	5	6	7	8	9	10	
	19	1	2	3	4	5	6	7	8	9	10	
	20	1	2	3	4	5	6	7	8	9	10	
	21	1	2	3	4	5	6	7	8	9	10	
	22	1	2	3	4	5	6	7	8	9	10	
	23	1	2	3	4	5	6	7	8	9	10	
	24	1	2	3	4	5	6	7	8	9	10	

Appendix 6

Novelty test answer sheet

Gender: M ❑ F ❑ Age: ____

Please rate the chairs in terms of **Novelty** of the design from **1** to **10**.

Least Novel	No.	1	2	3	4	5	6	7	8	9	10	Most Novel
	1	1	2	3	4	5	6	7	8	9	10	
	2	1	2	3	4	5	6	7	8	9	10	
	3	1	2	3	4	5	6	7	8	9	10	
	4	1	2	3	4	5	6	7	8	9	10	
	5	1	2	3	4	5	6	7	8	9	10	
	6	1	2	3	4	5	6	7	8	9	10	
	7	1	2	3	4	5	6	7	8	9	10	
	8	1	2	3	4	5	6	7	8	9	10	
	9	1	2	3	4	5	6	7	8	9	10	
	10	1	2	3	4	5	6	7	8	9	10	
	11	1	2	3	4	5	6	7	8	9	10	
	12	1	2	3	4	5	6	7	8	9	10	
	13	1	2	3	4	5	6	7	8	9	10	
	14	1	2	3	4	5	6	7	8	9	10	
	15	1	2	3	4	5	6	7	8	9	10	
	16	1	2	3	4	5	6	7	8	9	10	
	17	1	2	3	4	5	6	7	8	9	10	
	18	1	2	3	4	5	6	7	8	9	10	
	19	1	2	3	4	5	6	7	8	9	10	
	20	1	2	3	4	5	6	7	8	9	10	
	21	1	2	3	4	5	6	7	8	9	10	
	22	1	2	3	4	5	6	7	8	9	10	
	23	1	2	3	4	5	6	7	8	9	10	
	24	1	2	3	4	5	6	7	8	9	10	

Appendix 7

Design task answer sheet

DESIGN TASK **Allowed time: 45 minutes**

Name: **Gender: M ◯ F ◯** **Student Number:**

Design a multifunctional controller device applying following criteria:

Function:

This controller is meant to be used during an academic presentation.

Features:

Laser pointer, changing and controlling the slides, slide notes (text only) appearing on the screen, it has to be a handheld device.

Rules:

1. Design only the front view.

2. The design must be in true scale (1:1).

3. Maximum size is 80x160mm and minimum size is 40x80mm.

4. All types of user interface are allowed except touchscreen.

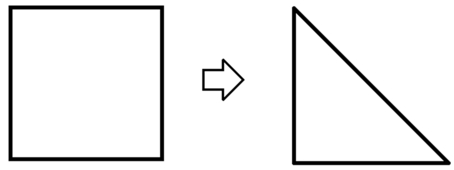
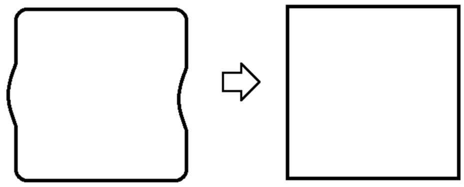
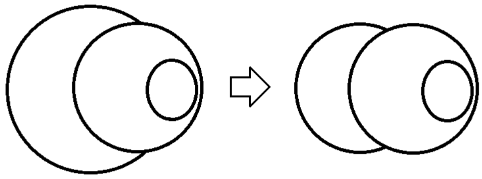
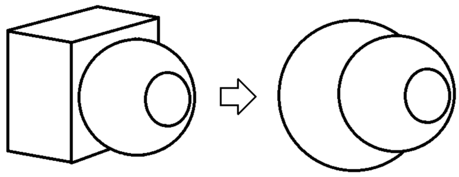
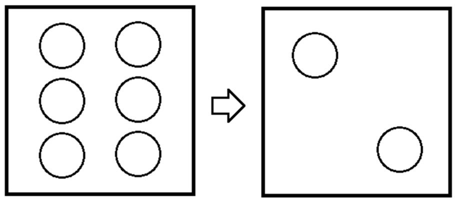
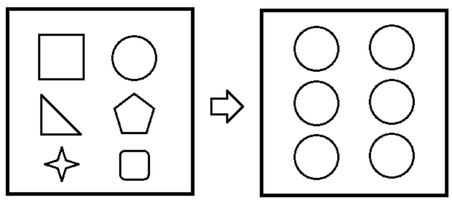
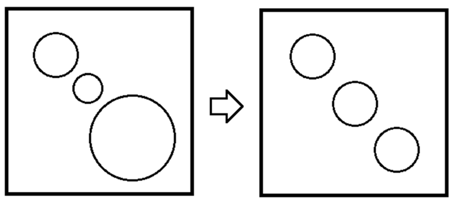
5. The design must be fully rendered and represent the real model.

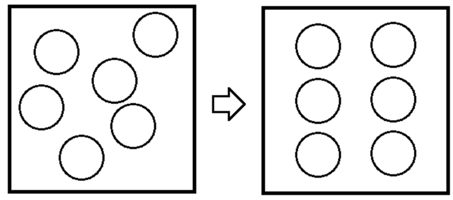
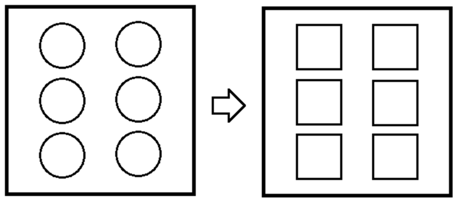
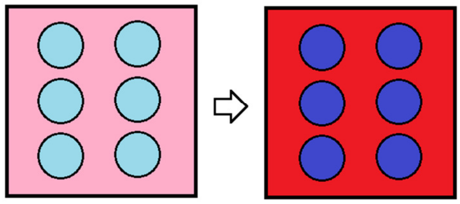
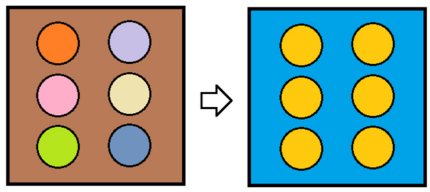
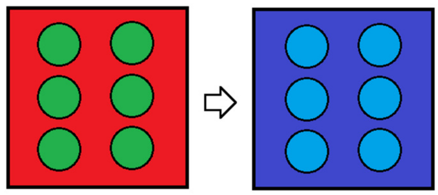
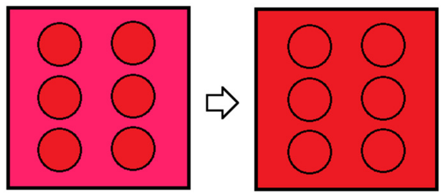
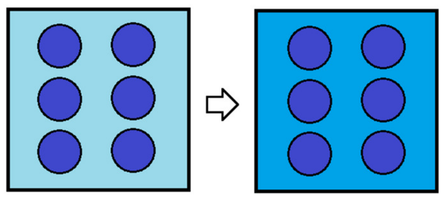
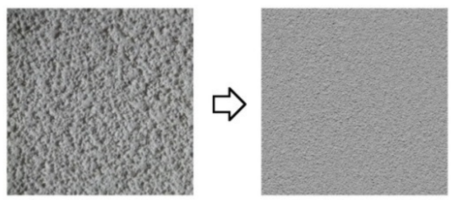
6. The final design must be created on this paper only in the specified area.

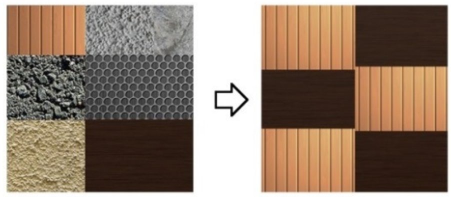
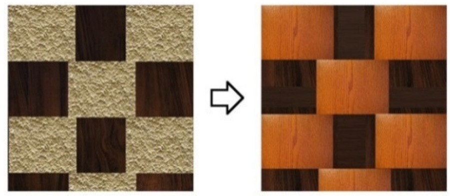
7. Aesthetics, user interface, and ergonomics are the main factors.

Appendix 8

Instruction examples of increasing pureness and proportion in different elements

Quality	Instruction	Example
Pureness in form	Decreasing number of lines	
	Decreasing number of changes in line nature (straight/curve)	
Proportion in form	Increasing similarity within the form in size	
	Increasing similarity within the form in nature	
Pureness in shape	Decreasing number of separate shapes	
Proportion in shape	Increasing similarity between the shapes' nature	
	Increasing similarity between the shapes' size	

	Increasing similarity between the locations	
Proportion in form and shape	**Increasing similarity between the shapes and the form**	
Pureness in colour	**Increasing the saturation of colours**	
	Decreasing number of different colours	
Proportion in colour	**Increasing the similarity between colours' hue**	
	Increasing the similarity between colours' saturation	
	Increasing the similarity between colours' value	
Pureness in texture	**Increasing the smoothness of the texture**	

	Decreasing number of different textures	
Proportion in texture	**Increasing similarity between the nature of textures**	
Proportion in texture colour	**Increasing similarity between the colour of textures**	

Appendix 9

Instruction of applying beauty metrics and measured effect values

No.	Target design contrast (Condition of design elements)	Metric Code	Effectiveness in beauty value	Instruction of applying the metric
01	Very Low (Low number of elements with low proportion in nature and location)	MC1-57	56%	Increasing number of elements
02	High (Low proportion between the shapes in nature)	MC2+37	51%	Increasing the proportion of the shapes in nature
03	Medium (Low proportion between the shapes in nature with a few elements)	MC1-57_2+37	40%	Decreasing the pureness by adding more elements and increasing the proportion by increasing similarity between shapes
04	High (Low proportion between the shapes in nature)	MC2+37_MC2-57	30%	Increasing the proportion of the shapes in nature and decreasing the proportion of the shapes in location
05	High (Low proportion between the textures' nature)	MC1+39	29%	Increasing the pureness by using less number of different textures
06	High (Low pureness in terms of number of elements and low proportion between the shapes' nature	MC1+57_2+37	26%	Increasing the pureness by using fewer elements and increasing the proportion by make the similar shapes in terms of nature
07	Very High (Low proportion of the form and shape, low pureness in terms of number of	MA2+36, MC1+57_2+37	25%	Increasing the proportion of the form by using parallel lines, increasing the pureness of shapes using fewer elements,

	elements and different colours)			increasing the proportion of the shapes using similar shapes in terms of nature
08	Very High (Low proportion in terms of shapes' location)	MC2+57	23%	Increase the proportion by increasing the similarity between the locations of the shapes
09	Very High (Low proportion between the nature of different parts of the form in nature and dimension)	MC2+36	22%	Increasing the proportion by making similarity in nature of different parts of the form
10	Low (Low proportion between the shapes' dimension, high pureness having few elements)	MC1-57_2+47	21%	Decreasing the pureness by adding more elements and increasing the proportion in dimensions of the shapes
11	Medium (High proportion between form and shape's nature, low proportion between shapes' dimension)	MC2-367_2+47	21%	Decreasing the proportion between shape and form in nature, increasing the proportion of shapes in terms of dimensions
12	Very Low (High proportion between shape's and form's nature, size and location)	MC2-367	18%	Decreasing the proportion between shape and form in nature
13	High (Low pureness in terms of using different colours)	MC1+38	16%	Increasing pureness by decreasing number of different colours
14	High (High proportion in terms of similarity between form and shape's nature and low proportion in shapes' location and dimension)	MC2-367_2+57	10%	Decreasing the proportion between shape and form in nature, increasing the proportion between the location of shapes

15	**Very High (Low proportion in similarity between shape's and form's nature, high proportion between the shape's nature)**	**MA1-36_1+37**	**10%**	**Decreasing the pureness of form by increasing number of lines, Increasing the pureness of shapes by decreasing number of lines**
16	**Medium (Low proportion and pureness in form)**	**MA1+36_2+36**	**10%**	**Increasing the pureness and proportion of form by making similar and parallel lines**
17	**Medium (Low pureness in form)**	**MA1+36**	**9%**	**Increasing the pureness of form by lessen the number of lines**
18	**High (Low proportion in terms of dimension of different parts of the form)**	**MC2+46**	**9%**	**Increasing the proportion by making similar dimensions between different parts of the form**
19	**High (Low proportion in terms of shape's location)**	**MC2+47_2-57**	**8%**	**Increasing the proportion by making the similarity between the locations of shapes and decreasing the proportion by changing the size of the shapes**
20	**High (Low proportion in terms of shape's dimension)**	**MC2+47**	**6%**	**Increasing proportion by making similar dimensions between the shapes**
21	**Low (Low proportion in texture's nature)**	**MC2+39**	**5%**	**Increasing the proportion between the textures in nature**
22	**Low (Low pureness in terms of colour saturation)**	**MC1+38**	**5%**	**Increasing pureness of the colour by increasing the colour saturation**
23	**Very High (Rough texture)**	**MA1+39**	**3%**	**Increasing the pureness of the texture by making smoother texture**
24	**Very Low (High proportion in colour's nature)**	**MC2-38**	**1%**	**Decreasing the proportion of colours in nature by making different colours**

Appendix 10

Appropriateness metrics in chair design and measured effect values, all dimensions are in centimetre.

No.	Target chair condition		Change	Effect value
	Metric	Status		
01	M1	N/A	Ergonomic rectangle	54%
	M2	N/A	High density sponge + Leather	
	M3	N/A	50 (W) x 12 (D) x 45 (H)	
	M4	Flat	Ergonomic rectangle	
	M5	Plastic	High density sponge + Leather	
	M6	40 (W) x 40 (D) x 40 (H)	50 (W) x 45 (D) x 8 (H)	
	M7	Cubic	Tetramerous leg	
	M8	Plastic	Metal	
	M9	40 (W) x 40 (D) x 40 (H)	60 (W) x 60 (D) x (Adjustable H)	
02	M1	Flat trapezoid	Ergonomic trapezoid	44%
	M2	Plastic	High density sponge + Leather	
	M3	52-21 (W) x 1.3 (D) x 44 (H)	55 (W) x 18 (D) x 48 (H)	
	M4	Flat trapezoid	Ergonomic rectangle	
	M5	Plastic	High density sponge + Leather	
	M6	24-52 (W) x 44 (D) x 1.3 (H)	30 (W) x 50 (D) x 12 (H)	
	M7	Flat Triangular	2 circular + 2 square legs	
	M8	Plastic	Wood	
	M9	66 (W) x 44 (D) x 55 (H)	75 (W) x 60 (D) x 32 (H)	
03	M1	Flat cribriform rectangle	Ergonomic trapezoid	39%
	M2	Wood	High density sponge + Leather	
	M3	60 (W) x 4 (D) x 27 (H)	24-32 (W) x 6 (D) x 40 (H)	
	M4	Square	Square	
	M5	High density sponge + Leather	High density sponge + Leather	
	M6	60 (W) x 60 (D) x 10 (H)	40 (W) x 40 (D) x 9 (H)	
	M7	4 rectangular legs	4 rectangular legs	
	M8	Wood	Wood	
	M9	60 (W) x 60 (D) x 28 (H)	50 (W) x 50 (D) x 34 (H)	
04	M1	Flat trapezoid	Ergonomic rectangular	32%
	M2	High density sponge + Fabric	High density sponge + Leather	
	M3	27-54 (W) x 15 (D) x 26 (H)	40 (W) x 3 (D) x 40 (H)	
	M4	Rectangular	Rectangular	
	M5	High density sponge + Fabric	High density sponge + Leather	
	M6	27 (W) x 42 (D) x 16 (H)	45 (W) x 45 (D) x 14 (H)	

	M7	Pyramidal + Flat surface	4 rectangular legs	
	M8	Sponge + Fabric + Metal	Wood	
	M9	55 (W) x 55 (D) x 32 (H)	50 (W) x 50 (D) x 24 (H)	
05	M1	Flat rectangular	Flowered	29%
	M2	Plexiglass	High density sponge + Leather	
	M3	40 (W) x 1.2 (D) x 42 (H)	40-68 (W) x 6 (D) x 31 (H)	
	M4	Flat rectangular	Flowered	
	M5	Plexiglass	High density sponge + Leather	
	M6	40 (W) x 40 (D) x 1.2 (H)	42 (W) x 42 (D) x 6 (H)	
	M7	Spider fitting + flat surface	Circular bar + surface	
	M8	Steel	Steel	
	M9	40 (W) x 40 (D) x 45 (H)	50 (W) x 50 (D) x 34 (H)	
06	M1	Flat rectangle	Rectangular	25%
	M2	Wood	Wood	
	M3	50 (W) x 1 (D) x 32 (H)	30 (W) x 3.5 (D) x 50 (H)	
	M4	Flat rectangle	Trapezoidal	
	M5	Wood	High density sponge + Leather	
	M6	50 (W) x 35 (D) x 1 (H)	40-32 (W) x 40 (D) x 5 (H)	
	M7	Flat rectangle	4 rectangular legs	
	M8	Wood + Steel	Wood	
	M9	60 (W) x 58 (D) x 36 (H)	40-34 (W) x 46 (D) x 40 (H)	
07	M1	Flat rectangle	Rectangular	20%
	M2	Plastic	High density sponge + Fabric	
	M3	40 (W) x 1 (D) x 32 (H)	60 (W) x 32 (D) x 44 (H)	
	M4	Flat rectangle	Rectangular	
	M5	Plastic	High density sponge + Fabric	
	M6	40 (W) x 45 (D) x 1 (H)	60 (W) x 48 (D) x 9 (H)	
	M7	Curved flat rectangle	Boxy	
	M8	Plastic	Carbon fibre	
	M9	72 (W) x 50 (D) x 35 (H)	60 (W) x 56 (D) x 30 (H)	
08	M1	Curved rectangle	Ergonomic cribriform rectangle	14%
	M2	Plastic	Plastic	
	M3	36 (W) x 2 (D) x 10 (H)	50 (W) x 1.5 (D) x 36 (H)	
	M4	Circular	Ergonomic cribriform rectangle	
	M5	Plastic	Plastic	
	M6	36 (W) x 36 (D) x 6 (H)	50 (W) x 40 (D) x 1.5 (H)	
	M7	Bar + Circular surface	Bent bar	
	M8	Plastic + Steel	Steel	
	M9	36 (W) x 36 (D) x 70 (H)	68 (W) x 58 (D) x 45 (H)	
09	M1	Flat rectangle	Curved rectangle	13%
	M2	Wood	High density sponge + Leather	

	M3	**40 (W) x 2.5 (D) x 30 (H)**	**48 (W) x 5.5 (D) x 40 (H)**	
	M4	**Flat rectangle**	**Rectangular**	
	M5	**Wood**	**High density sponge + Leather**	
	M6	**40 (W) x 33 (D) x 2.5 (H)**	**55-30 (W) x 60 (D) x 8 (H)**	
	M7	**4 flat rectangular legs**	**4 rectangular legs**	
	M8	**Wood**	**Wood**	
	M9	**45 (W) x 40 (D) x 33 (H)**	**64-44 (W) x 68 (D) x 40 (H)**	
10	**M1**	**Curved rectangle**	**Curved trapezoid**	**11%**
	M2	**Wood + Sponge + Fabric**	**High density sponge + Fabric**	
	M3	**48 (W) x 6 (D) x 40 (H)**	**64-40 (W) x 2.5 (D) x 50 (H)**	
	M4	**Semi-circular**	**Semi-elliptical**	
	M5	**High density sponge + Fabric**	**High density sponge + Fabric**	
	M6	**66-32 (W) x 56 (D) x 12 (H)**	**60-40 (W) x 44 (D) x 2.5 (H)**	
	M7	**Pentameric spooled legs**	**3 flat rectangular legs**	
	M8	**Wood**	**Wood**	
	M9	**56 (W) x 52 (D) x 36 (H)**	**88-4 (W) x 80 (D) x 36-26 (H)**	
11	**M1**	**Curved triangle**	**Ergonomic rectangle**	**6%**
	M2	**Plastic**	**Fabric**	
	M3	**48-12 (W) x 3 (D) x 46 (H)**	**40 (W) x 40-12 (D) x 52 (H)**	
	M4	**Curved triangle**	**Ergonomic rectangle**	
	M5	**Plastic**	**Fabric**	
	M6	**12-48(W) x 44 (D) x 8 (H)**	**40 (W) x 44 (D) x 12 (H)**	
	M7	**4 diagonal-positioned legs**	**2 flat rectangular surface**	
	M8	**Steel**	**Steel**	
	M9	**48 (W) x 50 (D) x 40 (H)**	**40 (W) x 100 (D) x 32 (H)**	
12	**M1**	**Curved rectangle**	**Rectangle**	**1%**
	M2	**Plastic**	**High density sponge + Leather**	
	M3	**50 (W) x 2.5 (D) x 48 (H)**	**40 (W) x 12 (D) x 34 (H)**	
	M4	**Curved rectangle**	**Rectangle**	
	M5	**Plastic**	**High density sponge + Leather**	
	M6	**52 (W) x 52 (D) x 2.5 (H)**	**40 (W) x 48 (D) x 12 (H)**	
	M7	**Curved rectangle**	**Hollow hemisphere + Circular surface and bar**	
	M8	**Plastic**	**Carbon fibre + Steel**	
	M9	**52-12 (W) x 47 (D) x 44 (H)**	**56 (W) x 56 (D) x 24 (H)**	

Appendix 11

Novelty metrics in chair design and measured effect values, all dimensions are in centimetre.

No.	Target chair condition		Change	Effect value
	Metric	Status		
01	M1	Rectangular	Flat trapezoid	59%
	M2	Wood	High density sponge + Fabric	
	M3	30 (W) x 3.5 (D) x 50 (H)	27-54 (W) x 15 (D) x 26 (H)	
	M4	Trapezoidal	Rectangular	
	M5	High density sponge + Leather	High density sponge + Fabric	
	M6	40-32 (W) x 40 (D) x 5 (H)	27 (W) x 42 (D) x 16 (H)	
	M7	4 rectangular legs	Pyramidal + Flat surface	
	M8	Wood	Sponge + Fabric + Metal	
	M9	40-34 (W) x 46 (D) x 40 (H)	55 (W) x 55 (D) x 32 (H)	
02	M1	Ergonomic trapezoid	Flat trapezoid	53%
	M2	High density sponge + Leather	Plastic	
	M3	24-32 (W) x 6 (D) x 40 (H)	52-21 (W) x 1.3 (D) x 44 (H)	
	M4	Square	Flat trapezoid	
	M5	High density sponge + Leather	Plastic	
	M6	40 (W) x 40 (D) x 9 (H)	24-52 (W) x 44 (D) x 1.3 (H)	
	M7	4 rectangular legs	Flat Triangular	
	M8	Wood	Plastic	
	M9	50 (W) x 50 (D) x 34 (H)	66 (W) x 44 (D) x 55 (H)	
03	M1	Ergonomic cribriform rectangle	Flat rectangle	42%
	M2	Plastic	Wood	
	M3	50 (W) x 1.5 (D) x 36 (H)	50 (W) x 1 (D) x 32 (H)	
	M4	Ergonomic cribriform rectangle	Flat rectangle	
	M5	Plastic	Wood	
	M6	50 (W) x 40 (D) x 1.5 (H)	50 (W) x 35 (D) x 1 (H)	
	M7	Bent bar	Flat rectangle	
	M8	Steel	Wood + Steel	
	M9	68 (W) x 58 (D) x 45 (H)	60 (W) x 58 (D) x 36 (H)	
04	M1	Ergonomic rectangular	Flat rectangular	37%
	M2	High density sponge + Leather	Plexiglass	
	M3	40 (W) x 3 (D) x 40 (H)	40 (W) x 1.2 (D) x 42 (H)	
	M4	Rectangular	Flat rectangular	
	M5	High density sponge + Leather	Plexiglass	
	M6	45 (W) x 45 (D) x 14 (H)	40 (W) x 40 (D) x 1.2 (H)	

	M7	4 rectangular legs	Spider fitting + flat surface	
	M8	Wood	Steel	
	M9	50 (W) x 50 (D) x 24 (H)	40 (W) x 40 (D) x 45 (H)	
05	M1	Curved rectangle	Flat rectangle	31%
	M2	Plastic	Plastic	
	M3	36 (W) x 2 (D) x 10 (H)	40 (W) x 1 (D) x 32 (H)	
	M4	Circular	Flat rectangle	
	M5	Plastic	Plastic	
	M6	36 (W) x 36 (D) x 6 (H)	40 (W) x 45 (D) x 1 (H)	
	M7	Bar + Circular surface	Curved flat rectangle	
	M8	Plastic + Steel	Plastic	
	M9	36 (W) x 36 (D) x 70 (H)	72 (W) x 50 (D) x 35 (H)	
06	M1	Flat cribriform rectangle	Curved trapezoid	29%
	M2	Wood	High density sponge + Fabric	
	M3	60 (W) x 4 (D) x 27 (H)	64-40 (W) x 2.5 (D) x 50 (H)	
	M4	Square	Semi-elliptical	
	M5	High density sponge + Leather	High density sponge + Fabric	
	M6	60 (W) x 60 (D) x 10 (H)	60-40 (W) x 44 (D) x 2.5 (H)	
	M7	4 rectangular legs	3 flat rectangular legs	
	M8	Wood	Wood	
	M9	60 (W) x 60 (D) x 28 (H)	88 (W) x 80 (D) x 36-26 (H)	
07	M1	Flat rectangle	Rectangular	27%
	M2	Wood	High density sponge + Fabric	
	M3	40 (W) x 2.5 (D) x 30 (H)	60 (W) x 32 (D) x 44 (H)	
	M4	Flat rectangle	Rectangular	
	M5	Wood	High density sponge + Fabric	
	M6	40 (W) x 33 (D) x 2.5 (H)	60 (W) x 48 (D) x 9 (H)	
	M7	4 flat rectangular legs	Boxy	
	M8	Wood	Carbon fibre	
	M9	45 (W) x 40 (D) x 33 (H)	60 (W) x 56 (D) x 30 (H)	
08	M1	Ergonomic trapezoid	Ergonomic rectangle	26%
	M2	High density sponge + Leather	Fabric	
	M3	55 (W) x 18 (D) x 48 (H)	40 (W) x 40-12 (D) x 52 (H)	
	M4	Ergonomic rectangle	Ergonomic rectangle	
	M5	High density sponge + Leather	Fabric	
	M6	30 (W) x 50 (D) x 12 (H)	40 (W) x 44 (D) x 12 (H)	
	M7	2 circular + 2 square legs	2 flat rectangular surface	
	M8	Wood	Steel	
	M9	75 (W) x 60 (D) x 32 (H)	40 (W) x 100 (D) x 32 (H)	
09	M1	Ergonomic rectangle	Curved rectangle	22%
	M2	High density sponge + Leather	Wood + Sponge + Fabric	

	M3	50 (W) x 12 (D) x 45 (H)	48 (W) x 6 (D) x 40 (H)	
	M4	Ergonomic rectangle	Semi-circular	
	M5	High density sponge + Leather	High density sponge + Fabric	
	M6	50 (W) x 45 (D) x 8 (H)	66-32 (W) x 56 (D) x 12 (H)	
	M7	Tetramerous leg	Pentameric spooled legs	
	M8	Metal	Wood	
	M9	60 (W) x 60 (D) x (Adjustable H)	56 (W) x 52 (D) x 36 (H)	
10	M1	N/A	Curved rectangle	18%
	M2	N/A	Plastic	
	M3	N/A	50 (W) x 2.5 (D) x 48 (H)	
	M4	Flat	Curved rectangle	
	M5	Plastic	Plastic	
	M6	40 (W) x 40 (D) x 40 (H)	52 (W) x 52 (D) x 2.5 (H)	
	M7	Cubic	Curved rectangle	
	M8	Plastic	Plastic	
	M9	40 (W) x 40 (D) x 40 (H)	52-12 (W) x 47 (D) x 44 (H)	
11	M1	Curved rectangle	Rectangle	16%
	M2	High density sponge + Leather	High density sponge + Leather	
	M3	48 (W) x 5.5 (D) x 40 (H)	40 (W) x 12 (D) x 34 (H)	
	M4	Rectangular	Rectangle	
	M5	High density sponge + Leather	High density sponge + Leather	
	M6	55-30 (W) x 60 (D) x 8 (H)	40 (W) x 48 (D) x 12 (H)	
	M7	4 rectangular legs	Hollow hemisphere + Circular surface and bar	
	M8	Wood	Carbon fibre + Steel	
	M9	64-44 (W) x 68 (D) x 40 (H)	56 (W) x 56 (D) x 24 (H)	
12	M1	Curved triangle	Flowered	4%
	M2	Plastic	High density sponge + Leather	
	M3	48-12 (W) x 3 (D) x 46 (H)	40-68 (W) x 6 (D) x 31 (H)	
	M4	Curved triangle	Flowered	
	M5	Plastic	High density sponge + Leather	
	M6	12-48(W) x 44 (D) x 8 (H)	42 (W) x 42 (D) x 6 (H)	
	M7	4 diagonal-positioned legs	Circular bar + surface	
	M8	Steel	Steel	
	M9	48 (W) x 50 (D) x 40 (H)	50 (W) x 50 (D) x 34 (H)	

Figure's references

All the figures used in this thesis are produced by the author except following:

Figure 17

1, 5: Edifier® MP300 Plus (http://www.edifier-international.com/)

2, 6: Pangolin® Bag (http://pangolin.com.co/)

3, 8: Apple® MAC Mini (http://www.apple.com/)

Figure 24

Eye Health (http://www.nhs.uk/Livewell/Eyehealth/)

Figure 25

Eye-tracking device (http://www.lfe.mw.tum.de/en/research/)

Figure 29

Left: Fastec® TS3 (http://www.fastecimaging.com/)

Right: Canon® EOS-1DX (http://www.canon.co.uk/)

Figure 38

1: Calvin Klein® Watch (http://uk.calvinklein.com/)

2, 8: Leica® Camera (http://www.leica-camera.com/)

6: Renault® Radiance (http://www.renault-trucks.co.uk/radiance/)

7: Diesel® DZ7125 (http://store.diesel.com/gb/men/onlinestore/watches/)

12: MAN® Truck (http://www.entry.man.eu/uk/en/index.html)

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