Word-Colour Associations in Design

By

Yun Chen

Submitted in accordance with the requirements for the degree of
Doctor of Philosophy

The University of Leeds
School of Design

March, 2021

The candidate confirms that the work submitted is his/her own and that appropriate credit has been given where reference has been made to the work of others.

To my beloved husband and parents

Acknowledgements

I would like to express my gratitude to all those who helped me in completing this long journey. My deepest gratitude goes first and foremost to Professor Stephen Westland, my supervisor, who has offered me valuable academic studies suggestions.

Second, I would like to express my thanks to my second supervisor Dr. Vien Cheung for her guidance and constructive advice throughout my PhD. I am also grateful to my lovely colleagues in our Colour Group and all the participants who took part in my studies, without their help, this research would not be possible.

Last but not least, I would like to express the special thanks to my beloved family: my husband and parents, who gave me their loving supporting, listening to me and helping me work out my problems during the difficult time.

Abstract

Colour conveys multiple types of information and is widely used in Art and Design. The critical role of colour in design is undoubted, and colour selection is an important step or process that can affect whether a design is successful or not. Colour association plays an essential role in colour selection in design. It can help designers to create satisfying and useful colour schemes which meet the requirements of consumers, brands and aesthetics. It has long been established that strong associations exist between colours and concepts. The term 'association' refers to a connection or cooperative link between someone or something. Colour association expresses a specific relationship between colour and various concepts or objects. However, it is noticed that when the colour association is discussed, it is often in one direction, that is, from colours to concepts. However, in this thesis, it is argued that colour association is bidirectional, meaning that we can also start with a word or concept and ask the question which colour (or colours) are associated with it. An important contribution of this work is to emphasis the direction word-->colour in terms of colour association.

The research focused on word→colour associations in design. This topic is interesting in itself but may have practical application in the design field. This thesis contains both qualitative and quantitative research. The main contribution of this research is: 1) to highlight and evidence strong associations from word to colour; 2) to identify the (three) main characteristics of these associations through the introduction of a practical method to analyse their characteristics; 3) to explore the influence of culture on word→colour associations and to develop a two-aspect cultural influence model (and an evaluation system to quantify the effect of culture on word→colour associations). This research may provide a meaning discussion for colour selection in design and help people exploring the theoretical and practical methods of colour selection. It is also hoped that this research could attract more attention to the colour association discussion, especially the discussion of the colour association from concept→colour.

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction

This chapter describes the research background, aims and research scope. The thesis structure is also presented at the end of the chapter.

1.1 Background

Colour in Design. Colour is a fundamental element by which humans recognise objects in nature (Goethe, 1810). It is also a form of non-verbal communication in the most immediate form (Ambrose, Gavin & Harris, 2005). Colour contains multiple types of information and is widely used in Design and Art. In general, colour plays an irreplaceable role in all design fields and has been considered as a design element in art and design over at least five centuries (Osborne, 2012). Additionally, colour can also be regarded as a flexible and powerful tool in design. It may be viewed as a kind of language of communication between humans and their surroundings (Sherin, 2012) and between humans. Colour selection is the process by which a designer selects colours for a particular design solution. The essential role of colour for design is undoubted (Grossman Wisenblit, 1999; Ares and Deliza, 2010), and colour selection is a critical factor that can affect whether a design is successful or not (Adams, 2013). However, many papers have discussed the colour selection process and concluded that it is generally performed based on a designer's subjective ideas and experience (Hsiao, 1995), often without reference to theory or theoretical knowledge (Smith, 2002). Thus, understanding the colour selection process in design, exploring the essential steps of this process is an important topic that needs to be discussed in the design area.

Colour Associations. Colour association is not an unknown concept in colour research. It is established that strong associations exist between colours and concepts (Gage, 1999). When we are reminded of a specific object, a particular substance, a person, a time or a region by the stimulation of colour, this is sometimes referred to as colour association (Kress, 2002). The term 'association' refers to a connection or cooperative link between someone or something (Oxford English Dictionary, 2015). Colour association

expresses a specific relationship between colour and concepts or objects. However, it is noticed that when colour associated is discussed, it is often in one direction, from colours to concepts, such as colour emotion (Ou *et al.*, 2004) and colour meaning (Elliot and Maier, 2007). However, in this thesis, it is argued that colour association is bidirectional, representing the relationship from colour to concept or concept to colour, due to the essential meaning of the term 'association' (Castree *et al.*, 2013) (Figure 1-1). This indicates colour association which from concept to colour, is important and deserves further investigation. The concepts are generally formed as specific words, such as people associate blue with calming, depressing, peaceful, quiet, serious, and nostalgic (Goanga, 1912). Thus, colour associations can be discussed as the relationship between colour and a specific word.

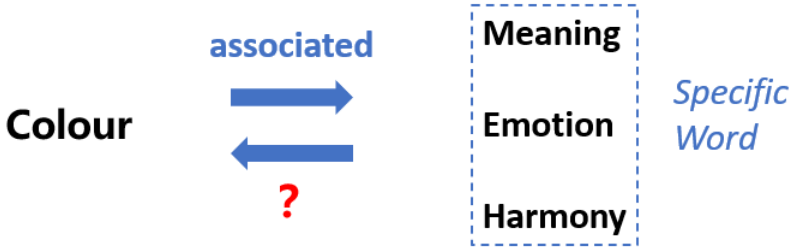


Figure 1-1 Colour associations

Word-Colour. In discussing the word and colour relationship, first, there is a rich history of work that relates colours to language through their colour names. For example, the Berlin and Kay study (1999) was concerned with essential colour names and found some similarities between different cultures in the development and use of at least the most basic colour names such as red, yellow and blue. The Berlin and Kay study was impressive in its contribution to arguments about the Sapir-Whorf hypothesis; this much-debated hypothesis states that the language a person speaks will affect their thought (or, in this particular case, their colour perception). This debate still rages on, and more recently, there has been opposition to the universalist view represented by the original Berlin and Kay study (Wierzbicka, 2006). There have also been studies to map the use of colour names to specific colourimetric boundaries (Sivik and Taft, 1994). However, another aspect of the relationship between colour and language is language to represent the

emotions or concepts that colours may evoke. It is this aspect of colour and language that this research is concerned with.

In summary, the research addressed in this thesis is motivated by 1) a current lack of research on colour associations from concept→colour; 2) the critical role of colour in design and the importance of colour associations in colour selection. Therefore, this research focuses on discussing word→colour associations in design, which may help colour selection in the design process. It is hoped that this research could attract more attention to the colour association discussion, especially the discussion of the colour association from concept→colour.

1.2 Research Aims and Research Questions

This research aims to explore the colour associations from specific words to colours, which is useful and meaningful in the colour selection process of design. In order to achieve this aim, the following objectives are carried out:

- To understand the colour selection process of designers and to identify the meaning and application of word-colour associations in design

  (Study 1, Chapter 4).

- To evidence that strong associations exist from word→colour and find out which types of words are associated with colours stronger than others

  (Study 2, Chapter 5).

- To analyse the characteristic of word→colour associations

  (Study 3, Chapter 6).

- To explore the cultural influence of word→colour associations

  (Study 4, Chapter 7).

Four main research questions (RQ) have been identified for this research:

RQ 1: What is the general process of colour selection for a designer?

RQ 2: Are there strong associations from words→colours?

RQ 3: Are there significant characteristics in the associations from word→colour?

RQ 4: Are there significant differences in the associations from word→colour in different cultures?

1.3 Thesis Structure

In the discussion of word→colour associations in design, this research is constructed by eight chapters:

Chapter 1: Introduction

At the beginning of the thesis, the general background, research aims and structure are introduced.

Chapter 2: Literature Analysis and Synthesis

This chapter provides a review of some fundamental concepts and definitions related to the research topic: the basic knowledge of colour theories, the significance and potential advantages of the role of colour in design, a critical overview of colour associations. Based on this review, the research topic has been developed.

Chapter 3: Research Methodology

This chapter outlines the research methodologies and describes the research plan and data collection approaches for conducting this study. The research design is presented (see Table 3-4); the research framework is developed (see Figure 3-1), and the description of the research methodology (see Table 3-6).

Chapter 4: Study 1 - Methods used by designers to choose colour

This study explored through an interview study to collect new research data from the designers and gathering the ideas from their routine design work. It summarised a three-step colour selection method from designers and identified the meaning and application of word→colour associations in design. This study led to the topic and pointed out the meaning of the topic.

Chapter 5: Study 2 - Evidence for strong associations exist from word to colour.

To discuss word→colour associations, the first step is to identify whether strong associations exist. This chapter evidences word→colour associations through a psychophysical experiment (*Experiment 1*) and finds that adjectives are more strongly associated with colours than other words. Then, an online questionnaire is carried out to integrate the results with Experiment 1 and provide more supplementary information to support the interview study in Chapter 4.

Chapter 6: Study 3 - The characteristic of the associations from word to colour.

After concluding that word→colour associations exist, this chapter discusses the characteristics of the associations from word to colour. An analysis method of the associations was introduced, and three main points of the associations were summarised through a psychophysical experiment (*Experiment 2*).

Chapter 7: Study 4 - The cultural influence of the associations from word to colour.

In the last step of discussing word-colour associations, the associations from word→colour will be discussed in the cultural aspect and to explore the characteristic of cultural influence in word and colour associations. *Experiment 3*, it evidenced the cultural influence is specific and noticeable; the characteristic of the cultural influence is summarised as four main categories. A theoretical model and an evaluation system were developed for cultural influence analysis.

Chapter 8: Discussion and Future Work

The last chapter summarises the essential findings and contributions of this research through the three main studies. The research limitations and the further work of this topic are also discussed.

Chapter 2
Literature Analysis and Synthesis

Chapter 1 provides an overview of the research motivation and scope, along with the aim and objectives. In this chapter, some fundamental concepts and definitions related to the research topic are reviewed: the basic knowledge of colour theories will be summarised first; then, the significance and potential advantages of the role of colour in design are highlighted; in the last part, a critical overview of colour associations is carried out. The initial framework will then be refined and designed in the research through the synthesis of relevant literature in these fields.

2.1 Fundamentals of Colour

Colour is an intangible human sense formed in the brain and is one of the most essential elementals in our daily life. According to one reliable estimate, humans can distinguish about ten million colours (Judd and Wyszecki, 1975). This section will introduce basic colour concepts about colour visual perception, colour order systems, colour measurement and colour information.

2.1.1 Colour Visual Perception

It is evident that colour is usually caused by light and observed in the spectrum (Hanson, 2012; Newton, 1672). When the eye receives physical stimulation by light, the retina (which is on the inside back lining of the eye) responds to the stimulation and transmits information to the brain, where the sensation of colour is experienced. Naturally, light is a precondition for colour perception and objects appear coloured because of how they interact with light and ultimately reflect some of the incident light to the eye (Ohta and Robertson, 2006). It is often stated that three conditions are required for colour perception: light, object and visual system. However, strictly speaking, this is probably not true because we can see the light emitted by light

sources directly, for example. Another simplification that is sometimes made is to compare the visual system to a camera system since both respond to light and generate images (Ohta and Robertson, 2006). Whereas photographic film responds to light with a chemical reaction (and modern digital cameras respond electrically), specialist cells within the retina of the human eye undergo a photochemical reaction and produce an electrochemical response to light that is subsequently transmitted to the brain. Figure 2-1 shows schematically an eye and a camera for comparison. The corresponding components listed in Table 2-1.

Table 2-1 Corresponding Components of the Eye and Camera

Camera	Eye
Black box	Sclera and choroid
Lens	Cornea and lens
Shutter	Eyelid
Diaphragm	Iris
Film	Retina

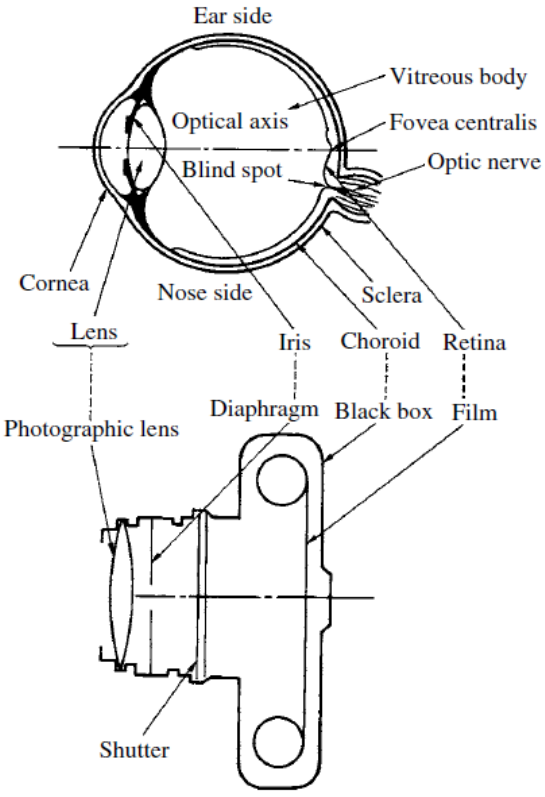


Figure 2-1 Structure of eye and camera (Ohta and Robertson, 2006).

However, the comparison of the eye and the camera is superficial. Although they have some corresponding components, the visual process is an active process that includes both top-down and bottom-up processes. Light – considered essential to make objects visible to humans - is electromagnetic radiation characterised by specific wavelengths (Hanson, 2012). People can only respond to a small part of the full electromagnetic spectrum. Human eyes are generally sensitive to wavelengths between 360 and 780 nm (Westland *et al.*, 2007). Note, however, that the definition of light is usually 360-780nm or 400-700nm. It is not easy to definitively give upper and lower bounds for the sensitivity of the visual system. For example, under certain conditions, humans can perceive light in the infra-red region at wavelengths as long as 1000 nm (Palczewska *et al.*, 2014). The lens absorbs typically light below about 400nm, but humans who have had their lens removed (a condition known as aphakia) have been reported to see the light at wavelengths as low as 300nm.

In the 17th C, Newton (1952) demonstrated that when broadband white light is passed through a prism, it is separated into seven “rainbow” colours: red, orange, yellow, green, blue, indigo, and violet. The idea that there are seven colours in the visible spectrum persists today, as shown in Figure 2-2. Children are taught these seven colours with the mnemonic Richard of York Gave Battle in Vain. However, many people will report that they can only see six bands of colour in the rainbow (red, orange, yellow, green, blue and violet), and in writing about seven bands, Newton was likely influenced by ideas that associate the concepts of colour and music. Furthermore, given that wavelength varies continuously, it is not clear why we should see distinct bands of colour at all rather than a continuing variation in hue.

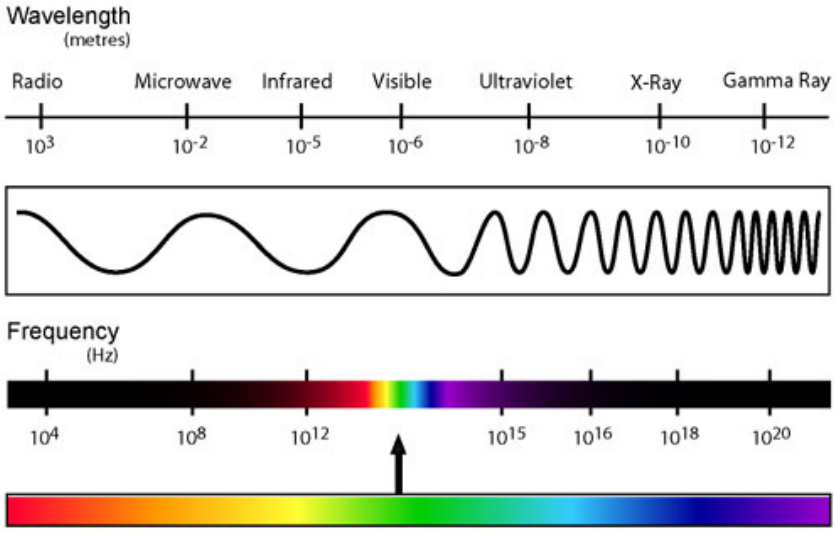


Figure 2-2 The visible spectrum (Holtzschue, 2012).

However, it is known that human colour vision is mediated by three classes of light-sensitive cells called cones. The cones have relatively broadband spectral sensitivity but peak sensitivity at about 430nm, 540nm and 570nm. The observation that we have three types of cones is consistent because our perception of colour is 3-dimensional. Visual attributes of colour are often cited as being lightness, chroma and hue. At lower levels of illumination (known as scotopic vision), there is insufficient light to activate the cones, and under these conditions, vision results from activation of the rods (Wandell, 1995). We cannot see colour at these so-called scotopic levels and, instead, see only in shades of grey. This is real colour blindness. However, the term *colour blindness* is often used to describe problems with colour discrimination which usually result when individuals lack one of the cone classes (in which case they are dichromats) or have one of the cone classes slightly shifted in wavelength sensitivity (in which case they are anomalous trichromats).

2.1.2 Colour Order Systems

Colour is a large subject that has been researched for a very long time and covers multiple disciplines. However, since the seminal work by Newton, colour theory has become dominated by the idea of trichromacy. In 1766, Moses Harris wrote a book, the Natural System of Colour, which presented

red, yellow and blue as primary colours; it suggested that these three colours are basic colours, from which all other colours can be obtained by mixture (Feisner, 2006). In the early 18th century, Le Blon developed a commercial system to create copies of fine-art paintings based on a mixture of these three primaries. Therefore, the trichromatic nature of colour has a very long history and certainly predates the discovery of human cone spectral sensitivities. Today, some of these early ideas have remained and confuse when the modern understanding of colour is applied. For example, we now know that using three primaries in a mixture can generate all hues but cannot generate all colours (Westland et al., 2007).

In addition to trichromacy, another concept with a long history is the idea of a hue circle. Our perception of hue is nearly circular; if we observe the visible spectrum's longest wavelengths, they are somewhat similar in hue to the shortest wavelengths. Newton introduced the concept of a hue circle. Later, in the early 20th century, Ostwald's colour model was introduced. The Ostwald system is both a systematic and artistic model with 24 hues in a colour circle but presents colour as a three-dimensional space in which hue is just one of the dimensions (the other two being lightness and chroma) (Ostwald, 1931).

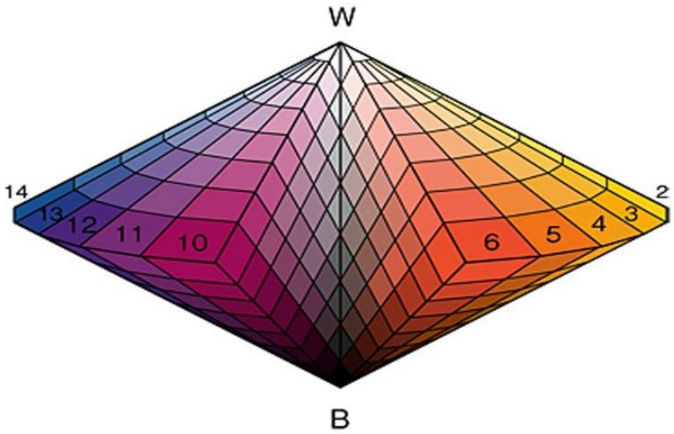


Figure 2-3 Ostwald's colour model (Ostwald, 1931)

Ostwald's colour model is only one of several colour models that were introduced at a similar time. Munsell introduced the Munsell system in 1905.

It is, like Ostwald's model, a 3-d model with a hue as a circular term. The other two terms are chroma and value. Munsell value is similar to Ostwald's concept of lightness. In the early 20th Century, models such as those introduced by Ostwald and Munsell were important conceptually and often used to teach students about colour perception. However, today popular colour systems such as the Pantone system and the Natural Colour System have used more colour communication tools.

There are two fundamental colour theories in colour mixing: additive and subtractive (Ohta and Robertson, 2006). When more than one colour is mixed additively, the resulting colour is lighter because more light is added when mixing. As mentioned, red, yellow and blue have been identified as the primary colours (Moses, 1766); however, the primary colours of additive colour mixing are red, green and blue. Newton discovers that white can result when the three primary light colours are mixed in equal amounts. Additive colour mixing has practical use in the generation of colour images on screens (e.g. smartphones, television, cinematography), but how dyes and pigments mix together is referred to as subtractive colour mixing (Diane and Cassidy, 2009). The optimal three primary subtractive colours are cyan, magenta and yellow rather than the red, yellow and blue that have been historically taught. Black typically results when the three subtractive primaries are superimposed (for example, in print or textiles). In both colour theories, the primary colours cannot be produced by mixing other colours in the system (Diane and Cassidy, 2009); but note that this does not mean that they cannot be produced by mixing other colours. Colour mixing is another topic that is frequently misunderstood in textbooks. One of the reasons for this is that the term colour mixing is a misnomer. In fact, it is impossible to mix colours; it is only possible to mix lights or colourants to generate colours.

Based on additive colour mixing, to display colour on an emissive display (e.g. computer system, internet and television), an RGB colour system is usually used. There are multiple RGB standards (Westland and Cheung, 2012). However, over the last couple of decades, a particular standard known as sRGB, developed jointly by HP and Microsoft in 1996 (International Electrotechnical Commission, 2010), has become ubiquitous. The CMYK colour system (Cyan-Magenta-Yellow-Black) is based on subtractive colour mixing and is used in colour printing. Different colour primary systems yield different colour gamuts. It is not possible, for example,

to display all of the colours that can be obtained using an sRGB system with a subtractive CMYK system (and vice versa). This has led to the emergence of some so-called wide-gamut RGB standards. The Adobe RGB colour system, for example, was published to supplement the sRGB system; it allows a broader colour gamut that includes most of the achievable colours in CMYK colour system (Yurek, 2012).

2.1.3 Colour Measurement

Colourimetry is the science of colour measurement (Tzeng and Berns, 2000). The CIE system (Commission Internationale de l'Éclairage) is a modern colour specification and measurement system. It was introduced in 1931 by the CIE and quickly became an internationally accepted standard system. It is based on three additive primaries referred to as X, Y and Z that can specify any colour. The amounts of the three primaries needed to match any colour are called the tristimulus values and represent a specification of that colour. The chromaticity coordinates x, y and z can be calculated as proportional tristimulus values, X, Y and Z, defined thus:

$$\mathrm{x} = \frac{X}{X+Y+Z}, \qquad \mathrm{y} = \frac{Y}{X+Y+Z}, \qquad z = \frac{Z}{X+Y+Z} = 1 - x - y$$

Eqn 1

Many authors (for example, Zwinkels, 1996) have described how colour measurement instruments such as tristimulus colourimeters, spectroradiometers, and spectrophotometers can measure colour (that is, to measure CIE XYZ and/or xy). The chromaticity diagram (see Figure 2-4), where two of the chromaticity coordinates are plotted, is very useful in many applications of colourimetry. It is particularly useful because the chromaticities that result from additively mixing two lights fall on the straight line that joins the chromaticities that represent the two lights. This means that a triangle defines the gamut of a trichromatic additive system in chromaticity space, where the vertices of the triangle are the chromaticities of the three primaries.

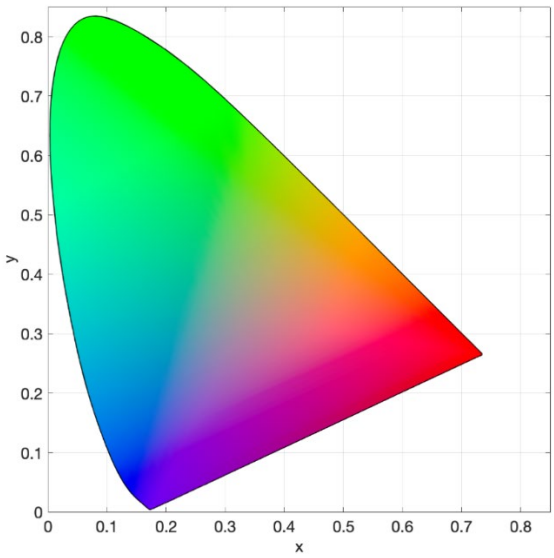


Figure 2-4 CIE chromaticity diagram

Although the original 1931 CIE system was adequate for colour specification, it was not suitable for many other problems. For example, practitioners were also concerned with whether two colours are a visual match. The concept of colours matching is essential to many manufacturing industries. If two samples have the same XYZ values, they will be a visual match. However, the practical question is how far apart do XYZ values need to be in order for the two colours that they represent to look different? The 1931 CIE was limited because it was not perceptually uniform; equal distances in the space do not represent the same visual differences.

Limitations in the 1931 system led the CIE to introduce a new space in 1976 called CIELAB (Wyszecki and Stiles, 1982; Hunt, 1998). CIELAB colour space is more uniform than the original 1931 space and has three dimensions that correspond quite well to the three dimensions of our colour perception: lightness, chroma and hue. Prediction of colour difference between single patches can be accurately measured by the distance between two colour space points that represent those colours (Witt, 1995). The CIE normalised colour difference as a distance metric Delta E or ΔE in CIELAB colour space. The equation for Delta E is based on the Euclidean distance thus:

$$\Delta E^*_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Eqn 2

The last 50 years have seen many alternative colour-difference formulae being published; the majority of these are based on CIELAB colour space, including CIE94, CMC, and most recently CIEDE2000, which is the current CIE recommendation for small colour differences (Fordand and Roberts, 1998; Luo *et al.*, 2001). The equations CIE94, CMC, and most recently CIEDE2000 were evolutions to address residual perceptual non-uniformities while retaining the CIELAB colour space. These equations often allowed application-specific weights to optimise the equations for specific tasks (Melgosa, 2000; Luo *et al.*, 2001). Currently, CIEDE2000 is recommended for small colour differences, but CIELAB is still preferred for large colour differences (Gomez-Polo *et al.*, 2015).

2.1.4 Colour Information

Colour information is a relatively new concept. Won (2015) defined it as ‘interpretations, abstractions and knowledge regarding colour data in natural sciences, technology, art, psychology, history, and design.’ Colour information is essential in the design field and is considered a tool that helps colour selection in design (Yu, 2020). Many factors are included in colour information and often influence the visual element in design (Calver, 2004), such as colour preference, colour meaning.

Won (2015) reviewed 229 related academic papers and ten books and gathered every colour information terms by title and keywords analysis. She identified 13 types of colour information which were significantly examined in colour research fields: Colour in art and design, Colour harmony, Colour history, Colour and light, Colour meaning, Colour measurement, Colour notation, Colour perception, Colour preference, Colour printing, Colour Psychology, Colour theory and Colour trend (Table 2-2).

Table 2-2 Definitions of 13 types of colour information by Won (2016).

13 Colour Information Terms	
Colour in art and design	The applications of colour are well-known in art or design works (Osborne, 2012).
Colour harmony	When colours are viewed together and aroused, pleasing affective responses (Judd, 1952; Burchett, 2002).
Colour history	The background of colour, the chronological development of colour in painting, fashion, dyeing and science (Osborne, 2012; Feisner, 2006).
Colour and light	When the eye receives physical stimulation by light, the retina responds to the stimulation and transmits information to the brain, where the sensation of colour is experienced (Hanson, 2012; Newton, 1672).
Colour meaning	Specific meanings that are associated with certain colours (Osborne, 2012).
Colour measurement	Quantifying colours. (Zwinkels, 1996) The CIE system (Commission Internationale de l'Éclairage) is a modern colour specification and measurement system.
Colour notation	Colour can associate different feelings on a semantic level, same as colour semiotic (Darrodi, 2012).
Colour perception	The perception or responses of people react to colour (Webster, 1996; Zeki, 1999).
Colour preference	The individual preferences of the colour (Mikellides, 2012).
Colour printing	The colour in photography, graphic design, or advertisements by printing techniques (Parraman, 2012).
Colour psychology	The relationship of colours with affective, cognitive responses and behaviour (Osborne, 2012).
Colour theory	The systematic rules and knowledge of colour research psychologically and scientifically (Feisner, 2006).
Colour trend	The prediction of the specific colours which will be popular (Hidefi, 2012).

2.2 Colour in Design

Colour is a fundamental element by which humans recognise objects in nature (Goethe, 1810). It is also non-verbal communication in the most immediate form (Ambrose, Gavin & Harris, 2005). It contains multiple types of information and is widely used in Design and Art. In this section, colour in design will be discussed: the role of colour in design; how colour influences design; colour selection in design.

2.2.1 The Role of Colour in Design

The term ‘design’ refers to the process of producing an idea or drawing to show the appearance and function of a specific object before it is made, or ‘a decorative pattern’ (Oxford English Dictionary, 2015). Winters proposed pattern (which is the fundamental notion of design) as a form of rhythm repetition (2005). He summarised this repetition as the essence of grouping: lines, shapes, size, forms and colours are repeated as a rhythmic unit. Inevitably, it is commonly acknowledged that colour plays an indispensable and non-substitutable part in pattern or design.

In different design fields, colour has specific functions. From the public perception, the categorisation within design fields does not have clear delineation boundaries (Margolin, 1989); it depends on individual accumulated knowledge and particular cultural settings (Cantor and Mischel, 1979; Forgas, 1983). From characteristic, professional status and general requirements, graphic design, fashion design, interior design, and product design were roughly considered four main design categories (Smith and Whitfield, 2015). In these four categories, the role of colour was discussed in related research:

Graphic design

In the graphic design field, colour is often considered to be a basic design element (Table 2-3). Software describes images in terms of point, line, plane, shape, volume, **colour** and transparency (Lupton and Phillips, 2008:13).

White (2011:17) summarised the basic visual codes as shapes, **colour**, texture, pattern and contrast. Analogously, Samara (2007) indicated the graphic design maintains five main elements: imagery, symbols, type, **colour** and material. Landa's (2010:46-52) analysis organises line, shape, value, **colour**, texture and format as a basic design element in graphic design. In Poulin's (2011:5) research, the basic design elements are point, line, shape, light, **colour**, balance, contrast and proportion in graphic design. Although much related research has discussed graphic design elements and provided their own summary, it is evident that colour is a necessary element that is always present in basic design elements.

Table 2-3 The list of design elements organisation.

	Graphic design elements	**Sources**
Colour is a basic design element.	point, line, plane, shape, volume, **colour** and transparency	Lupton and Phillips, 2008
	shapes, **colour**, texture, pattern and contrast	White, 2011
	imagery, symbols, type, **colour** and material	Samara, 2007
	line, shape, value, **colour**, texture and format	Landa, 2010
	point, line, shape, light, **colour**, balance, contrast and proportion	Poulin, 2011

Fashion design

In the fashion design field, colour has been considered a major fashion design element (Zhang, 2013). The fabric of a garment occupies most of the cost, which is around 60%, and colour selection is the first and most important step in commencing with fabric manufacturers (Jackson, 2007; Scully and Johnston Cobb, 2012). Therefore, Jackson (2007) indicated that colour is an essential part and one of the first steps in design development of fashion design. Moreover, colour was recognised as an essential component that influences consumers purchasing behaviour (Fehrman and Fehrman,

2000). It has been concluded that colour, shade, style and patterns consisted of consumers' preference which can impact consumers' assessment of fashion design choices (Zhang, 2013). Therefore, colour is a major element in fashion design.

Interior design

In the interior design field, colour is an essential element and has a considerable effect and change on people's psychological and emotional (Isreal, 2003). The visual harmonious affected people positively or negatively whether it is aware in a room, specifically, their colour, texture and pattern influenced people's perception (Itten, 1973:13). Haller (2017: 317-318) mentioned that colour is the first aspect that people always noticed in interior design, and it has long been established in many related works. Besides, Space structure, skylights, walls and furniture were summarized as the main interior space elements (Ching, 1987). Therefore, colour was considered the basic underpinning design, and every element of interior design contains colour (Francis, 1987).

Product design

In the product design field, colour is a crucial element influencing consumer behaviours (Yu, 2020). A manufactured product is presented through shape, form, colour and texture (Demirbilek and Sener, 2010). Clearly, it is suggested that colour is one of the most powerful and crucial visual elements in product design and potentially affects consumers' deep level of affective at the first impression (Kauppinen, 2014). Specifically, it was indicated that functionality (features and related benefits), aesthetics (appearance, colour, form) and meaning were three crucial aspects that influenced a product design (Srinivasan *et al.*, 2012). In terms of designers, producing sketches or models, estimating costs, customers requirements, and materials were the main aspects in the product developing (Baxter, 1995:11), and colour is a crucial element included in this process. In terms of consumer, attractiveness (form and colour), functionality, ease-of-use, safety, recyclability, and affordability were all attributes of the factors of

considerations (Demirbilek and Sener, 2010). The impact of product colour has been discussed in many papers, and it is recognized that colour is a crucial element in product design.

In summary

Colour used to be defined as 'an inherent property of all materials and surfaces including everything from light and paint to art, from aesthetics to functionality and as an inseparable element of design' (Dalke et al.,2006).

In general, colour plays an irreplaceable role in all design fields and has been considered a design element in art and design over at least five centuries (Osborne, 2012). Additionally, colour can also be regarded as a flexible and powerful tool in design. It may be viewed as a kind of language as they serve as communication tools between humans and their surroundings (Sherin, 2012).

2.2.2 The Impact of Colour on Design

Kandinsky (1977) reported the two kinds of value that colour can provide: visual value (physical effect) and associative value (psychology effect). In particular, it has been suggested that almost 80% of the human brain is concerned with responding to visual stimuli (Lightfoot and Gerstman, 1998), and our brain and eyes have a significant perception to process colour (Gegenfurtner and Kiper, 2003). Colour is defined as an essential aesthetic response, an emotional reaction, that can help design developing attractiveness (Abbott *et al.*, 2009; Rocchi and Stefani, 2005). In terms of colour itself, while acknowledging the crucial impact of visual aesthetics (Riley, 1995; Gage, 1999; Zelanski Fisher, 1999; Feisner, 2006; Osborne, 2012), the effect of colour psychology cannot be neglected in design, such as colour emotion and colour meaning (O'Connor, 2009:230). This section will discuss the impact of colour in design from the visual and psychological aspects.

2.2.2.1 Colour Visual Impact

It has been noted that visual elements are the first factors that capture consumer attention (Grossman and Wisenblit, 1999). Other research has indicated that almost 90% of consumers made purchasing decisions through visual examination of the design (Clement, 2007). To be specific, it is noticed that people observe a design from the exterior appearance subconsciously, and the surface colour communicates the primary information before a further understanding of the design (Kopacz, 2017:243). Kopacz (2017) also presented that 'Effective colour in design elicits a viewer's reaction due to innate human response.'

Meanwhile, it is considered that colour presents a significant impact on consumers' purchasing behaviour (Grossman Wisenblit, 1999; Ares Deliza, 2010). In terms of marketing, it is evident that colour can attract attention either voluntarily or involuntarily (Kauppinen, 2014). In many cases, people had attracted attention voluntarily when standard colours were used, and the colours are stored in their memory (Kahneman, 1973; Kauppinen, 2014). In particular, red as the primary colour of Coca-Cola strengthens colour memory and attracts voluntary attention; the colour red is novel compared with other cola brands (Kauppinen, 2014). On the other hand, for a well-chosen colour of design, the colour was in addition to enhancing the conspicuity of design (Barbur *et al.*, 1991), it also made a contribution in coding, classify and grouping the visual information of the design, which could significantly improve the visual performance in design information transmission (Yu, 2020).

Figure 2-5 Red, as the primary colour of Coca-Cola, is used to strengthen colour memory and attract attention voluntarily.

Overall, the colour visual impact is a nonnegligible part that influenced the finial appearance of the design directly. Choosing the appropriate design colour would stimulate consumers to make a purchase decision, attacking consumers' attention and conveying primary information (Ares Deliza, 2010; Kauppinen and Räisänen, 2014).

2.2.2.2 Colour Psychology Impact

As the associative value of colour is closely related to colour psychology, people tend to associate the colour with a specific object or a phenomenon with emotive value or high symbolic subconsciously (Kandinsky, 1977). Colour psychology is defined as 'affective, cognitive and behavioural responses and associations linked to specific colours' (O'Connor, 2009:230). It could be considered the word 'feeling': colour is commonly related to our feeling, and colour always influences our mood and well-being in the specific environment (Kwallek *et al.*, 2007). This property of colour is widely used in the design field, such as architects and artists, pacify emotion with cool colours or stimulate feeling with warm colours (Mikellides, 2007; Bayes, 1970). By manipulating the hue dimension in space, designers could provide immediate and affective impressions (Mikellides, 2007).

A substantial body of studies published，to explore the impact of colour on psychometric performance and cognitive (Darrodi, 2012). For instance, Garrett and Brooks (1987) indicated that ballot papers' colour affects voters' decision. In preschool children, the environment colour, especially the wall colours, influences children's cooperation (Read *et al.*, 1999). Wise and Wise (1988) reviewed over 200 related interior design works and ascertained the ubiquitous effects of colours on human psychometric performance, health and well-being. It is also indicated that the process of design information communicating always influenced by colour unconsciously, semiconsciously or consciously (Lee and Lee, 2006; Chan and Andrade, 2010). Figure 2-6 shows the influence on emotions of product colour in three levels: an unconscious level (innate), semiconscious level (culturally learned or life experience) and conscious level (personal colour

preference based on personal experience) (Lee and Lee, 2006; Chan and Andrade, 2010).

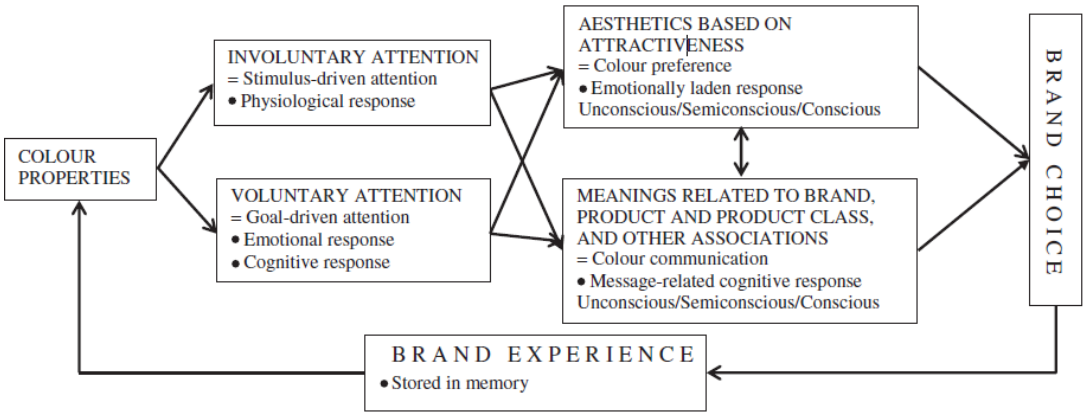


Figure 2-6 Three different level of influence emotions of product design colour: an unconscious level (innate), semiconscious level (culturally learned or life experience) and conscious level (personal colour preference based on personal experience) (Lee and Lee, 2006; Chan and Andrade, 2010).

2.2.3 Colour Selection in Design

Colour selection is the process by which a designer selects colours for a particular design solution. The essential role of colour for design is undoubted (Grossman Wisenblit, 1999; Ares and Deliza, 2010) and colour selection critical factor that can affect whether a design is successful or not (Adams, 2013). In this section, the general colour selection process of designers will be introduced and discussed.

2.2.3.1 General colour selection process

Designer's subjective selection based on experience.

Many papers have discussed the colour selection process and conclude that it is generally performed based on a designer's subjective ideas and experience (Hsiao, 1995), often without reference to theory or theoretical knowledge (Smith, 2002). In particular, Adams (2013) mentioned that colour is considered the most subjective element in design and that, therefore, colour presents inherent design challenges and opportunities for designers. Successful colour planning in design depends on the designer's experience and knowledge and its interaction on their own aesthetic view (Green-

Armytage, 2006; O'Connor, 2010). The aesthetic perspective of colour for a designer may vary between individuals and may be influenced by age, gender, affective states and cultural background (O'Connor, 2010). Thus, colour selection may depend upon a designer's aesthetic response to colour (Lang, 1992; Nasar, 1992; Ritterfeld, 2002: 369-386) and personal understanding of a brand, market, and target audience (Won and Westland, 2018). In practice, design knowledge or rules is mostly tacit, relying on personal subjective view or experience rather than formal documented design theory (Won and Westland, 2018). For example, designers could automatically select the colour, which is harmonious through knowledge acquired from experience or intuition (Wong and Radcliffe, 2000).

Making selections by considering colour associations.

The design process is a multifaceted activity that usually considers consumers, competitors, design categories and brand requirements, any or all of which may directly influence the result (Ambrose and Harris, 2011). Consequently, successful design is often highly dominated by various requirements for a designer. Even though the colour selection is subjective in general, colour associations (which include colour emotion, colour harmony and colour meaning), materials and trends in colour design may pressure designers to conform in their colour selections (Smith, 2002). Developing satisfying colour schemes that meet consumers' requirements, brands, and aesthetics is too complicated (Schmitt and Pan, 1994). Though Ulrich *et al.* (2008) suggested using qualitative methods such as questionnaires, interviews, or focus groups to demonstrate the design requirements and develop a design topic, selecting colour schemes according to the specific topic is still challenging (Shiba, 2001). Traditionally, it is recommended to choose the design colour by colour associations. For example, they sought colours by considering the colour meanings coincident with the product or brand meaning in packaging design (Won and Westland, 2016). Won (2017) also indicated that colour meaning is an essential aspect of colour selection that the designer needs to consider communicating the design idea or topic with consumers effectively. Ural and Yilmazer (2010)

presented: ‘Harmony of colour combinations is a major concern for colour designers.’ They pointed out that experienced designers often select colours quickly by colour harmony to create a pleasing colour scheme. Another study from Wei (2014) reported the same view in product design; it effectively makes positive emotional connections with consumers by selecting harmonic colours. Also, this step needs rich experience and knowledge and understanding of colour association in colour selection.

Traditional tools.

There are several traditional tools for colour selection that are available. For example, designers frequently use colour wheels and colour books or charts to plan specific colour schemes after they have a general concept of design colours by experience (MacDonald, 1990). For example, the colour wheel presents the relationship between different colours and illustrates the classification of colours (Figure 2-7). It has often been used to obtain a visual colour balance by colour harmony (Ambrose and Harris, 2005). Fisher and Zelanski (1999) and Feisner (2005) believe that interior designers mostly refer to colour wheels to select satisfying colours. Of the colour books or charts that often appear in the colour selection process, perhaps the best known is Pantone (Sutton and Whelan, 2017). However, in reality, the Pantone system is a colour communication tool that uses physical samples to specify colour and does not encapsulate colour relationships in the way that, for example, the colour wheel does.

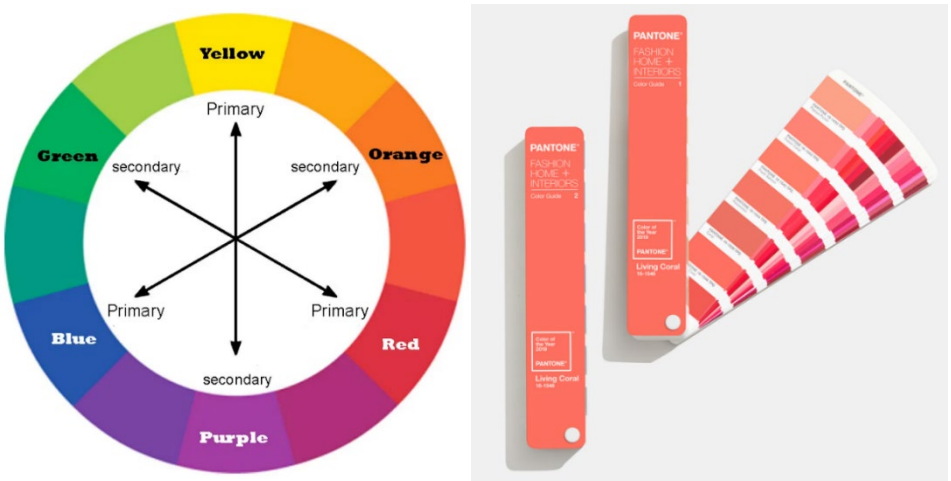


Figure 2-7 The colour wheel (left) and Pantone colour book (right).

2.2.3.2 Quantitative colour selection

Traditional colour selection processes have frequently been criticised. Hsiao (1995) pointed out that it is sufficiently subjective and inefficient when designers make colour decisions based on personal experience and knowledge. Moreover, aesthetic judgements of colour selections depend on the individual's value system, which cannot always be eligible or objective (Palmer, 2013: 77-107); this can be especially problematic for new design students (O'Connor, 2010).

Some researchers have explored methods to help designers to qualify their subjective views and selected colours. Ou and his colleague (2008) published the concept for a colour-design tool based on empirical studies. Based on several psychophysical studies from their previous work, which focused on semantic associations of colour, they introduced a tool to help designers to make colour decisions using principles of colour association and colour harmony (Ou *et al.*, 2004a; Ou *et al.*, 2004b; Ou and Luo, 2006). They provided a method of evaluation and testing selected colour schemes in terms of semantic associations (e.g. feminine/masculine or warm/cool) and colour harmony to help people obtain the desired colour's characteristic and categorise (Figure 2-8). That is evaluation of the colour requirement and making the colour decision by colour associations.

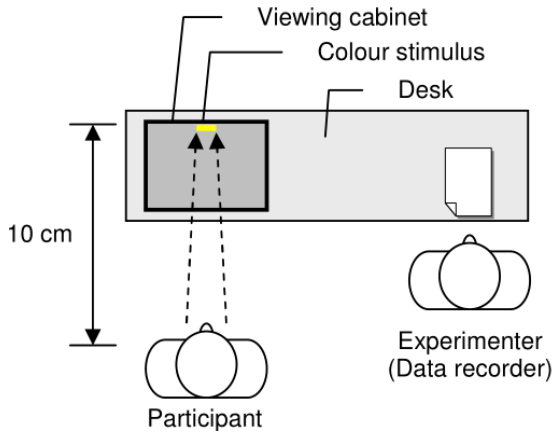


Figure 2-8 Every participant was presented with the 20 colour samples in a random sequence individually, and they were asked to rate each colour using 10 semantic scales: fresh-stale,heavy-light, warm-cool,clean-dirty, active-passive, modern-classical, hard-soft, tense-relaxed, masculine-feminine and like-dislike (Ou *et al.*, 2008).

Moreover, Hsiao (1995) explored a quantitative method for colour selections in product design conducted with fuzzy set theory. He explored a grey system method that evaluates the relationship between colours and users' perception by product image vocabulary (Hsiao, 1995). Ural and Yilmazer (2010) summarised an approach that rates colour harmony and colour emotions by semantic scales. Ding and Dong (2019) built a MEPCD system which is a product colour selection method. It also quantifies the emotional requirements and helps designers selecting satisfy design colours that meet the complex and varied dynamic requirements of consumers (Ding and Dong, 2019).

Overall, some researchers noticed the weakness of the traditional colour selection process and explored the specific method to improve and help the selection process quantify their subjective views. It is worth noting that most of the methods or systems are based on the quantification of colour association, such as colour emotion and colour harmony. Whether those methods could make contributions in colour selection, in reality, needs to be investigated thoroughly. Thus, colour associations will be discussed in the next section.

2.3 Colour Associations

It is established that strong associations exist between colours and concepts (Gage, 1999). When we are reminded of a specific object, a particular substance, a person, a period or a region by the stimulation of colour, this is sometimes referred to as colour association (Kress, 2002). The term 'association' refers to present a connection or cooperative link between someone or something (Oxford English Dictionary, 2015). Colour association expresses a specific relationship between colour and concepts or objects. Thus, the association is bidirectional, which includes from colour to idea or concept to colour.

In this section, colour associations will be discussed from two aspects: from colour to concepts and from concepts to colour. Besides, there is evidence that colour associations vary with culture (Aslam, 2006; Jacobs *et al.*, 1991) and presented in the end.

2.3.1 The Associations from Colour to Concepts

Dorcus (1926) published that colour could be associated with specific objects. For instance, blue is related to the sky, red colour is associated with ripe berries and fruits, and brown is associated with faeces and rotten fruit (Gage, 1999). The use of colours to symbolise ideas has been evident in art since the Renaissance, if not earlier (Gage, 1999; Lamb & Bourriau, 1995). On the other hand, colour can also associate with feelings (Gothe, 1970). It is considered that people associate blue with calming, depressing, peaceful, quiet, serious, and nostalgic (Goanga, 1912); associate yellow with serene, gay and softly exciting (Goethe, 1970), or warm and sunny (Weizbicka, 1996); associate green with envy, red with passion, black with death, yellow with cowardice, blue with loyalty etc. (Caivano, 1998).

Many academic studies in the 20th Century investigated these relationships (Xin *et al.*, 1998), which have sometimes been expressed as colour emotions (Ou *et al.*, 2004), sometimes said in terms of semiotics (Kauppinen-Räisänen & Jauffret, 2018) and sometimes described of colour meanings or colour harmony (Won, 2015).

2.3.1.1 Colour Emotions

It has been noted that some authors conflate the term colour association with the term ‘colour emotion’ (Sato *et al.*, 2003; Ou *et al.*, 2004). Colour emotion is a critical factor that can evoke the attractiveness response, and human colour emotion affects preference (Chan and Andrade, 2010). Colours or colour combinations evoke corresponding feelings such as excitement, energy and calmness (Ou *et al.*, 2003). This is sometimes referred to as colour emotion. Colours emotions are triggered by learned

associations or shaped by nature. Likewise, Tofle *et al.* (2004) also claimed that emotional responses evoked by colour are an outcome of learned associations based on culture and individual-related features. Cherry (2015) has explored the link between colour and mood. Cool colours are linked with the attitudes as calm, serene and comfortable. Conversely, warm colours are relevant to stressful and exciting moods. According to Hemphill (1996), bright colours are linked with positive emotions like happiness, joy and hope. Likewise, Elliot and Maier (2007) consider more brilliant colours as friendly, cultured, pleasant and beautiful. Conversely, dark colour is associated with negative emotions like boredom and sadness (Camgöz *et al.*, 2002).

To explore the practical significance of colour emotions in the design process, generating colour-emotion scales is extensively studied. Based on earlier studies introduced by Osgood et al. (1957), Ou et al.(2004) used the semantic differential method to categorize many single-colour emotions scales into smaller groups. According to their literal meanings, ten colour-emotion scales were crudely categorized into three groups, as shown in Table 2-4. Based on the categoriation, in Ou's colour emotion study, they used ten bipolar colour-emotion scales and required each participant to select a special rate from the emotion scales for each set of sample colours. Besides, this method also carried out in a cross-culture study to make a comparison between different cultural groups.

Table 2-4 The list of three primary factors identified by *Ou et al.* (2004)

Three primary factors identified	Colour emotions
Evaluative factors	Clean – dirty
	Fresh – stale
	Like – dislike
Potency factors	Heavy – light
	Hard – soft
	Masculine – feminine
Activity factors	Warm – cool
	Modern – classical
	Active – passive
	Tense – relaxed

Subsequently, six colour-emotion scales (happiness, showiness, forcefulness, warmth, elegance, and calmness) were derived from 48 colour-emotion scales (Wright and Rainwater, 1962). They suggested that hue's influence on colour emotions was smaller than lightness and chroma by analysing three colour-appearance attributes. Furthermore, four factors, colour-emotion scales: impact, usualness, evaluation, and warmth, were identified from 12 colour-emotion scales by principal component analysis (Hogg, 1969). Kobayashi (1981) provided three main dimensions of colour-emotions: warm-cool, soft– hard, and clear– greyish in his “colour image scale” study. Ou *et al.* (2013) developed four colour-emotion scales: warm-cool, heavy-light, active-passive and hard-soft, evaluated from ten colour-emotion scales. These are concluded in Table 2-5.

Table 2-5 The series studies of colour emotion scales.

Researchers	Colour-Emotion Scales
Wright and Rainwater (1962)	Happiness Showiness Forcefulness Warmth Elegance Calmness
Hogg (1969)	Impact Usualness Evaluation Warmth
Kobayashi (1981)	Warm–cool Soft– hard Clear– greyish
Ou et al. (2013)	Warm-cool Heavy-light Active-passive Hard-soft

2.3.1.2 Colour Semiotics

It is indicated that the colour can associate different feelings on a semantic level (Darrodi, 2012). For example, a red-orange environment may increase the sense of warmth (yellow though red-purple are warm), whereas green-blue expresses a sense of coldness (yellow-green though purple is cold) (Lüscher, 1976). Another example is that in many respects, pink is a sign of girls, and blue is a sign of boys. Specifically, it is widely acknowledged that colour is a powerful visual signal which communicated the ideas from designers to others (Milton, 1991). Caivano (1998) also mentioned that one of the main functions of colour is as a sign. The term signal or warning is included in the field of semiotics, also known as semiology (Monmonier, 1985). Therefore, colour semiotics mean colour plays a sign to signify or represent other objects or concepts, transmitting information, meanings, and conceptions (Caivano, 1998). Colour is an essential semiotic resource mode and is multifunctional in information communication (Kress, 2002).

Darrodi (2012) described the generalities of colour semiotics into three levels of representation: 1) in the pragmatics level of colour, colour has the function on physiology and psychology effects to influence men's wellbeing behaviour in the natural and cultural environment; 2) In the semantics level of colour, colour acts as a sign to represent or signify other things, to transmit the meanings, information and conceptions beyond themselves; 3) in the syntactic level of colour, it acts as a dictionary of colour to represent many different colour order system, which has variable for the identification and the definition of all possible.

2.3.1.3 Colour Meanings

According to Elliot and Maier (2007), colour may generate associations and responses, and they take the meaning of colour as bipartite. It is well known that one of the fundamental properties of colour is information imparting. Thus, colour meaning has been widely involved in the design field (Won and Westland, 2017). In some case, "meaning" may represent a kind of mental stimulation (Osgood *et al.*, 1957). Seahwa (2014) definitions colour meaning

in her research: “Colour meaning is not about combinations that create adequate responses (colour harmony), not about the processes with which people understand and react to colour (colour perception), and not about liking a particular colour among alternatives (colour preference). Instead, it is concerned with the meanings that are associated with certain colours.”

Colour meanings are likely to derive from multiple sources. For example, social-economic conditions may have led to purple being associated with luxury items and cultural behaviours almost certainly shown to pink and blue being associated with females and males, respectively (Koller, 2008). Indeed, it has been suggested that colours per se (that is, without context) have no meaning and that the meanings that colours are associated with are derived, for example, from their use in culture and commerce (Grieve, 1991). It has been suggested that social groups that share common purposes around colour are often relatively small and specialized compared to groups who share speech or visual communication (Kress and Van, 2006). From this, there would be extensive differences in colour meanings between different social groups, and there is some anecdotal evidence for this (Gage, 1999). For example, in the UK (and in many western societies), the colour green is associated with good luck (Crozier, 1999; Adams and Osgood, 1973). Note that the association is cognitive rather than emotional. Green may communicate colour to a consumer but might not necessarily make them feel lucky but may be necessary for a design context. However, in China, it is the colour red (not the colour green) associated with good luck (Tao *et al.*, 2016; Kommonen, 2011). Several such cultural differences will be introduced in the later section (Section 2.3.3).

Many academic studies summarized the general colour meaning. For example, a survey of different colours represents are mainly located in the context of North America. With the expansion of North American culture, interpreting colour meanings worldwide have been alternated and shown a tendency of convergence. The colour meanings identified in North America are presented in Table 2-6.

Table 2-6 The list of colour meanings of ten primary colours.

Colour	Meanings	Effects
Red	Energy, action, desire, low, passion	Stimulating, exciting, motivating, attention-capturing, assertive, aggressive
Orange	Adventure and risk-taking; Social communication, interaction, friendship	Enthusiasm, rejuvenation, Simulation, courage, vitality, fun, playful
Yellow	Mind, intellectual; happiness and fun, communication of new ideas	Creative, quick decisions; anxiety; Producing; critical; non-emotional ; Light, warmth motivation
Green	Harmony, balance, growth, hope, wealth, health, prestige Serenity	Rejuvenation, nurturing; dependable Agreeable diplomatic, possessiveness; envy
Blue	Communication, peace and calm; honesty, authority, religion, wisdom	Conservative; Predictable; Trustworthy, trustworthy, secure, responsible
Purple	Inspiration; imagination, royalty, mystery, nostalgia, individuality	dignity Empathy; controlled emotions Impractical Respectable
Pink	Unconditional love; compassion; nurturing; hope, girlish	Calming; non-threatening; Affectionate
Gray	Neutrality; compromise, control	Indecision, detached, depression, unemotional
White	Innocent, pure, new beginning, equal, unity, fairness	Impartial; rescuers, futuristic, clean, efficient, soft noble
Black	Black mystery; power and control; prestige; value; timelessness; sophisticated Formal, dignified and sophisticated	Formal, dignified and sophisticated Depressing Pessimistic

2.3.1.4 Colour harmony

Colour harmony has a wide range of meanings, but it could be briefly described as when colours are viewed together and aroused adequate affective responses (Judd, 1952; Burchett, 2002). It has been accepted in art and design (Westland *et al.*, 2007). For example, using harmonic colours in

product design is an effective way to create positive emotional connections with consumers (Wei *et al.*, 2014). In particular, colour is differentiated by hue, brightness and saturation (Ogden et al., 2010). In terms of shade, colours can be categorized into warm colours (e.g. orange and red) and cool colours (e.g. violet, blue). Brightness and saturation are also significant in colour perception. Brightness plays an essential role in determining the lightness or darkness of the colour; saturation suggests purity of colour. For example, it was found that colour is much more pleasant with enhanced attributes (Camgöz et al., 2002).

Colour harmony is an indispensable part of colour research, and many researchers have tried to define it. In 1975, Judd described it as “when two or more colours seen in neighbouring areas produce a pleasing effect, they are said to produce a colour harmony.” Subsequently, Granville (1987) argued that colour harmony is a kind of colour usage that pleases people and mentioned some quality relation between colour preference and colour harmony. Hope and Walch (1990) thought colour harmony is difficult to define and describe because harmonies are subjective, and it is evidenced that formulating or establishing absolute rules for harmony is impossible. However, the human eyes and brains are efficient and sensitive in colour, responding and creating colour harmony. Birren (1985) agreed that it is hard to use rules or laws to measure colour harmony. The reason is that colour harmony is an uncertain concept that many factors could influence. Three different factors have been concluded by Judd and Wyszecki (1975), the size of the absolute and relative colour covered areas, the shape of elements, and the meaning of the objects.

However, some researchers have tried to categorise colour harmony. Ou and Lou (2006) mentioned two categories of colour harmony: the interrelationship between colours and the orderly arrangement of colours. Based on the interrelationship between colours, the condition of colours could harmonize the colours under the similar hue, lightness or chroma as mentioned by Goethe (1970), Chevreul (1839), Moon and Spencer (1944),

Albers (1975), and Chuang and Ou (2001). They also argued that colours could harmonize based on the orderly arrangement of colour when the object was coloured overlapping chose systematically from a hue circle.

Caivano (1988) provided three forms of colour combinations, “interiority”, “overlapping”, and “juxtaposition”. The first one is that colour is applied inside or over anther; the second one is two colours beside each other; the third one is two colours overlap each other partially. There are shown in Figure 2-9.

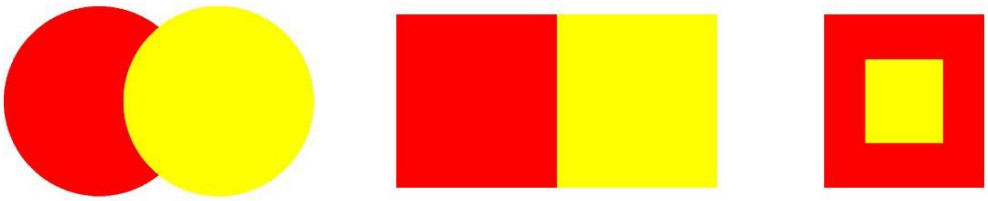


Figure 2-9 Three forms of colour combinations (Caivano, 1998)

Moreover, five kinds of colour harmony have been recently described (Rikard, 2015): direct harmony, split complementary, triadic harmony, analogous harmony, tetradic harmony (as shown in Figure 2-10).

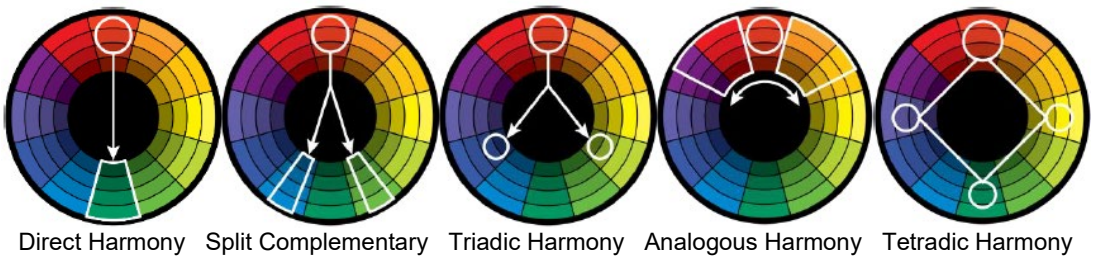


Figure 2-10 Five type of colour harmony (Rikard, 2015)

2.3.2 The Associations from Concepts to Colour

As presented in the previous section, colours are associated with ideas, concepts, meanings, emotions and so on (Grieve). The colour associated is often discussed as a single relationship from colours to concepts, such as colour emotion and colour meaning (Ou *et al.*, 2004). However, the colour association is bidirectional, representing the relationship from colour to

concept or concept to colour due to the essential meaning of the term ‘association’ (Oxford English Dictionary, 2015). For example, melancholy is often associated with colour blue (Adams and Osgood, 1973).

In particular, the colour associations could be divided into two levels which is concrete and abstract colour associations (Goethe, 1970; Karen and Stephen, 2011). For instance, there are well-known colour associations for specific objects, such as the sky is often associated with blue, strawberry with red, or cognitively, females and males associated with pink and blue, respectively (Koller, 2008). In terms of abstract colour associations, some evidence is widely used, such as lucky or auspicious always using the colour red to present in some Asian countries (Martell, 2020; Yau, 1994); luxury visual environment often created by using a large area of colour golden or black (Baek *et al.*, 2018).

Such associations are essential for successfully applying colour in product design, advertising and marketing (Ares and Deliza, 2010). As mentioned in the previous discussion (Section 2.2.3), colour selection is generally performed based on a designer’s subjective idea and experience (Hsiao, 1995). According to colour associations, designers picked an appropriate colour scheme that conforms to the design topic (Smith, 2002). Many design processes begin with a brief, and it is here where concepts that define the intended design originate; in these situations, the designer seeks colours that can represent or communicate these concepts (Won and Westland, 2018), which is from ideas to colour.

However, it is noticed that relatively little research has been carried out on the colour associations from concepts to colours. Despite this, there is a wealth of literature that has explored the associations from colour to ideas. Significant contributions have been made by Xin et al. (1998) and by Ou *et al.* (2004) in many experiments that typically have used semantic differential scaling or categorical scaling as investigative techniques. With these methods, participants are shown colours (either physical samples or colours

on screen). They are asked to indicate the strength of the association of the colour about two bi-polar terms (such as maleness and femaleness) in the case of semantic differential scaling or the strength of the association with a single term (such as maleness) using a fixed-number discrete scale in the case of categorical scaling. Whilst these methods provide valuable data and have produced some models that allow the associations of any colour to be determined (about the limited number of terms used in the experiments), they are not easy to apply in a design context. In part to address this issue, the colour association research from concepts to colour is imperative.

2.3.3 Cultural Effects of Colour Association

Some studies have discussed colour associations among different cultures, and the cross-cultural difference in colour associations have been identified (Philbrick, 1976; Trueman, 1979). Colours may differ because of dependence on lighting conditions, observation position and surrounding, especially the adjacent colour (Osgood, 1973). All these factors can shape the ways of perceiving a specific colour. Moreover, even when people are exposed to the same colour, how they perceive colour, and the meanings and emotions of the same colour, are different among people due to gender, age, educational and culture, childhood association and others (Scott-Kemmis, 2013).

Osgood and his partners (1973) have carried out related research across 20 countries. They chose high schools and asked them to rate seven (red, orange, yellow, green, blue, black and white) colours for 12 semantic differential items. The results analysed using scaling used “evaluation, potency and activity” as reference. The products were broadly similar for the 20 countries; blue was the most highly evaluated colour, green and white followed; black and red were the most potent colours; the most active colour was red, whereas grey and black were the most passive colours. In 1991, research indicated some differences and similarities in four cultures (Japan, China, South Korea, and the United States). The students from those four countries were asked to summarize the most closely colour associated with

13 words which are often used in describing objects from eight sample colours. As a result, red was associated with love and blue with high quality for all four cultures. Black was consistently associated with powerful and expensive. In contrast, purple associations showed a sharp difference between three Asian countries (Japan, China and South Korea) and the United States. In the three Asian countries, purple was associated with expensive products, while in the United States, purple represents typically inexpensive.

Colour meaning is the nonnegligible term in cultural effect discussion. The meanings linked with colours are sometimes different in different cultures. Thomas (1999) explored cross-cultural similarities and dissimilarities in colour preferences and colour meanings associations in six areas (Austria, Brazil, Canada, Colombia, China and the United States). In his results, green, white and blue were consistently associated with “calming”, “peaceful”, and “gentle” in all six countries. Green, white and blue were also associated with “pleasant” (Austria, Colombia, United States, and to a lesser extent China) and “beautiful” (Brazil, China and United States). However, those three colours also represent unique meanings separately in different countries while sharing the meanings in the research. No absolute universal meanings can therefore be attributed to specific colours. Moreover, “Spectrum of Colour Meaning”, which is a colours pattern forming a spectrum of meaning, is evident among those countries has been presented (as Figure 2-11 shown).

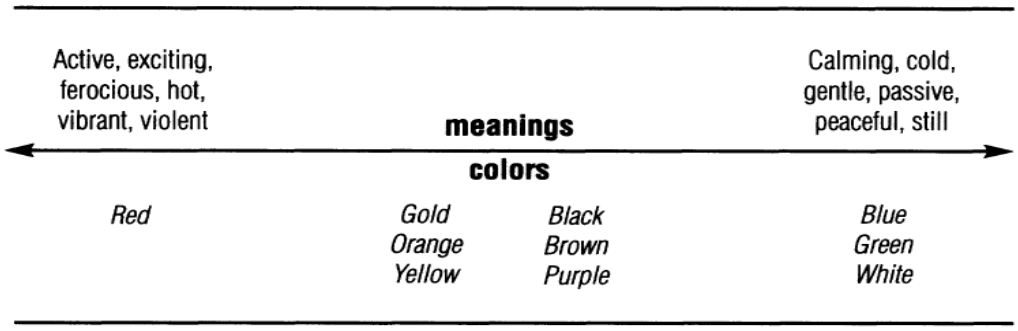


Figure 2-11 Spectrum of Colour Meaning (Thomas, 1999)

Their research evidenced that green, white and blue share similar meanings and are all well-liked in the eight areas; red and black shows a difference in many cases and still with a high liking rating (the results shown in Table 2-8).

Table 2-8 Similarity in Meaning Between Colour Pairings (Thomas, 1999)

Area	**Green**	**Red**	**Blue**
Austria	Similar	Similar	Similar
Brazil	NA*	Dissimilar	Similar
Canada	Dissimilar	Similar	Similar
Colombia	Similar	Dissimilar	NA
Hong Kong	Similar	Dissimilar	Similar
PRC	Dissimilar	Dissimilar	Similar
Taiwan	Dissimilar	Similar	Similar
United States	NA	Dissimilar	Similar

*NA=not applicable

In summary, colour association are complex and multifaceted. It is noticed that there is a rich history of work in the cultural effect of colour associations. However, the discussion of the cultural influence on the colour association is incomplete. These works are always analysis the colour association from colour to concepts. In reality, the research on the cultural effect of colour associations from concepts to colour is absent and imperative, especially for designers.

2.4 Conclusions

This chapter aims to build up an understanding of colour in design and colour association. First, basic colour theory, which involved science and design of colour research, was introduced. Then, it also covers three key topics:

- ***The role of colour in design and the colour impact;***

In terms of the significance of colour in design, several prior studies have identified. Colour influenced the visual design elements and emotion transmission as an essential and irreplaceable part of the design.

- ***The colour selection process;***

Colour selection is a critical part that decided whether a design is successful or not. Surprisingly, many research indicated that this process is subjective based on a designer's personal views and experience. The designers integrated and considered the design requirements and plan colour scheme according to colour associations.

- ***Investigation of colour association;***

Colour association is a primary colour concept with a long history (since the 20th Century). It usually discussed as the relationship from colour to other related concepts, such as colour emotion or colour meaning. However, another side from specific concepts to colour is rarely explored. Relatively little research has been carried out on this topic.

Thus, some critical views are produced based on the overview of the related literature. First, it is worth noting that the designers considering in reality, select colours from the design topic or requirements by colour associations, which is from specific topic or concepts to colours. On the contrary, the general recommended and frequently-used colour selection such as colour meaning, colour harmony, or colour emotions is typically from colours to concepts (emotion, meaning, harmony).

Although some researchers noticed the colour selection process's weakness and explored the specific methods to improve the selection process by quantifying their subjective views, it is worth noting that those research used colour emotion, colour harmony and so on, such topics still focused on the single colour associations which are from colour to concepts.

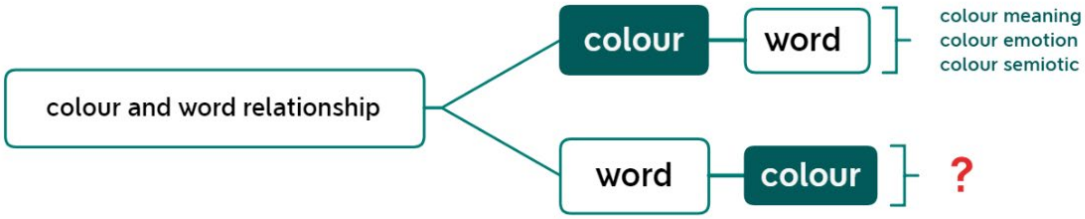


Figure 2-12 The discussion of colour associations

In the colour of theoretical research, it is also noticed that the colour associated is often discussed as a single relationship from colours to concepts (Figure 2-12). However, the colour association is bidirectional, representing the relationship from colour to concept or concept to colour due to the essential meaning of the term ‘association’ (Oxford English Dictionary, 2015). For further research, it is necessary to pay more attention to this side and explore the associations from specific concepts to colour.

Chapter 3
Research Methodology

In Chapter 2, some fundamental concepts and definitions about colour and design were reviewed. It was argued that colour association has a bidirectional character in which associations can be 'from colour to concept' or 'from concept to colour'. It was noted that relatively little research had been carried in terms of concept-->colour. Thus, this research focused on investigating the associations from concept (specific word) to colour. This chapter outlines the research methodologies and describes the research plan and data collection approaches for conducting this study.

3.1 Introduction

It is essential to select an appropriate methodology or research design before starting the main work (Robson, 2011). The research methodology was stated as a data collection tool and analysis that addresses the research aim and identifies the critical elements of the research (Blaikie, 2000).

To select an appropriate research methodology, the first thing to consider is the research purpose: the source and reason of the research (Harmon *et al.*, 1999) and the types of knowledge that are to be produced (Blaikie, 2000). Blaikie (2000) classified research purpose as *exploration*, *description*, *explanation* or *prediction*. Table 3-1 briefly summarises these four types of research purpose.

Table 3-1 The four types of research purpose (Blaikie, 2000).

Type	Descriptions
Exploration	➢ Find out what is happening when knowledge about the topic is very little. ➢ Explore new insight. ➢ Collect new ideas and hypotheses. ➢ Adopt flexible methods.

Description	➢ Attempt to find out what will happen or in which way. ➢ Build an accurate account for some phenomenon, characteristics or attitude for an issue. ➢ Require previous research and knowledge, which narrowly defined focus, can be investigated.
Explanation	➢ Find out the causes of events or regularities and to provide ➢ causal explanations. ➢ Identify the factors or element to explain why particular regularities occur.
Prediction	➢ Predict what might happen in a later situation. ➢ Use previous knowledge to postulate certain conditions.

The research strategy is another essential component in research design. It provides logical methods to address the research aim (Remenvi *et al.*, 2003). Case (2008) stated it as simply, 'how to find out. Research strategy can also be classified into four types: *inductive*, *deductive*, *reproductive* and *abductive* (Blaikie, 2000). The way to consider research strategy is *quantitative* (including inductive and abductive research strategy) or *qualitative* (including deductive and reproductive research strategy). Specifically, the quantitative research method focuses on testing theories or hypotheses through statistical analysis (Creswell, 1998). On the other hand, the qualitative research method focuses on exploring subjective ideas and formulating theories or hypotheses through summarising, categorising or interpreting (Tracy, 2019). Table 3-2 presents a summary of these ideas about research strategy.

Table 3-2 Research strategies (Blaikie, 2000).

Types of strategy	Research category	Aim	Approach
Inductive	**Quantitative**	- Established the description of characteristics.	Collecting data or observation, summarization, build the laws to explain further observations.

Deductive	**Qualitative**	- Test the previous theories; - Find out the false information and support the correct information.	Modelling a theory, deducing hypotheses, testing the ideas.
Retroductive	**Quantitative + Qualitative**	- Discover and explain observed regularities through the previous theories.	Constructing a theory, modelling a hypothesis of a mechanism, building a simple mechanism by observation.
Abductive	**Quantitative + Qualitative**	- Describe and explain social life through social actors (motives and accounts)	Observing and discovering lay concepts, meanings and motives from daily life, producing a technical account from the lay account, developing a theory.

Overall, in the general research process, the main steps of the research design might be:

- Identifying the research purpose (the source and reason of the research, what is the research question);
- Selecting the research strategy (the specific method and theory, quantitative or qualitative or mixed);
- Following the research purpose and strategy, determine the specific data collection and data analysis methods;
- Concluding the results.

In this thesis, the research design followed these steps to adopt an appropriate research strategy and methodology.

3.2 Research Design

After discussing the general research design process in section 3.1 and considering previous published colour associations studies, specific research strategies and methodologies were designed for this research. This section contains three parts: developing the research strategies and methods, the research design framework, and developing the experimental methods.

3.2.1 Adopting the Research Strategies and Methodologies

This research focuses on exploring colour associations from word to colour in the design. Deductive method and inductive method have been selected to explore or build theories according to several specific research purposes. Both quantitative and qualitative research methods have been employed to collect quantitative and qualitative data in this research. Table 3-4 presents the research design (including research purpose, research methodologies, aim and research activities).

Specifically, in the discussion of word→colour associations:

- The first step is laying out the meaning and the reason for this research (the meaning and application of word→colour associations in design);

- In the second step, exploration and deductive this topic is feasible (evidence strong associations exist from word to colour);

- In the third step, description and inductive the characteristic of the research object (collecting and summarising the characteristics of word→colour associations);

- In the last step, prediction the influencing factor of the research object (exploring the cultural influence of word→colour associations).

Table 3-3 Research Design for this thesis.

Research purpose	Research strategy	Categories	Aim	Research activities
Description	***Deductive***	Qualitative	- To explore the general colour-selection process in design. - To find out the meaning and application of word→colour associations in design.	**Interviews** *(Chapter 4)*
Exploration	***Inductive*** ***Deductive***	Quantitative Qualitative	- To test whether strong associations exist from word to colour. - To find out which type of words associated with colour stronger and useful in colour-selection of design.	**Laboratory Experiment** **Online Survey** *(Chapter 5)*
Description	***Inductive***	Quantitative	- To describe the characteristic of word→colour associations.	**Laboratory Experiment** *(Chapter 6)*
Prediction	***Inductive***	Quantitative	- To explore the cultural influence of word→colour associations.	**Laboratory Experiment** *(Chapter 7)*

3.2.2 The Research Design Framework

Five research activities have been undertaken; an interview, an online survey and three laboratory experiments carried out in separate studies. Studies 1-4 are described in Chapters 4-7, respectively. A four-step framework was developed to complete this research, and this is presented in Figure 3-1.

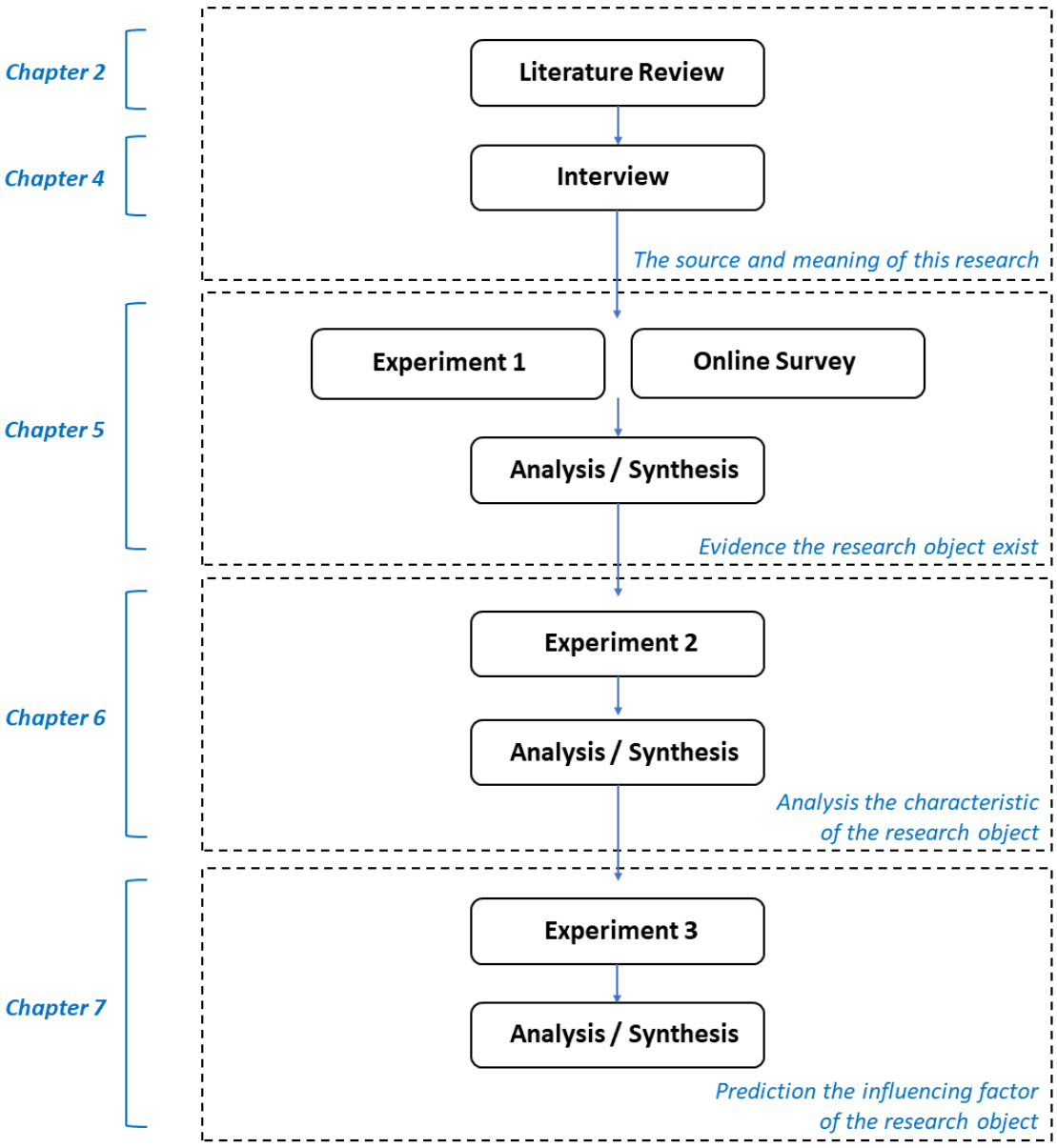


Figure 3-1 The framework of the research

3.3 Experimental Methods and Configuration

In this section, the experimental methods and configuration, data collection and analysis methods are presented.

3.3.1 Qualitative studies – Interview & Online survey

3.3.1.1 Interview

A semi-structured interview method was carried out, in a one-to-one interview format, to investigate the virtual process of design and identify the colour-selection method used by designers. This process also explored the practical significance of word-colour associations in design.

Interview Type. Structured interviews, semi-structured interviews and unstructured interviews are the three main types of interviews (Robson, 2011). For semi-structured interviews, the list of questions also needs to be prepared, but it is flexible, and any valuable extended information could be included. The semi-structured interview approach was chosen in this research to collect an in-depth understanding from designers, and the comprehensive response (Muratovski, 2015:61) will be included following the research structure.

Participants. Due to understanding designers and their design process, the target participants must have design working experience and a design educational background. Guest *et al.* (2006) suggested that six participants are sufficient for an interview study to collect valuable data. Since this study involves three groups of designers (junior, intermediate and senior), eighteen participants were deemed appropriate. A total of twenty participants were used for this interview. The number of participants is relatively low, but the data are augmented by a later study (an online survey with one hundred participants).

Data coding method - Grounded Theory Method. Grounded theory is a common and popular social science method to theorise qualitative data since Glaser and Strauss first published this method in 1967 (book: 'The Discovery of Ground Theory'). In this research, this method was used to help build the main idea or explain a theme from the research data (Saunders *at*

el., 1997:398). Nvivo 12, a qualitative data analysis software tool, was used to code the text data. More details are presented in Section 4.4.1.

3.3.1.2 Online Survey: Questionnaire

An online survey (questionnaire) was conducted to collect ideas from a design point of view: Specifically, this explored which types of words are usually used in design to select colours. To integrate the results with the psychophysical experiment and indicate the characteristic of practicable words as the concept keywords in colour-selection of design. Besides, it also provides more data to support the interview study.

Survey type. Saunders (1997) suggested that the questionnaire is an efficient data collection method for gathering responses from many participants. A questionnaire study was selected in this research to collect more responses from designers. A self-administered questionnaire method was chosen instead of an interviewer-administered approach because of the requirement of a relatively large number of participants (Saunders *at el.*, 1997:282). A web-based questionnaire was used over postal or other types due to the higher response rate and faster completion (Robson, 2011). Several websites exist that provide questionnaire collection. Google Forms was selected as the data collection tool.

Participants. This study focuses on collecting many responses from designers. Thus, the target participants had design working experience or a design educational background. The research took two months to collect responses, and in total, one hundred responses were gathered in this study. The participants were from different countries and different design disciplines.

Data collection. The online questionnaire was distributed as a link and available on the mobile phone, computer, or any other electronic equipment to simplify the survey procedure. A short introduction to the survey was

provided, and the five questions followed. Without any contact with the researcher, each participant could complete the questionnaire by themselves in a fast and efficient way.

3.3.2 Quantitative Studies - Psychophysical Experiments

This research developed a new methodology to explore colour associations from concept or word to colour directly. Based on this method, three psychophysical experiments were carried out to collect quantitative data: Experiment 1 (Chapter 5), Experiment 2 (Chapter 6) and Experiment 3 (Chapter 7).

3.3.2.1 Experiment Method Developing

The methodological approach of most previous research has been to start with a colour and to ask participants, for example, the extent to which the colour represents maleness or femaleness, often using a semantic differential scale (e.g. Ou *et al.*, 2004a; Ou *et al.*, 2004b; Ou *et al.*, 2004c; Won & Westland, 2017). Often bi-polar (opposite) terms such as warm and cool are used, and participants use a slider bar in a graphical user interface to indicate their response to colour for these terms. In this research, similar psychophysical experiments were employed, but the problem is reversed; in that participants are shown a word and asked to select related colours for that word which is from word to colour.

However, the colour association is not a one-to-one relationship. For example, the colour meaning is not a unique concept, and one colour might be. In the experiments, participants were asked to choose the three most related colours for each given the word. In the experiments, participants were asked to select the associated colours for each sample word. The display part of the design required the development of a GUI, and this was done by writing MATLAB code for the experiments. (Figure 3-2, the example of the GUI for the experiments).

Figure 3-2 The GUI for the experiments

3.3.2.2 Experimental Samples

In this research, the experiments were started with specific words and collected related colours of the sample words from participants.

Experiment 1. The main aim of this study is to explore whether strong associations exist from word to colour. The terms used in the experiment should be general and universal. Thus, different classifications of words were included in the experiment. In consideration of the motivation of participants and the experimental length, 70 target words were selected, which consisted of 7 classes (with ten words for each category): ‘concrete noun’, ‘abstract noun’, ‘proper noun’, ‘verb’, ‘adjective’, ‘adverb’ and ‘function word’.

Experiment 2. It was indicated that adjectives are the strongest word-class associated with colours and are recommend as practicable words in helping the colour-selection process of design in the previous study. Thus, adjectives are the appropriate choice as the samples in exploring the characteristic of associations from word to colour due to the strong associations of adjectives with colours. Thirty adjectives were employed as the sample and were translated into Chinese to enable a cultural analysis

(the British participants viewed English words and the Chinese participants viewed Chinese words).

Experiment 3. To compare with Experiment 2, this study employed the same 30 adjectives as the experimental sample words. However, this experiment focuses on comparing the difference between the two cultural groups. As in Experiment 2, they were displayed in English and Chinese.

Table 3-4 Summary of experimental details.

	Number	**Categories**	**Display**	**Name lists**
Experiment 1	N=70	7 classes*	In English	Table 5-2
Experiment 2	N=30	Adjectives	In English and Chinese	Table 6-2
Experiment 3	N=30	Adjectives	In English and Chinese	Table 7-2

**7 main word classes: 'concrete noun', 'abstract noun', 'proper noun', 'verb', 'adjective', 'adverb' and 'function word' (10 words for each class).*

3.3.2.3 Data Collection and Analysis

In the three experiments, quantitative data were collected in each experiment. The participants were asked to select related colours for each sample word. For each word, the related colour data were gathered together as a colour palette. Their RGB values defined the colours displayed and collected in the experiment. However, it was necessary to convert the data to CIELAB value since these are recommended for subsequent colour-difference calculations (McDonald, 1990; Witt, 1995). After each experiment, all the selected colour patches were measured by Konica Minolta CS-2000 spectroradiometer one by one. Each colour data was transferred to CIELAB value from RGB value by measuring spectral radiance from the display (and using the white display point in the calculations).

Several statistical analysis methods were carried out. Table 3-5 includes a brief description of the methods used in the data analysis of the experiments. More details of data analysis are presented in the later chapters.

Table 3-5 Quantitative Data collection and analysis.

	Data collection	Data analysis	Method
Experiment 1	**70 Related colour palette** Each palette includes 90 related colours for each word (30 participants x 3 colours)	calculating the colour similarity of each colour palette.	- Pearson Correlation Coefficient
Experiment 2	**30 Related colour palette** Each palette includes 90 related colours for each word (30 participants x 3 colours)	- calculating the colour similarity of each colour palette; - analysis the characteristic of each palette.	- Pearson Correlation Coefficient - K-Means Clustering Analysis
Experiment 3	**60 Related colour palette** Each palette includes 45 related colours for each word (15 participants x 3 colours)	- calculating the colour difference between British and Chinese result palette of each word; - analysis the characteristic of cultural difference	- CIELAB - K-Means Clustering Analysis

3.4 Overview of the research methodology

This chapter has introduced the research design and methodology that was developed for this research. Both quantitative and qualitative research methods have been carried out to collect quantitative and qualitative data. Table 3-4 presents an overall summary of the research design (including research purpose, research methodologies, aim and research activities). Figure 3-1 shows the framework of the research. Essential to the research methodology, four studies were carried out in this research in the following chapters.

Table 3-6 Overview of the research methodology

Research activities	Data collection	Data analysis	Purposes	Chapter
Literature analysis	Secondary resources	Qualitative analysis	To identify the research purpose and research questions	***Chapter 2***
Interview	Semi-structured interviews	Qualitative analysis	To investigate the virtual process of design and identify the colour-selection method of designers; To found out the practical significance of word-colour associations in design which indicated the research source and meaning.	***Chapter 4***
Experiment 1	Word-colour associations experiment	Quantitative analysis	To explore whether strong associations exist from words to colours; To identify whether noticeable differences of associations exist from different types of words to colours.	***Chapter 5***
Online survey	Online questionnaire	Qualitative analysis + Quantitative analysis	To indicate which classification of words were normally used in design to select colours; To integrating the results with the psychophysical experiment and indicate the characteristic of words which are practicable as the concept keywords in colour-selection of design; To provide more supplementary information to support the interview study.	
Experiment 2	Word-colour associations experiment	Quantitative analysis	To analyse the characteristic of the association from word to colour.	***Chapter 6***
Experiment 3	Word-colour associations experiment	Quantitative analysis	To discuss whether the specific cultural influence of word and colour associations by different cultures; To analyse the characteristic of the cultural influence in word and colour associations	***Chapter 7***

Chapter 4
Study 1: Methods used by designers to choose colour

4.1 Introduction

The literature review about colour in design in Chapter 2 revealed that colour plays an irreplaceable role in most design fields and has long been considered an essential design element in art and design over at least five centuries (Ambrose and Harris, 2005). The crucial role of colour for design is undoubted (Grossman and Wisenblit, 1999), and colour selection is often a critical factor that can affect whether a design is successful or not (Adams, 1987). Colour selection is the process by which a designer selects colours for a particular design solution. Although many design process studies and design theories have been presented, in reality, designers rarely follow standard rules (Bengtsson, 2013:89); the design process is often more like a form of personal self-expression. The type of approach that designers use in their careers depends on their personal preference, experience and educational background (Muratovski, 2015:2-3); for example, it has been suggested that colour used in architecture is influenced by the designer's prejudices towards colour use and their level of colour education (Motamed and Tucker, 2018). Some studies have explored the relationship between colour use and the design process more generally (Smith, 2002). Thus, in this chapter, the focus is on how designers choose a colour within the context of their design practice and explore through an interview study.

This chapter employs a semi-structured interview approach in a one-to-one interview format to investigate the process of design and designers' colour-selection methods. Both quantitative and qualitative data are collected. Twenty designers were interviewed from different design areas, working experience, age groups, cultural background, and workplaces around Korea, China, South Africa, Mexico, and the United Kingdom.

New research data about designers' working processes is presented in this work. It is important to note here that the design category was not restricted while recruiting the participants because it focuses on collecting data in the general design process and colour-selection methods. Of course, it remains possible that nuances could exist in the processes used in specific design fields. Also, cultural differences were not considered. Note, however, that all participants/designers had Western design knowledge (they all had Western education background), and the majority of them had been involved with multinational projects (especially involving Western countries) in their career.

This chapter consists of five sections. Section 4.1 summarises the main content of the chapter. Section 4.2 outlines the research questions, objectives and presents a framework for the work. Section 4.3 offers the research procedure. Section 4.4 shows the results and data analysis. Section 4.5 presents analysis and conclusions relating to the research question before generating insights for further research. Figure 4-1 is a visual summary of the research process.

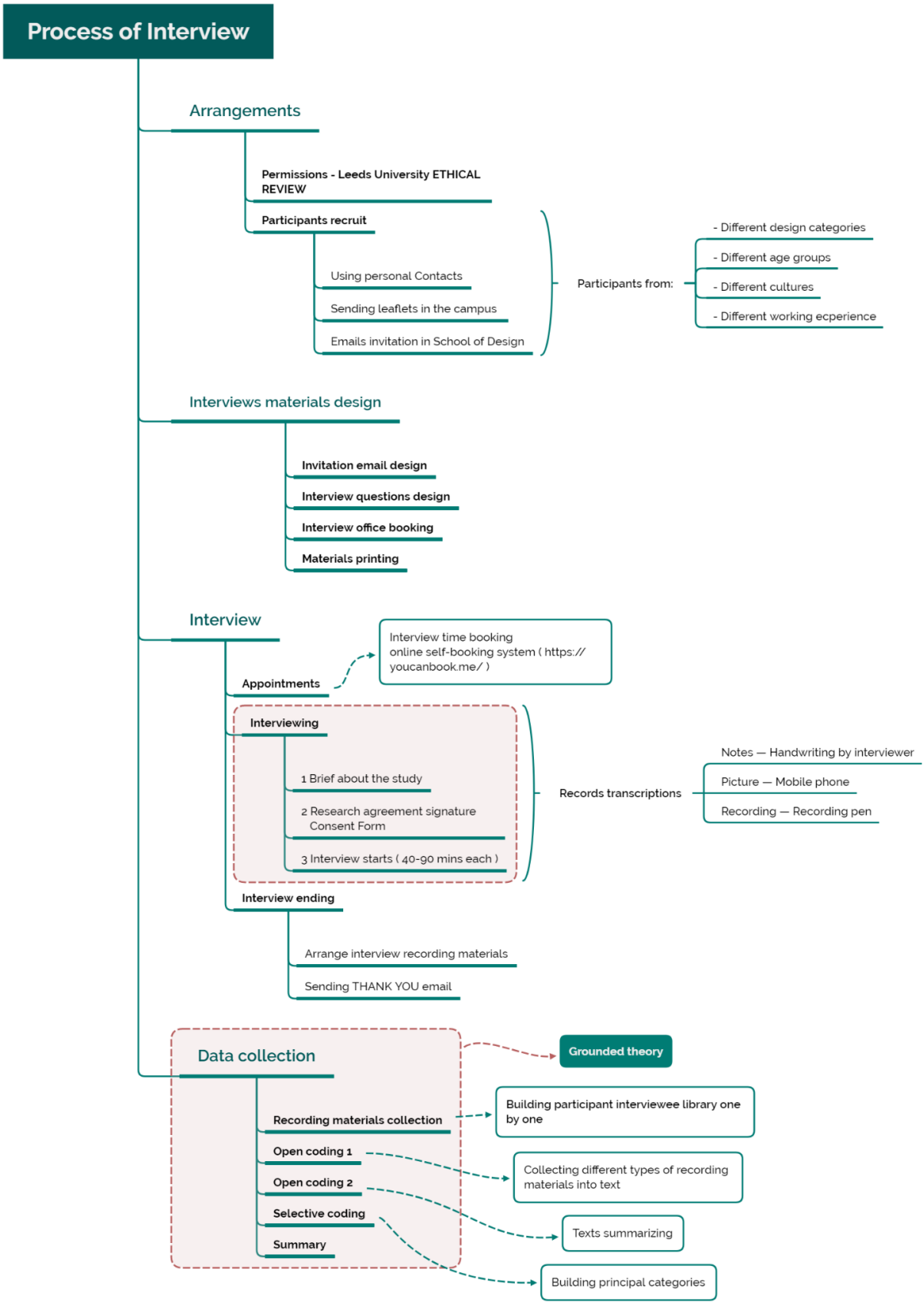


Figure 4-1 A visual summary of the research process

4.2 Research Questions and Objective

In this chapter, one main research question and three sub-research questions are considered (see Table 4-1). The research objectives are summarised according to the research questions: 1) to collect new data about the design process and colour-selection process for designers; 2) to understand whether colour decisions are difficult or not for different levels of designers; 3) to analyse the similarities in colour-selection by different designers; 4) to summarise a general method of colour-selection in the design process.

Table 4-1 Research questions for this study

Main research question	***Sub-research questions***
RQ 1: What is the general process of colour selection for a designer?	**RQ** 1.1: Is the level of difficulty in colour selection different for different levels of designers?
	RQ 1.2: What are the references when designers choose the colour?
	RQ 1.3: Are there any similarities in the colour selection methods of different designers?

4.3 Experiment Configuration

This chapter consists of four sections: data collection method, interview preparation, participant recruitment, and experimental procedure.

4.3.1 Data Collection Method: Interview

This work uses a semi-structured interview method, in a one-to-one interview format, to investigate the virtual process of design and identify the colour-selection method of designers. Both quantitative and qualitative data were collected in this study (see Table 4-2).

Table 4-2 Data collection method description

Research Method	***Type***	***Research Questions***	***Data***
		1.1: Is the level of difficulty in colour selection different for different levels of designers?	*Quantitative data*
Semi-structured interview	*One-to-one* *Face-to-face*	**1:** What is the general process of colour, choosing for a designer? **1.2:** What are the references when designers choose the colour? **1.3:** Are there any similarities in the colour-selection method of different designers?	*Qualitative data*

Structured interviews, semi-structured interviews and unstructured interviews are the three main types of interviews (Robson, 2011). Structured interviews use predetermined questions in a fixed order, and additional irrelevant conversation is not recorded. For semi-structured interviews, the list of questions also needs to be prepared, but it is flexible, and any valuable extended information could be included. Unstructured interviews are rarely used in information collection but can assist in consulting services (Mark *et al.*, 2011:246). The semi-structured interview approach was chosen in this study to collect an in-depth understanding from designers, and the extended response (Muratovski, 2015:61) will be included following the research structure.

A one-to-one interview format was selected rather than a group interview to understand the unique design process and colour-selection method for each participant. A face-to-face method was chosen; However, face-to-face communication has some limitations (the location is fixed, participant recruitment is usually from one city, etc.). The advantage is that participants

may be more cooperative than those engaged by telephone or other electronic media (Holbrook *et al.*, 2003).

4.3.2 Preparation of Interview

The interview consisted of two parts: a collection of participants' personal information (Q1~Q4) and the interview's main questions (Q5~Q12). Both parts were printed to record the interview notes. The research questions and aims were transformed into interview questions, as shown in Figure 4-2.

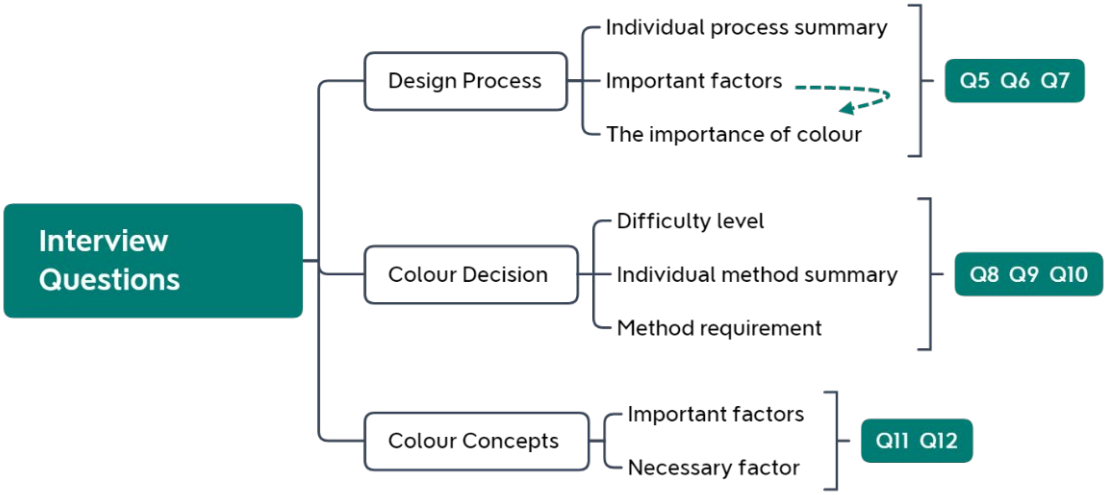
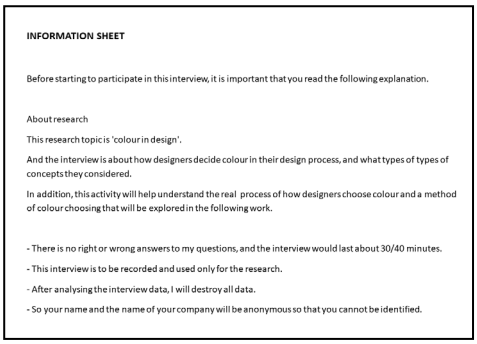
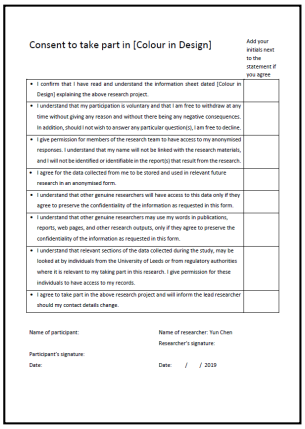
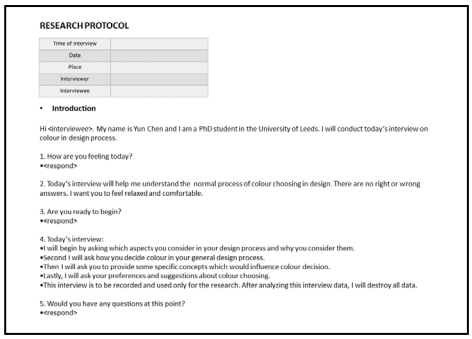
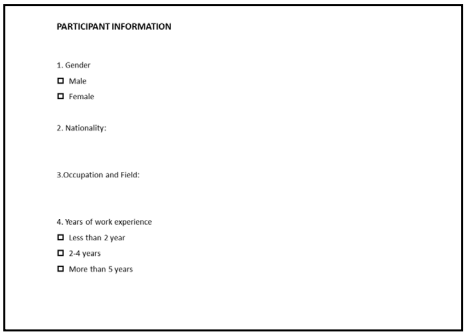
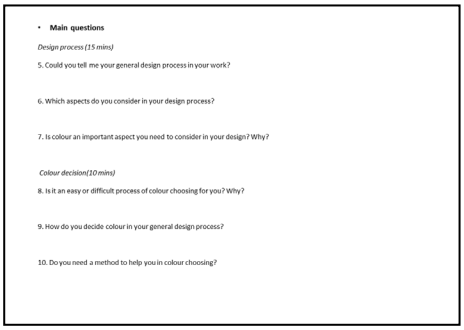
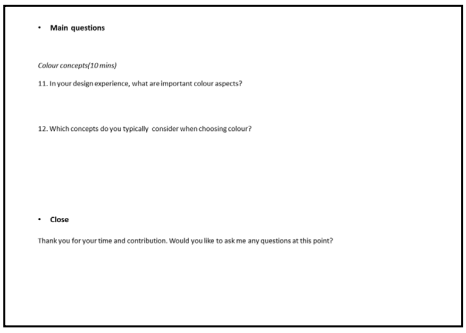


Figure 4-2 Description of interview questions

Fine details of the interview format were considered to optimise the interviewee experience; for example, the time dedicated for each question and the number of questions were considered. An initial pilot test was carried out to address this with two PhD students (each had a design background and were students at the University of Leeds). The final version of the interview contains two parts and twelve ordered questions. The structure of the interview sheet is described in Table 4-3.

Table 4-3 The structure of the interview sheet

Sheet Type	*Description*	*Sheet*
1. ***Cover***	The cover of the sheet includes the interview title, interview type and participant number. Each set of the sheet is one to one correspondence of each participant.	
2. ***Information sheet***	It presents the study's summary, showing the research objects and method, highlighting the secrecy and confidentiality clause of the interview data.	
3. ***Consent form***	It presents eight relevant clauses about the agreement of participating in this study. Each interviewee needs to read and sign. Otherwise, the interview would not be continued.	
4. ***Introduction***	This sheet includes interviewer self-introduction, warm-up questions. The purpose of this part is to make participants feel comfortable.	

5. ***Participants information***	This page presents four questions about the participant's information, gender, nationality, job field and design experience. The name and contacts are not included due to the secrecy consideration.	
6. ***Main questions***	It presents five questions divided into the "design process" and "colour decision" parts. It aims to understand the general design process and colour-selection method of the participant.	
7. ***Main questions***	It presents three questions divided into "colour concepts" and "colour-selection method requirement" part. To collect the main colour factors which they always considered in their design experience.	

4.3.3 Recruitment of Participants

The study focused on collecting from designers about their design process. The target participants were required to have design working experience and a design educational background. Guest *et al.* (2006) suggested that six participants are sufficient for an interview study to collect valuable data. Since this study involves three groups of designers (junior, intermediate and senior), eighteen participants would be appropriate. A total of twenty participants were used for this interview. The 20 participants were from different countries (seven from China, six from South Korea, four from the United Kingdom, two from Mexico and one from Africa). The profiles of interviewed designers are shown in detail (Table 4-4).

The recruitment of participants was through three approaches: 1) using personal contacts; 2) distributing leaflets on the campus (University of Leeds); 3) sending recruiting e-mails in the School of Design from the administration office (University of Leeds).

Table 4-4 Description of interviewed participants

Participants	***Years of design experience***	***Design areas***	***Countries***
1	More than 10 years	Graphic Design	South Korea
2	More than 10 years	Graphic Design	South Korea
3	More than 10 years	Service Design	South Korea
4	More than 10 years	Interior Design	South Korea
5	More than 10 years	Product Design	South Korea
6	More than 10 years	Product Design	Africa
7	More than 10 years	Interior Design	Mexico
8	5 – 10 years	Fashion Design	British
9	5 – 10 years	Fashion Design	Mexico
10	5 – 10 years	Information Design	British
11	5 – 10 years	Graphic Design	China
12	5 – 10 years	Product Design	China
13	5 – 10 years	Graphic Design	China
14	5 – 10 years	Product Design	China
15	Less than 5 years	Graphic Design	South Korea
16	Less than 5 years	Graphic Design	British
17	Less than 5 years	Product Design	China
18	Less than 5 years	Information Design	China
19	Less than 5 years	Information Design	China
20	Less than 5 years	Fashion Design	British

4.3.4 Experimental Procedure

All interviews took place in the PhD meeting room in the School of Design (University of Leeds). Each interview was generally around 40 – 90 minutes. The interview procedure is described below:

1) Setting up

Each interviewee received an introduction email which included the interview questions list and an information sheet (the description of interview aim, method and the use of data). The email also links to a self-booking system where the participant could easily select their interview time (*https://youcanbook.me/*).

2) Introduction

Each interview consisted of two personnel who are the interviewee and the interviewer (the researcher). The interviewer showed the information sheet and briefly summarised the interviewee's study before the primary interview started.

3) Agreement signature

A consent form was provided, which presents eight relevant clauses about the agreement of participating in this study. Each interviewee was required to read and sign. Otherwise, the interview would not be continued.

4) The main body of the interview

The interview followed twelve questions (Table 4-5). Each interview was audio-recorded with each interviewee's permission.

Table 4-5 Interview questions and the topic for each of these

	Questions	***Question Aim***
1	Gender (interviewer labelled)	*Personal information*
2	What is your nationality?	
3	What is your working field?	
4	How long have you worked in design?	
5	Could you tell me your general design process in your work?	*Design process*
6	Which aspects do you consider in your design process?	
7	Is colour an important aspect you need to consider in your design?	

8	Is it an easy or difficult process of colour choosing for you?	
9	How do you decide colour in your general design process?	*Colour decision*
10	Do you need a method to help you in selecting colour?	
11	In your design experience, what are important colour factors?	*Colour concepts*
12	Which concepts do you typically consider when choosing colour?	

4.4 Interview Results

4.4.1 Data Preparation and Analysis Method

Data coding method - Grounded Theory Method

In this study, the purpose is to understand the design process and, specifically, the colour-selection method that is used. Both quantitative and qualitative data were collected in the interview. Nvivo 12, a qualitative data analysis software tool, was used to code the text data. Grounded Theory Method is used in data organizing and helps build the main idea or explain a theme from the research data (Saunders *at el.*, 1997:398). There were five sequential steps of data organizing:

1) Recoding materials collection

The first step of data organizing is to build an interviewee-library for each participant. Collecting the participants' information and different types of recording materials into each interviewee-library correspondingly.

2) Open coding 1

The original data consists of audio recordings and handwriting notes for each interview. This step transcribed different types of recording materials into text with labels for each interview.

3) Open coding 2

Re-editing the text materials from the last step. Deleting the contents irrelevant to the subject and gathering any words or phrases related to design and colour.

4) Selective coding

Developed the principal categories and related subcategories according to the research aims (Figure 4-3). Coding the materials word by word, phrases by phrases into different types.

5) Summary

Summarising the coding data, planning the analysis method.

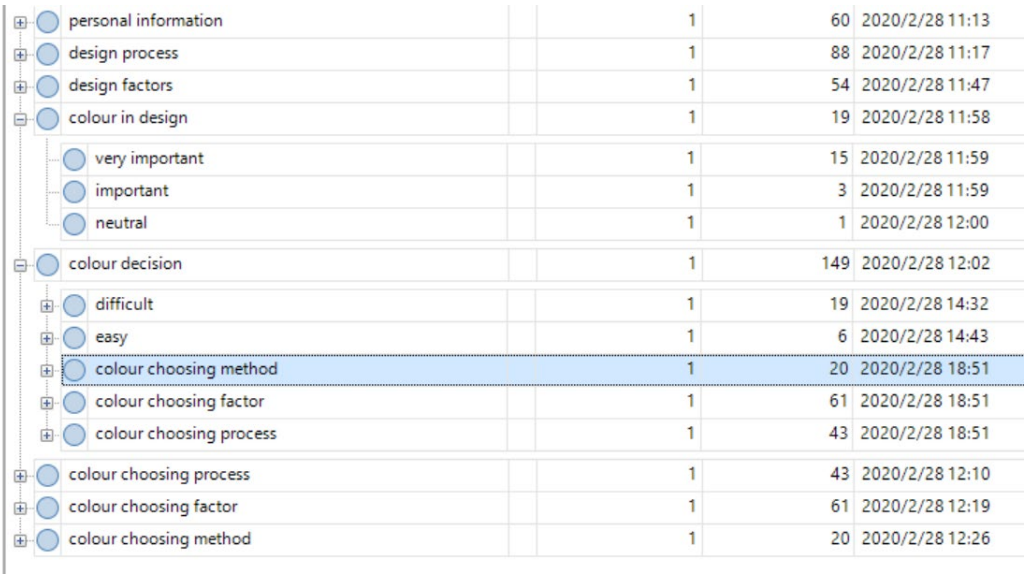


Figure 4-3 An example of the hierarchical coding scheme

Data analysis method – TF-IDF

In this study, most of the data is qualitative data. The TF-IDF statistical method was used to translate the qualitative data into an analytical visual result. TF-IDF stands for term frequency-inverse document frequency, and the TF-IDF weight is a weight often used in information gathering and text mining. This weight is a statistical measure method specialised for

evaluating the importance level of a word to a document in a collection or corpus.

In a target document, TF (Term Frequency) means the frequency of a specific word in the document. A word *i* in a document *j,* the number of times word *i* appears in the document *j* ratio to a total number of words (size) in the document, Eqn 3:

$$tf_{i,j} = \frac{n_{i,j}}{size\ (j)}$$

(Eqn 3)

IDF (Inverse Document Frequency) represents the general importance level. The IDF for a specific word *i* is divided the total number of documents *D* by the number of documents {j:ti∈dj} which containing the word, then taking the log of the result, Eqn 4:

$$df_i = log\frac{|D|}{|\{\text{j: ti} \in \text{dj}\}|}$$

(Eqn 4)

TF-IDF weight is multiplied by TF and IDF, Eqn 5:

$$w_i = tf_{i,j} \times df_i = \frac{n_{i,j}}{size\ (j)} \times log\frac{|D|}{|\{\text{j:ti}\in\text{dj}\}|}$$

(Eqn 5)

Therefore, the high frequency of the words in a particular file can produce a high-weight TF-IDF. In this study, all the results from 20 participants were organized together by each interview question. The high frequency of the words mentioned under each question was collected by measuring the TF-IDF weight. Then, the main opinions were summarised by the high-frequency words for each question.

4.4.2 Results

The main part of each interview contained eight questions (Q5 ~ Q12) which related to three topics:

1) Design Process
2) Colour Decision
3) Colour Concepts

4.4.2.1 Design Process

Question 5: Could you tell me your general design process in your work?

During the interviews, each participant described each step of their normal design procedure in detail. The answers were then organised into concrete steps by open coding 2. First, the number of design steps is collected: 15% of participants (N=3) reported using three steps; 45% participants (N=9) had four steps; 20% participants (N=4) had five steps, and 20% participants had more than five steps. In order to collect a general process from twenty interviewees, the data has been clustered by steps. Four steps clusters are collected. For the three participants who have three design steps, the first and second steps were categorized in step 1 and step 2, but the last step was categorized in step 4 instead of step 3 because the last step cluster in step 4. For the seven participants with more than four steps, the first step was categorized in step 1, and the last step was categorized in step 4, but the middle steps were categorized in step 2 and step 3 (Figure 4-4).

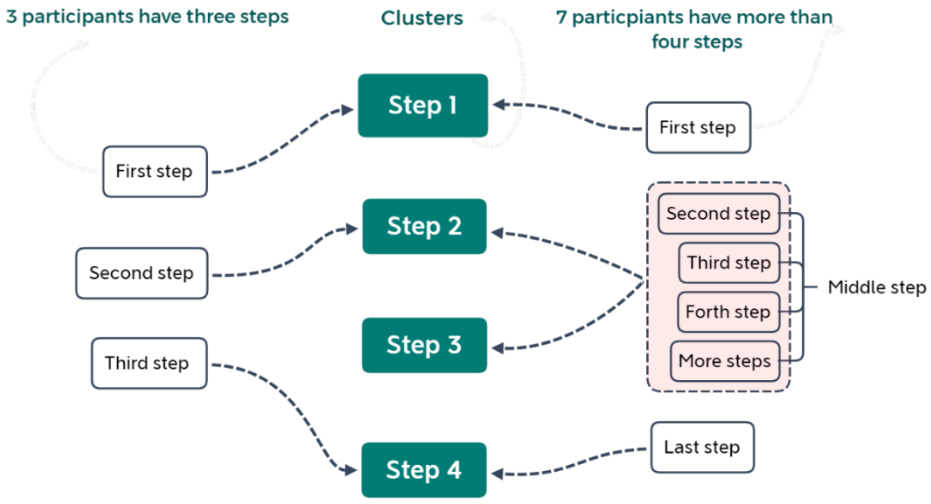


Figure 4-4 Four steps clusters categorize method

For the four clusters, the high-frequency words of each step were calculated TF-IDF weight. As Table 4-6, 4-7, 4-8, 4-9 show, the words list sorts by the weight value. The bigger the value, the more important word is, which means the words with high-value weight are representativeness in the cluster. According to the TF-IDF weight, the words which be marked in the tables are the typical words and represent the main idea of each step cluster.

Table 4-6 Word list of *Step 1* of design process

Step 1 of Design Process				
	Word	Frequency	Weight(%)	Associated items
√	*design*	11	16.18	concepts, planning, project
√	*requirements*	11	16.18	requirements
√	*collect*	10	14.71	collect
√	*topic*	8	11.76	topic
√	*decide*	7	10.29	decide
	consider	3	4.41	consider
	consumer	2	2.94	consumer, consumers'
	customers'	2	2.94	customers'

** Marked with √ are the typical words and represent the main idea of this cluster.*

Table 4-7 Word list of *Step 2* of design process

Step 2 of Design Process				
	Word	Frequency	Weight(%)	Associated items
√	create	20	21.26	build, create, decide, design, draft, reference
√	ideas	12	11.78	design, element, ideas, reference
√	design	12	8.62	design, draft
√	concepts	6	7.47	concepts, element
√	key	4	6.90	keywords
	collect	3	5.17	collect
	consider	3	5.17	consider
	experience	3	5.17	experience, testing
	personal	3	5.17	match, personal, technician

** Marked with √ are the typical words and represent the main idea of this cluster.*

Table 4-8 Word list of *Step 3* of design process

	Step 3 of Design Process			
	Word	Frequency	Weight(%)	Associated items
√	topic	21	17.19	topic
√	create	20	15.89	create, decide, design, draft, draw, project, reference
√	collect	16	9.38	collect
√	design	16	8.07	concepts, create, design, draft, idea, project
√	idea	14	7.16	design, element, idea, ideas, project, reference
√	draft	11	5.99	design, draft, drafting, draw
	competitors	5	3.69	competitor, competitors
	reference	5	3.69	identify, reference, related, research
	concepts	5	3.26	concepts, element, idea

** Marked with ✓ are the typical words and represent the main idea of this cluster.*

Table 4-9 Word list of *Step 4* of design process

	Step 4 of Design Process			
	Word	Frequency	Weight(%)	Associated items
√	design	9	14.06	concepts, design, show
√	create	7	10.94	create
√	idea	6	9.38	idea, ideas
√	choose	5	7.81	choose, preference
√	colour	5	7.81	colour
√	improve	5	7.81	improve
	consumers	4	5.25	consumers, consumers'
	draft	4	5.25	draft, drafts
	type	3	4.69	type

** Marked with ✓ are the typical words and represent the main idea of this cluster.*

‘Design’, ‘requirements’, ‘collect’, ‘topic’, and ‘decide’ are marked in the ‘Step 1 of Design Process’ table. According to the TF-IDF weight, those five words are the typical words and represent the main idea of the Step 1 cluster. Therefore, the main idea of step 1 could be: collecting the project requirements and deciding the design topic by the requirements. ‘Create’, ‘ideas’, ‘design’, ‘concepts’ and ‘key’ marked in the Step 2 cluster. The main idea of step 2 could be: collecting related design concepts or keywords to create design ideas. In Step 3 cluster, ‘topic’, ‘create’, ‘collect’, ‘design’, ‘idea’ and ‘draft’ was marked in the table. The main idea of step 3 could be: collecting ideas to create a design draft by the topic. ‘Design’, ‘create’, ‘idea’, ‘choose’, ‘colour’ and ‘improve’ are the typical words in the Step 4 cluster. The main idea of step 4 could be: improving the design ideas and draft and considering the design details, for example, design colour. As a result, the four steps design process were concluded as 1) topic decision; 2) related concepts; 3) ideas creative; 4) draft improvement (Figure 4-5).

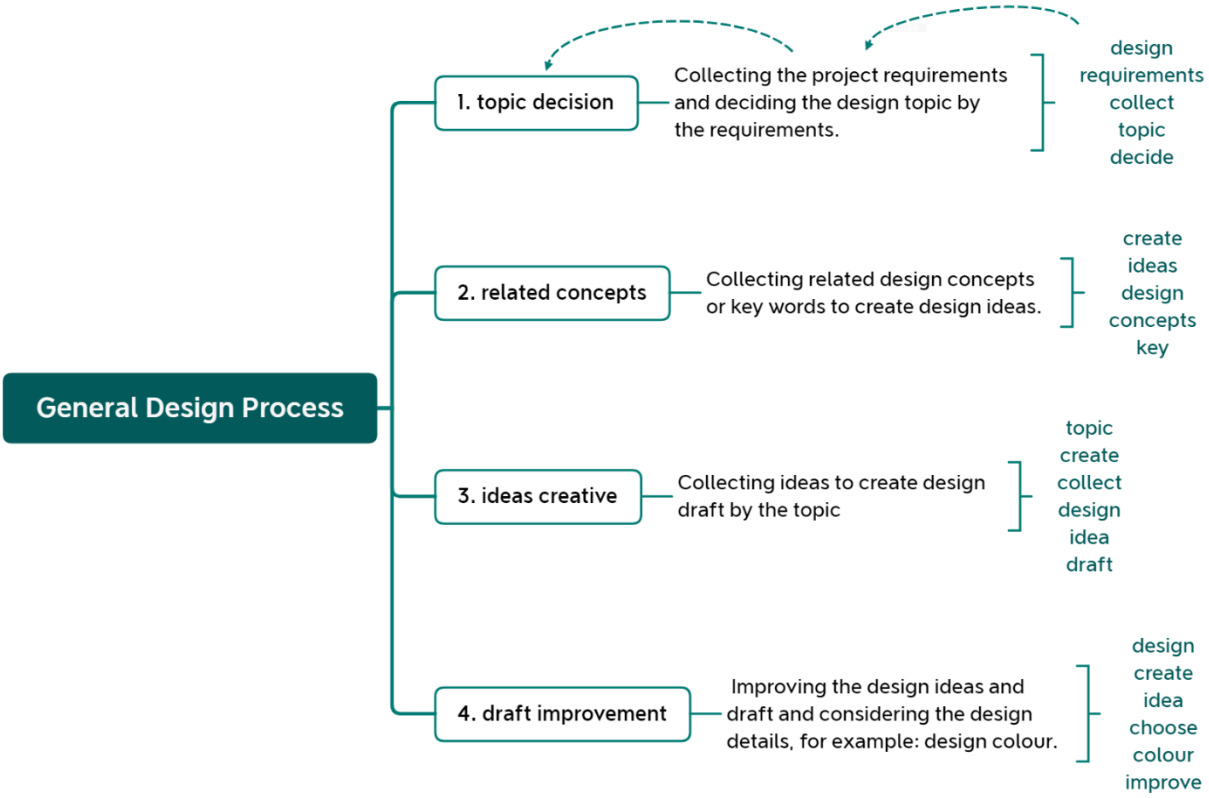


Figure 4-5 General design process summarised

Question 6: Which aspects do you consider in your design process?

The purpose of this question is to collect the main factors which designers usually considered and understand the essential factors for design. Therefore, the interviewer collected the main words mentioned during their answering and recorded the frequency of each word. TF-IDF weight was calculated as well. As the chat shows (Figure 4-6), 'Colour' was the highest frequency mentioned word, and with the highest weight value means colour is the most important factor during their design process. 'Design', 'topic', 'materials', and 'requirements' are the following. It represented the designers always considered the design topic, the materials and design requirements as well.

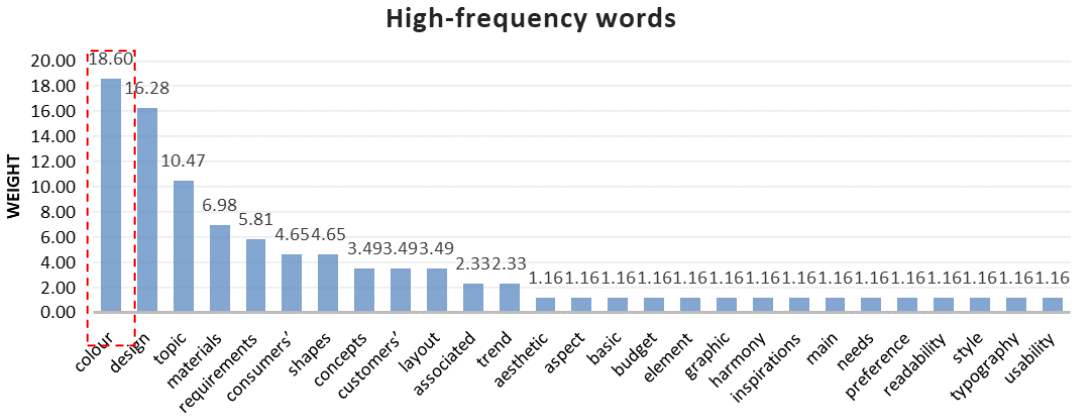


Figure 4-6 Words collection of the main factors which designers normally considered

Question 7: Is colour an important aspect you need to consider in your design?

This question is about the importance of colour as a factor in design. All participants responded that colour is an essential factor, and they always considered colour during their design process. The typical words ('design', 'colour', 'influence', 'directly', 'whole') that define the answers were collected (see Table 4-10) and represent the main idea: colour is a very important factor in design and could directly influence the whole design.

Table 4-10 The typical words of the answers.

	Colour Factor Important in Design			
	Word	Frequency	Weight(%)	Associated items
√	design	16	15.38	design, designer
√	colour	8	7.69	colour, colours
√	influence	8	7.69	influence, influenced, influences
√	directly	5	4.81	directly
√	whole	4	3.85	whole

**There are 57 words in total, it only presents the typical words in the table.*

** Marked with √ are the typical words and represent the main idea of this cluster.*

4.4.2.2 Colour Decision

Question 8: Is it an easy or difficult process of colour choice for you?

This question gathers ideas about whether colour decisions are easy or difficult. 30% of participants chose easy, and 70% of participants think it is not easy. The answers of their choice were collected, and the typical words were enumerated in Table 4-11 and Table 4-12 below. 'Colour', 'choose', 'concept', 'need', 'according to', 'design', 'experience' and 'material' were the represented words of 30% of participants' views which think colour selection is easy for them. Therefore, the main idea is: they could easily choose colour according to the design concept and materials or by their personal experience. In another group, 70% of participants think they had some difficulties when they chose colour. The typical words of their answers are 'colour', 'hard', 'find', 'choose', 'match', 'need', 'experience', 'topic' and 'understand'. It presents the main ideas: it is hard for them to choose the colour that matches the design topic by their experience.

Table 4-11 Word list of the answers of colour selection is easy

	Colour Decision – Easy			
	Word	Frequency	Weight(%)	Associated items
√	colour	7	20.59	Colour
√	choose	3	8.82	Choose
√	concept	4	8.82	concept, design
√	need	3	8.82	need, requirements
√	according	3	5.88	according
√	design	3	5.88	design, scheme
√	experience	2	5.88	experience
√	material	2	5.88	material, materials

**There are 18 words in total, it only presents the typical words in the table.*

**Marked with ✓ are the typical words and represent the main idea of this cluster.*

Table 4-12 The typical words of the answers of colour selection is difficult

	Colour Decision – Difficult			
	Word	Frequency	Weight(%)	Associated items
√	colour	14	12.28	colour
√	hard	11	9.65	hard
√	find	5	4.39	find, finding
√	choose	4	3.51	choose, choosing
√	match	4	3.51	match
√	need	4	3.51	need, needing
√	experience	3	2.63	experience
√	topic	3	2.63	topic
√	understand	3	2.63	understand

**There are 62 words in total, it only presents the typical words in the table.*

** Marked with ✓ are the typical words and represent the main idea of this cluster.*

Question 9: How do you decide colour in your general design process?

The aim of this question is to understand the process of colour-selection and to try to generate a general method that can represent this process. Participants introduced their normal approach to colour selection in detail, and the answers were organized into concrete steps by open coding 2. The number of steps is collected in the first: 20% participants (N=4) have two steps; 45% participants (N=13) have three steps, and 15% participants (N=3) have four steps. Similar to Question 5, the data has been clustered by steps, and three steps clusters are collected. For the four participants who have two design steps, the first steps were categorized in step 1, but the second step was categorized in step 3 instead of step 2 because the last step cluster in step 3. For the three participants with four steps, the first step was categorized in step 1, both the second and third steps were categorized in step 2, and the fourth step was categorized in step 3. Then, the high-frequency words of each step were calculated TF-IDF weight (Tables 4-13, 4-14, 4-15).

Table 4-13 Words list of *Step 1* of Colour Decision

Step 1 of Colour Decision				
	Word	Frequency	Weight(%)	Associated items
√	design	9	16.36	concepts, design
√	topic	9	16.36	topic
√	collect	5	9.09	collect
√	requirements	5	9.09	requirements
√	decide	4	7.27	decide
√	analysis	3	5.45	analysis
	consumers'	2	3.64	consumers'
	experience	2	3.64	experience
	trend	2	3.64	trend

** Marked with ✓ are the typical words and represent the main idea of this cluster.*

Table 4-14 Words list of *Step 2* of Colour Decision

	Step 2 of Colour Decision			
	Word	Frequency	Weight(%)	Associated items
√	related	10	11.72	associations, element, reference, related
√	collect	7	10.94	collect
√	decide	7	10.94	choose, decide, preference
√	concepts	6	9.64	colour, concept, concepts, element
√	design	6	8.33	concept, concepts, design, refer
√	topic	6	7.81	topic
	meaning	5	4.77	design, meaning, refer, reference
	materials	5	4.25	colour, materials

** Marked with √ are the typical words and represent the main idea of this cluster.*

Table 4-15 Words list of *Step 3* of Colour Decision

	Step 3 of Colour Decision			
	Word	Frequency	Weight(%)	Associated items
√	colour	18	26.87	colour
√	choose	16	23.88	choose
√	meanings	9	13.43	based, meaning, meanings, thinking
√	experience	6	8.96	experience
	personal	3	4.48	personal
	related	3	4.48	associate, related
	according	2	2.99	according
	concepts	2	2.99	concepts
	match	2	2.99	match

** Marked with √ are the typical words and represent the main idea of this cluster.*

The typical words were collected for each step. ‘Design’, ‘topic’, ‘collect’, ‘requirements’, ‘decide’ and ‘analysis’ were marked in Step 1 of colour-selection (Table 4-13), which shows the main idea is: collecting and analysis

the requirements and choosing a topic. In the Step 2 cluster(Table 4-14), ‘related’, ‘collect’, ‘decide’, ‘concepts’, ‘design’ and ‘topic’ were marked. The main idea of Step 2 is: collecting the related concepts according to design topic. ‘Colour’, ‘choose’, ‘meaning’ and ‘experience’ are the represented words in Step 3 of colour-selection (Table 4-15). They present the main idea is: According to the personal experience to choose colour by colour meanings. As a result, the three steps of the colour-selection method were concluded to be: 1) topic decision; 2) related concepts; and 3) colour selection (see Figure 4-7).

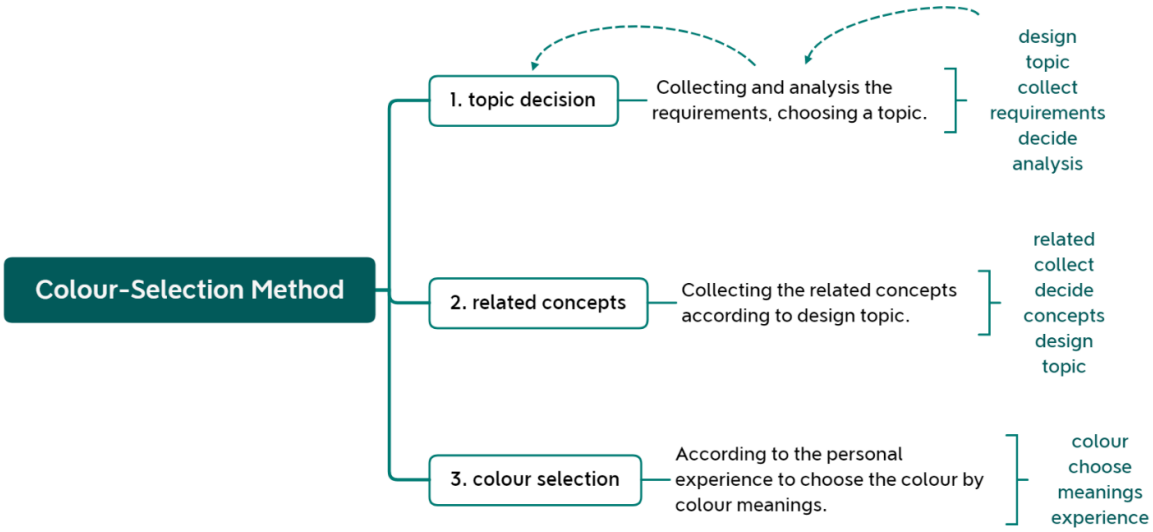


Figure 4-7 Three steps colour-selection method

Question 10: Do you need a method to help you in selecting colours?

This question enquires whether designers need a normative method to help them choose colour. Most participants (N=17) said they need a method to help them, but a minority of participants (N=3) said they did not require such a method. The reasons for their choice were collected, and the typical words were presented below (Table 4-16 and Table 4-17). ‘colour’, ‘design’, ‘give’, ‘help’ and ‘suggestions’ represent the reasons of they require a method and the main idea is: they need a method to give them suggestions and help them choosing colour. Only three participants responded that they did not require a method.

Table 4-16 The typical words of the reasons of the method is required.

Colour-Selection Method Requirement - Y				
	Word	Frequency	Weight(%)	Associated items
√	colour	8	10.00	colour
√	design	7	8.75	concept, design, designer, designers
√	give	7	8.12	give, gives, make
√	help	4	5.00	assist, help, helpful
√	suggestions	4	5.00	suggestions

**There are 39 words in total, it only presents the typical words in the table.*

Table 4-17 The reasons of the method is unrequired.

Colour Choosing Method Requirement - N	
Participant	Main ideas
1	He/ She prefers choosing colours from the inspirations and personal experience.
2	A normative method would influence his/her thinking.
3	A method would limited his/her thinking, it is better to use different ways to choose colour.

**Only three participants.*

4.4.2.3 Colour Concepts

Question 11: In your design experience, what are important colour factors?

The purpose of this question was to collect the main colour factors which they usually considered. Therefore, the main words which be mentioned with high frequency were collected from their answers. As the chat shows (Figure 4-8), ‘colour’ and ‘meaning’ were the highest frequency mentioned words and with highest weight value, which means colour meaning is the most important colour factor. Also, ‘brightness’, ‘harmony’, ‘material’, ‘preference’, ‘aesthetics’, ‘consumers’ and ‘saturation’ were mentioned.

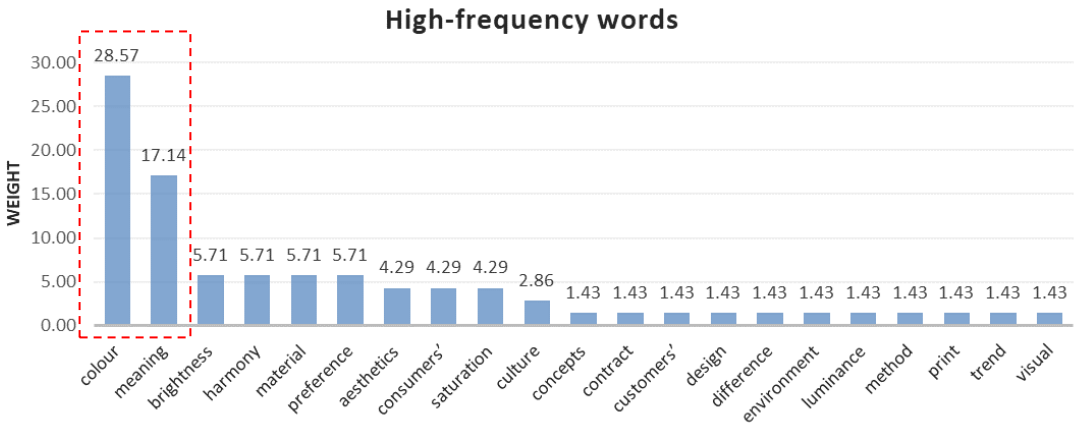


Figure 4-8 Words collection of the important colour factors

Question 12: Which concepts do you typically consider when choosing colour?

Following question 11, this question requested participants to choose one factor which they think is the most important factor that influenced their colour selection. The main words were collect (Figure 4-9). Obviously, colour meaning is the most frequent factor that they considered and influenced their colour selection.

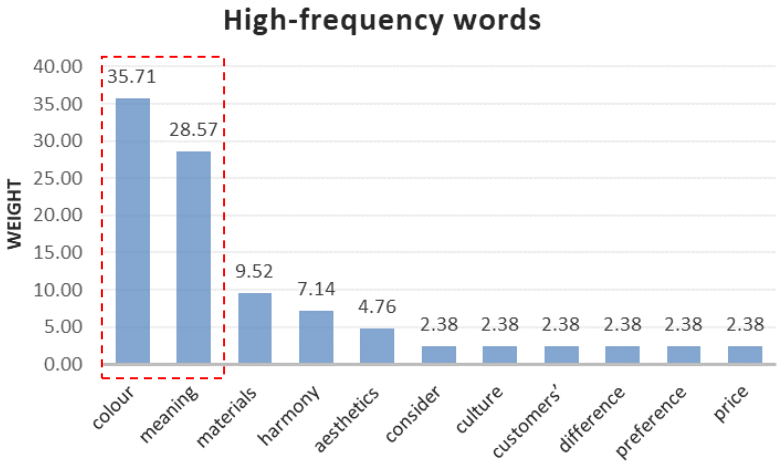


Figure 4-9 Words collection of the most important colour factor

4.5 Discussion and Conclusion

Some studies have explored the relationship between colour use and the design process generally (Smith, 2003). However, in this study, the focus is on understanding the design process and how designers choose colour within the context of their design practice. It is explored through an interview study to collect new research data from the designers and gathering the ideas from their routine design work.

4.5.1 Key Insights

First of all, this study summarised a general design process from the designers. Even though the participants were from different design areas and had varying design experience, some obvious similarities in their design process were identified. Four steps were identified in the design process: 1) topic decision; 2) related concepts; 3) ideas creative; 4) draft improvement. It was also evident from the study that colour is the most critical factor during the design process, and that colour directly influences the whole design. Some research has identified that colour is considered relatively late in the design process (Pile, 2007). However, the findings in this study are more consistent with other findings that colour is considered by designers at all stages in the design process from the very beginning (Attiah *et al.*, 2014). It is possible that a more detailed analysis involving many more participants might reveal differences in this regard between different design disciplines, but such an analysis was not possible using the number of participants upon which this study was based.

In the following, the process of colour decisions is investigated. The colour selection process was gathered in a straightforward method. Twenty designers described their personal approach, but the answers carried many associations and could be summarised as a three-step-method: 1) topic decision - collecting and analysing the requirements and choosing a topic; 2) related concepts - collecting the related concepts according to the design topic; 3) colour selection – choosing colours based on colour meanings and

according to personal experience. Also, this study collected some related information on colour selection. From the participants' view of practical design work, it is not easy for most of them (70%) to choose design colours and select appropriate colours to match the design topic is the hardest step for them (RQ1.1). They usually chose colour according to the design concept and colour meaning by their personal experience. Colour meaning is the most important colour factor they considered during the colour-selection process (RQ1.2)(RQ1.3).

Therefore, this study was further evidence that the importance of colour also indicated that they might face the difficulty of colour selection for a large proportion of designers. Thus, the three-step-method could provide a clear and effective idea of choosing colour, especially for the junior designers or the people who do not have design background. Besides, based on this three-step method, the colour-selection process is the process from a specific concept to colour (Figure 4-10). That is, finding associated colours for specific concepts or design topic which is based on colour association.

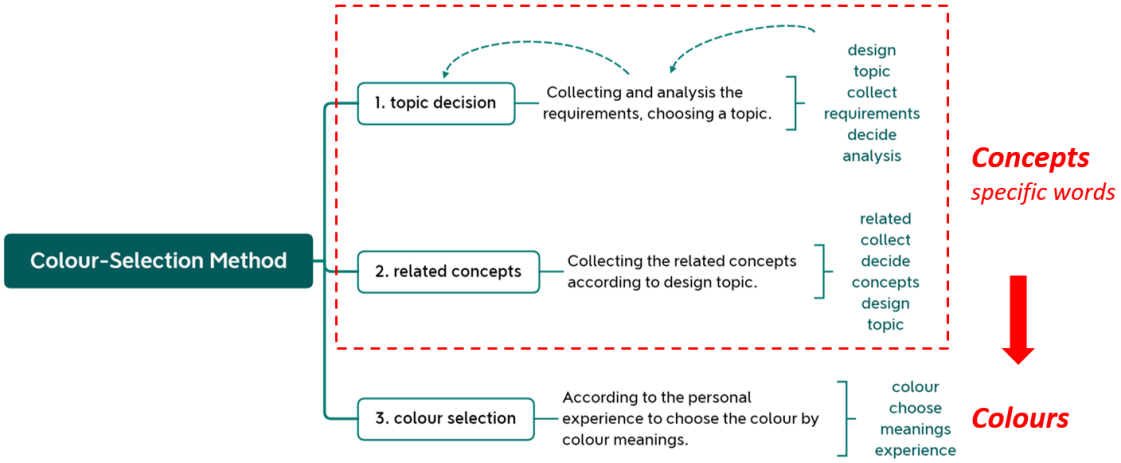


Figure 4-10 The analysis of the three-steps colour selection method

Colour association is not an unknown concept in colour research. It is established that strong associations exist between colours and concepts (Gage, 1999). The term ‘association’ refers to present a connection or

cooperative link between someone or something (Castree *et al.*, 2013). Colour association expresses a specific relationship between colour and concepts or objects. The colour associated is often discussed as a single relationship from colours to concepts, such as colour emotion (Ou *et al.*, 2004) and colour meaning (Elliot and Maier, 2007). However, colour association is bidirectional, representing the relationship from colour to concept or concept to colour due to the essential meaning of the term ‘association’ (Castree *et al.*, 2013). This indicates colour association which from concept to colour, is important and deserves further investigation.

4.5.2 Next Steps

In this study, a general method for selecting colours was summarised, consisting of three steps: topic decision – related concepts – colour selection. It is presented that the colour-selection process is the process from a specific concept to colour (Figure 4-10). Besides, selecting the appropriate colours to match the design concept was identified as the hard step for the designers. Thus, the colour association from specific concepts or topics to colours is a critical part of colour selection and design. Understanding this process may lead to enhanced tools for colour selection.

This study indicated the meaning and importance of the colour associations in design, leading to the main topic of this thesis. In the following work, it will focus on discussing the colour association, which from concept to colour by three steps:

1. Evidence, the associations, exist from specific concept (word) to colour.

   (Chapter 5)

2. Discussion of the characteristic of this kind of association.

   (Chapter 6)

3. Analysis of the cultural influence of this kind of association.

   (Chapter 7)

Chapter 5
Study 2: Evidence for strong associations from word to colours.

5.1 Introduction

Chapter 4 introduced the main topic of this thesis: colour associations, specifically the association from a concept (or word) to colour. Chapter 4 also provided evidence for the importance of colour associations in the design area. However, it is perhaps surprising that few studies have looked at the association between words and colour in the direction of word→colour. Therefore, this chapter presents some experiments to explore the association in this context. Specifically, the question (see Figure 5-1) addressed is to what extent are colours associated with words?

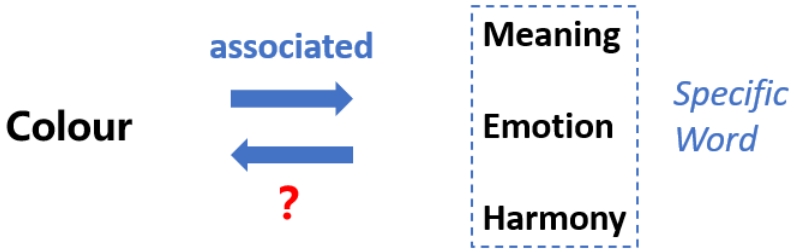


Figure 5-1 The research topic of this chapter.

There is a wealth of literature that has explored the relationship between colour→word. At first, it might seem self-evident that colours are associated with different words or concepts. The use of colours to symbolise ideas has been evident in art since the Renaissance, if not earlier (Gage, 1999; Lamb & Bourriau, 1995). Many academic studies in the 20th Century investigated these relationships (for example, Xin *et al.*, 1998), which have sometimes been expressed as colour emotions (Ou *et al.*, 2004) and sometimes expressed in terms of semiotics (Kauppinen-Räisänen & Jauffret, 2018). It is clear that these associations are not restricted to the English language (Al-Adaileh, 2012; Kommonen, 2011). However, despite this, some problems

are concluding that colours have clear and established associations with words and concepts. First, there is the issue of context. Several studies have explored the constancy (or lack of constancy) of colour associations with concepts in different contexts (Taft, 1997; Won & Westland, 2017). Consider what the colour red might represent on a strawberry yoghurt pot compared to what it might represent on an emergency-stop button? Indeed, this has sometimes led to the view that colour meanings have no meanings *per se* and that any meanings that they have are context-bound (Grieve, 1991). Therefore, if we ask participants which colours represent a word or concept in an abstract sense, how consistent will their responses be? However, if any systematic ways to provide a tool for designers are to be developed, this is a question that needs to be addressed.

This chapter describes a new psychophysical experiment to explore colour associations from word→colours directly. The work introduces a new methodology for studying the colour association problem. The methodological approach of most previous research has been to start with a colour and ask participants, for example, the extent to which the colour represents maleness or femaleness, often using a semantic differential scale (e.g. Ou *et al.*, 2004; Won & Westland, 2017). Often bi-polar (opposite) terms such as warm and cool are used, and participants use a slider bar in a graphical user interface to indicate their response to colour for these terms. However, this study starts with a word and asks participants to select colours associated with this word.

In this study, the psychophysical experiment used 70 target words (from different classifications of words) and asked each of 30 participants to identify the colours they associate with each word. The purpose was:

1. To collect ground truth data (that is, colours that people, on average, associate with these 70 words);
2. To ascertain whether a strong association exists from words→colours.
3. To explore the characteristics of associations from different classes of words→colours.

A data analysis method of similarity measurement was employed (Pearson correlation coefficient) to predict the degree of self-similarity within the colours selected for each word. This is useful because it indicates how consistent the words→colours relationship is across different participants. Suppose one argues, for example, that colours are only associated with words or concepts within specific contexts. In that case, if we ask participants which colours are associated with words and concepts in an abstract (context-less) sense, we might expect quite a low degree of self-similarity in the colour palette generated by a group of participants in response to a particular word. On the other hand, a higher degree of self-similarity suggests that colours have meanings *per se* (without the need for a context), though, of course, this does not preclude the idea that such abstract colour meanings might be modified by the context in any particular application.

Following the psychophysical experiment, an online survey (questionnaire) was conducted, completed by one hundred participants with design backgrounds. The purpose of the survey was to explore which types (or classifications) of words are typically used in design to select colours. Integrating the survey results with those from the first psychophysical experiment will provide insights about the characteristics of words that are practicable as concept keywords in colour-selection of design. Figure 5-2 is a visual summary of the research process in this chapter.

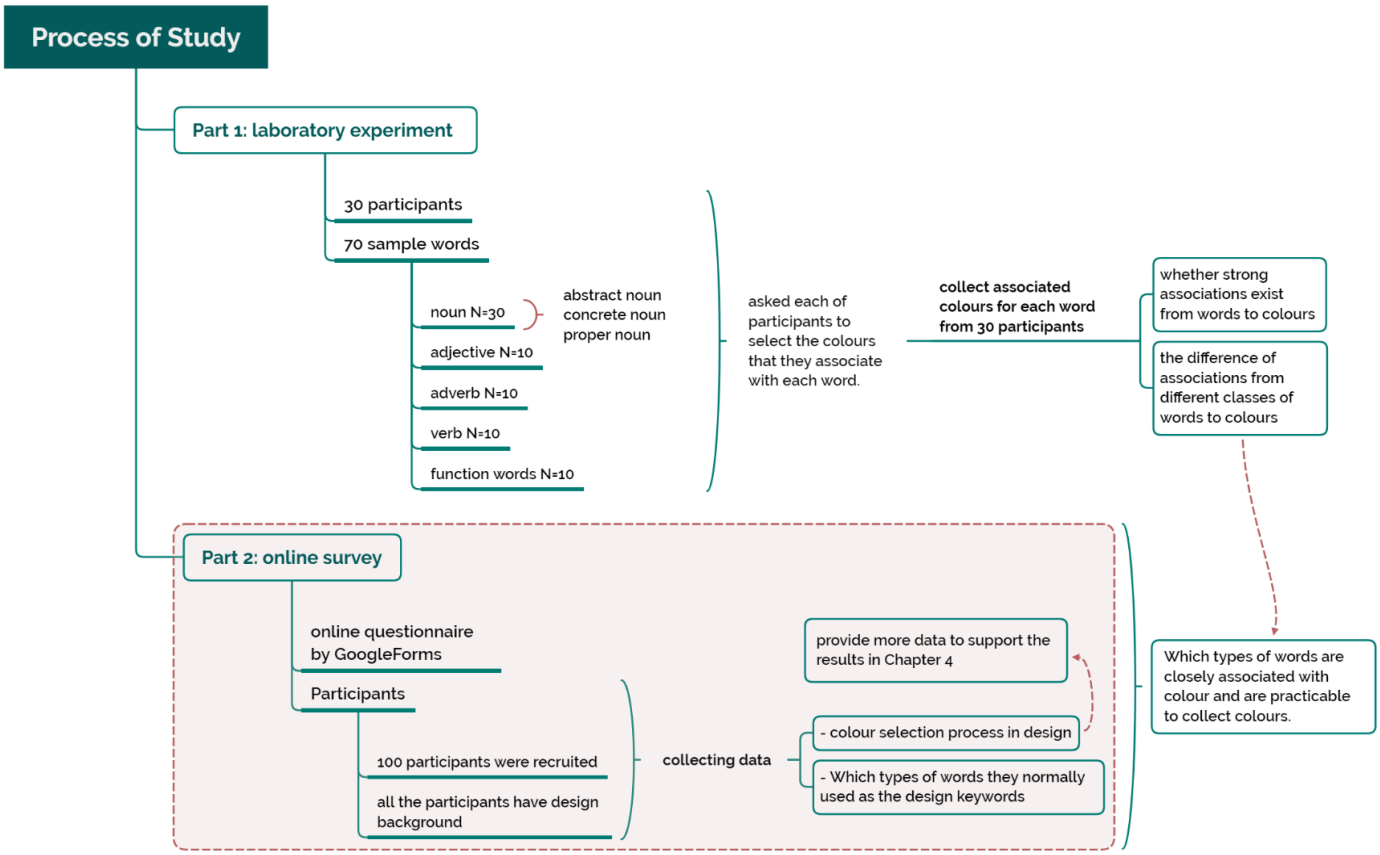


Figure 5-2 A visual summary of the research process in this chapter

5.2 Research Questions and Objective

In this chapter, one main research question and three sub-research questions are considered (see Table 5-1). The research objectives are summarised according to the research questions:

1. To explore whether strong associations exist from words→colours;
2. To gather the associated colours from words and explore the features;
3. To identify whether obvious differences in associations exist for different types of words;
4. To suggest which types of words are practicable and valuable, used as keywords of design topic or concept for designers.

Table 5-1 Research questions for this study

Main research question	*Sub-research questions*
RQ 2: Are there strong associations from words to colours?	**RQ** 2.1: Is there any corresponding significant relation from words to colours?
	RQ 2.2: What is the characteristic of associations from different classes of words to colours?
	RQ 2.3: Which types of words are practicably used as concept words in colour-selection of design?

5.3 Laboratory Experiment – Experiment 1

A psychophysical experiment is introduced in this section:

1. To collect ground truth data (that is, colours that people, on average, associate with these 70 words);
2. To ascertain whether a strong association exists from words to colours;
3. To explore the characteristic of associations from different classes of words to colours.

5.3.1 Experimental Structure

Many studies have previously been carried out using psychophysical experiments to collect data about colour meaning or colour emotion studies from colour to words. Ou *et al.* published three papers about colour emotion research (2004a; 2004b; 2004c) that described psychophysical experiments in which participants were shown sample colours and asked to select levels for various emotional terms for each colour. In this study, similar psychophysical experiments were employed, but the problem is reversed; in that participants are shown a word and asked to select related colours for that word which is from word→colour. It is unlikely that there is a unique 1→1 relationship between word and colour. For example, one colour might communicate several different meanings (Osgood *et al.*, 1957). Thus, for each specific word, there may well be more than one corresponding colour.

In the experiments, therefore, participants were asked to choose three related colours for each word.

Assuming that colours are associated with words, is the association equally strong, for example, for nouns and adjectives? Or do different types of words generally display stronger associations? In order to answer these questions, different types of words were employed. Volkova and colleagues (2012) presented a colour meaning study that collected concepts from colour and remarked that Nouns and Adjectives are the main syntactic categories that affected their results. Therefore, in this study, different classes of words were considered.

The display part of the design required the development of a GUI, and this was done by writing MATLAB code for the two experiments. For the first experiment (see Figure 5-3), a uniform grey (L*=50) was used as the background. The words were presented one at a time (and in a different random order for each participant) on the computer monitor. There were three buttons below each word, and by clicking, each of the participants could select a colour from a colour picker tool. In order to restrict the experiment to a reasonable length (it took each participant approximately 60 minutes to complete) and to avoid participant fatigue, a selection of 70 target words (10 words for each of 7 categories) (see Table 5-2) were used.

Figure 5-3 The GUI used in this experiment. Note that several colour picker tools were available on the GUI bottom-left, and participants were free to select the tool that they felt more comfortable to use.

5.3.2 Selection of Words

Renouf and Sinclair (1991) listed 'noun', 'verb', 'adjective', 'adverb', 'pronouns', 'determiners', 'numeral', 'auxiliary', 'preposition' and 'conjunctions' as the major word classes. The types 'pronouns', 'determiners', 'numeral', 'auxiliary', 'preposition', and 'conjunctions' could be classified as 'function words' (Selkirk, 2014). Therefore, the sample words selected were 'noun', 'verb', 'adjective', 'adverb', and 'function word' (Figure 5-4).

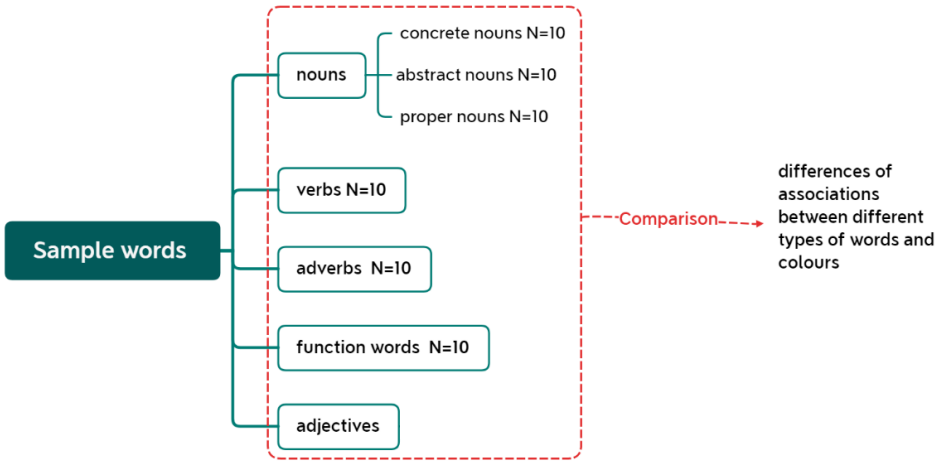


Figure 5-4 The sample words description

The 'noun' class of words is generally divided into 'common noun' and 'proper noun' (Renouf and Sinclair, 1991:25). Genetti (2014:108) also suggested that nouns can be categorised into three groups: 'concrete noun', 'abstract noun' and 'proper noun' by particular meanings. However, it is noticed that 'concrete noun', 'abstract noun' could correspond to 'common noun' and 'proper noun' in Renouf and Sinclair's study. Considering this, the sample words contain 'concrete noun', 'abstract noun' and 'proper noun'.

Therefore, in consideration of the motivation of participants and the experimental length, 70 target words were selected, which consisted of 7 classes (10 words for each class): 'concrete noun', 'abstract noun', 'proper noun', 'verb', 'adjective', 'adverb' and 'function word'. The 70 words chosen were among the most frequent words in each class, from frequency websites (Table 5-2).

Table 5-2 Sample words list

Categories	Words	Categories	Words	Categories	Words	Categories	Words
Concrete nouns[1]	Cat	***Abstract nouns[2]***	Ability	***Proper nouns[3]***	London	***Verbs[4]***	Ask
	Dog		Confidence		Google		Buy
	Jewellery		Friendship		Tom		Become
	Shoes		Goal		Maria		Begin
	Eyes		Life		China		Call
	Hand		Hope		Burberry		Can
	apple		Skill		Subway		Come
	Rice		Sleep		June		Feel
	Car		Love		Christmas		Find
	Stone		Information		Monday		Look
Adjective[5]	Active	***Adverbs[6]***	More	***Function words[7]***	A		
	Clean		Still		This		
	Cold		Actually		It		
	Dead		Probably		Two		
	Fresh		Recently		And		
	Hot		Usually		Or		
	Nature		Suddenly		No		
	Rich		Better		My		
	Safe		Quickly		At		
	Young		Simply		Although		

***Source:** 1. https://english.tutorvista.com/grammar/concrete-noun.html*

2. https://7esl.com/abstract-nouns/

3. http://www.writeawriting.com/grammar/proper-noun-list/

4. https://www.ef.com/wwen/english-resources/english-vocabulary/top-50-verbs/

5. https://www.talkenglish.com/vocabulary/top-1500-nouns.aspx

6. http://www.wordfrequency.info/

7. https://www.myenglishpages.com/site_php_files/vocabulary-lesson-function-words.php

5.3.3 Participant Recruitment

Previous psychophysical studies of colour meaning sample sizes were typically around 30 participants (e.g. Adams and Osgood, 1973; Ou *et al.,* 2004b). Therefore, due to the actionability of the Laboratory experiment, a total of 30 participants were recruited in this study (14 female and 16 male;

students or staff at the University of Leeds and of various nationalities), all aged above 18 with normal colour vision.

The recruitment of participants was through three approaches: 1) using personal contacts; 2) distributing leaflets on the campus (University of Leeds); 3) sending recruiting e-mails in the School of Design from the administration office (University of Leeds).

The experiments were conducted according to the University's code of ethical practice. An application was made to the ethical review committee and was accepted (reference number LTDESN-100).

5.3.4 Data Analysis Method

In this study, 30 participants were asked to identify the colours they associate with each specific word (70 sample words in total). As previously discussed, the similarity of selected colours for each word by different participants could measure the strength of association from word→colours. (This idea is further explored in Experiment 2 in the next chapter.)

In particular, for each word, a colour palette of 90 colours (30 participants x 3 colours) was collected (70 such colour palettes were collected in total). The colour similarity of each palette was analysed by visual analysis and data calculation. In term of calculating the self-similarity of each 90-colour palette, each participant's three-colour palette was compared to each of the other participant's three-colour palette (using a colour difference metric). To measure the colour difference within one colour palette: the colour difference between every two colours was calculated, and then the mean of these colour differences was calculated. A similarity measurement method was employed: the Pearson Correlation Coefficient method (Chen *et al.*, 2020). The similarity values of the words in different word classes were made a comparison in the end.

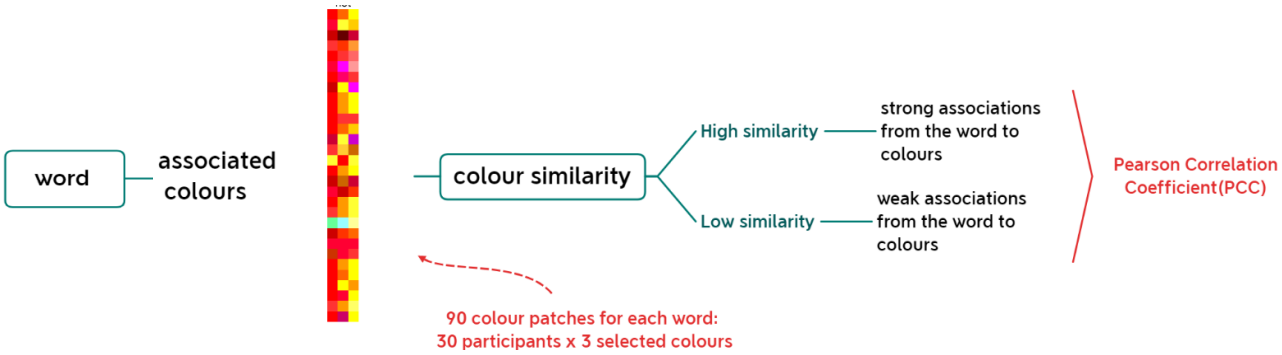


Figure 5-5 Data analysis process

Pearson Correlation Coefficient(PCC)

Many methods to calculate colour difference between two single colours have been published. For example, the International Commission on Illumination (CIE) has expressed colour difference as distance metric Delta E in CIELAB colour space. The distance between two points in colour space that represent two colours represent the visual difference between the two colours (Hunt and Pointer, 2011:57-58) as shown in Eqn 6:

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

Eqn 6

To measure the self-similarity within a colour palette, a current study pointed out that applying the Pearson Correlation Coefficient method to Delta E (Eqn 7) recommended in self-similarity colour difference measurement (Chen *et al.*, 2020; Benesty *et al.*, 2009:1-4). It could present the colour difference value, which is close to human visual difference. This method is used to measure the direction and the strength of the linear relationship between two variables which is the covariance of variables (*x,y*) divided by the product of the standard deviations, Eqn 7 (cov: covariance; σ: standard deviation):

$$P_{x,y} = \frac{cov(x,y)}{\sigma_x \sigma_y} = \frac{E\left[(x - \sigma_x)(y - \sigma_y)\right]}{\sigma_x \sigma_y}$$

Eqn 7

The value of PCC is within -1 and +1, which is -1 ≤ *P* ≥ +1:

If $P < 0$, two variables are positive correlation; if $P > 0$, two variables are negative correlation.

If $|P| = 1$, two variables are perfect linear correlation which is functional relation.

If $P = 0$, there is no linear correlation between the two variables.

When the absolute value of PCC is between 0 and 1, there is a correlation between the two variables. The $|P|$ is closer to 1, the higher correlation and the $|P|$ is closer to 0, the lower correlation. Correlation can be verbally described the strength of the correlation using the guide that Evans (1996) suggests for the absolute value:

- $0 < |P| < 0.2$ 'very weak'
- $0.2 \leq |P| < 0.4$ 'weak'
- $0.4 \leq |P| < 0.6$ 'moderate'
- $0.6 \leq |P| < 0.8$ 'strong'
- $0.8 \leq |P| < 1$ 'very strong'

Therefore, the correlation value was calculated between each set of three colours in each colour palette for each word by PCC algorithms (using the CIELAB values). That is, in each colour palette, each three colour patches (which were selected by one participant) were compared to the other three colour patches respectively to calculate P. For 30 participants, this results in 435 values of P, and this to generate these are averaged (ignoring the sign) to generate a value that represents the visual self-similarity between the 90 patches (30 participants x 3 colour selections) for each word. The details were presented below:

$$P_{x,y} = \max\{P_{x,y}^{i,j}\}$$

Eqn 8

$P_{x,y}$ represent the PCC value between two different partitpiants (x and y), so $1 \leq x \leq 30, 1 \leq y \leq 30, x \neq y$. Besides, $P_{x,y}$ is the maximum of $P_{x,y}^{i,j}$, where:

$$P_{x,y}^{i,j} = \frac{cov(R_x^i, R_y^j)}{\sigma_{R_x^i}\sigma_{R_y^j}} = \frac{E\left[\left(R_x^i - \sigma_{R_x^i}\right)\left(R_y^j - \sigma_{R_y^j}\right)\right]}{\sigma_{R_x^i}\sigma_{R_y^j}}$$

Eqn 9

Where:

$$1 \leq i \leq 6, 1 \leq j \leq 6$$

R_x^i or R_y^j is one of the six possible permutations of the participant x or y, respectively. For example:

$$R_x^1 = [C_x^1\ C_x^2\ C_x^3]$$

$$R_x^2 = [C_x^1\ C_x^3\ C_x^2]$$

$$R_x^3 = [C_x^2\ C_x^1\ C_x^3]$$

$$R_x^4 = [C_x^2\ C_x^3\ C_x^1]$$

$$R_x^5 = [C_x^3\ C_x^1\ C_x^2]$$

$$R_x^6 = [C_x^3\ C_x^2\ C_x^1]$$

C_x^1, C_x^2 and C_x^3 are the Lab value of the first, second and third selected colours from the the participant x:

$$C_x^1 = [L_x^1\ a_x^1\ b_x^1]$$

$$C_x^1 = [L_x^2\ a_x^2\ b_x^2]$$

$$C_x^1 = [L_x^3\ a_x^3\ b_x^3]$$

5.3.5 Experimental Procedure

This psychophysical experiment took place in the Experience Design Laboratory at the School of Design (University of Leeds, UK). It took one month of preparation to design the experiment, select the sample words, and recruit participants. It was carried out with controlled viewing conditions, lighting conditions and display technology (Figure 5-6). The viewing distance was about 40 inches from the observers' eyes to the computer screen. All observers passed a Colour Blindness Test (showed them the a series of

specially designed pictures composed of colored dots and asked to look for numbers, Appendix D1) before the experiment started. It generally took around 60 minutes for each participant, and the experimental procedure is described below:

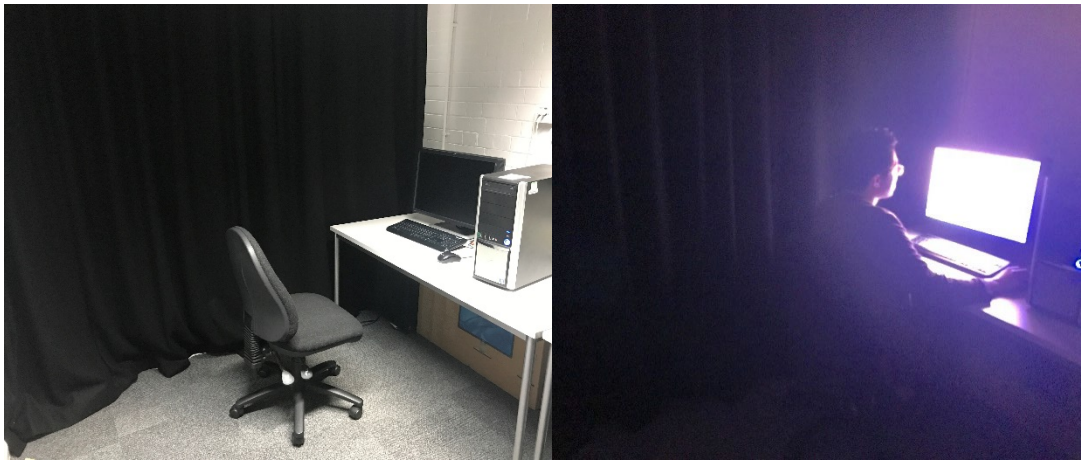


Figure 5-6 The experimental set-up

1) Setting up

Each participant received an introduction email which included an information sheet (the description of experimental aim, method and the intended use of data). The email also provided a link to a self-booking system where the participant could easily select their interview time (*https://youcanbook.me/*).

2) Introduction

Each event consisted of two personnel (the participant and organiser). The organiser showed the information sheet and briefly summarised the study to the participant before the main experiment started.

3) Agreement signature and a Colour Blindness Test

A consent form was provided, which presents eight relevant clauses about the agreement of participating in this study. Each participant was required to read and sign this agreement before the experiment could take place. A Colour Blindness Test was carried out for each participant to make sure they had a normal colour vision.

4) The main body of the experiment

Each participant viewed each of 70 target words and was asked to choose three colours related to the word. The words were presented separately (and in a different random order for each participant) on the computer monitor. There were three buttons below each word, and by clicking, each of the participants could select from a colour picker (note that there were several colour pickers, and the participants could use whichever one they considered to be more convenient).

5.3.6 Experimental Data Collection

This experiment was performed in the laboratory, displayed on an HP DreamColor LP2480zx Professional Display (24-inch Diagonal LCD Backlit Monitor). The colours displayed in the experiment were defined by RGB values. However, RGB values are device dependent, and CIELAB values are required for the subsequent colour-difference calculations. In total, 6300 colours or RGB combinations (30 participants x 70 words x 3 colours) were selected by the participants; each of these was subsequently measured using a Konica Minolta CS-2000 spectroradiometer after the experiment (Figure 5-7).

Figure 5-7 The colour measurement by the Konica Minolta CS-2000 spectroradiometer in the laboratory.

All the colour measurement were carried out in the laboratory with darkened environment (to avoid the influences from ambient light). Before the measurement, the device and screen were turned on to warm up for one hour. Each colour patch was displayed in the screen one by one, the

spectroradiometer measured spectral radiance at each wavelength, and these data were converted to CIELAB values (with reference to the white display point: CIE x = 0.3116, y = 0.3184) using standard methods (Westland *et al.*, 2012). The white point of the display was close to the blackbody locus (the colour temperature is 6659K) (Figure 5-8). Then, all the data after the measurements were be used for the following analysis and caculation.

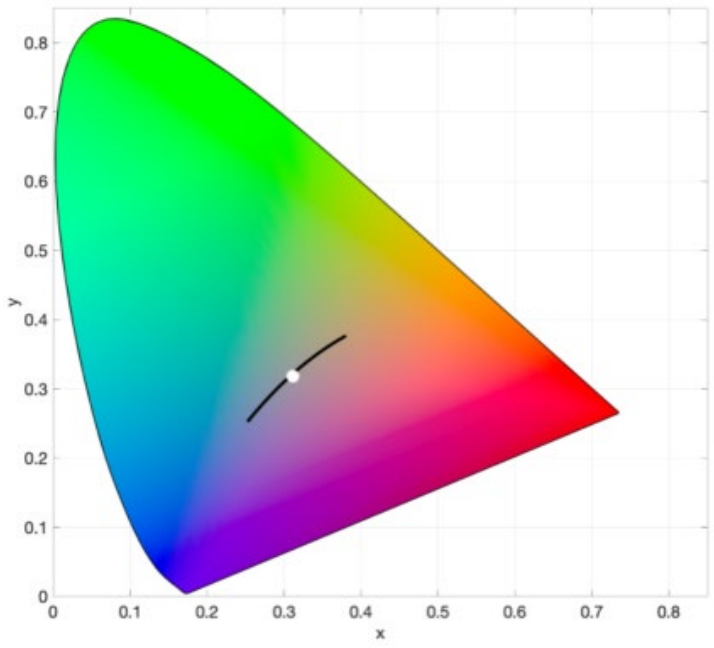


Figure 5-8 The white point (x = 0.3116, y = 0.3184) of the display in CIE chromaticity diagram.The Plankian locus between 4000K and 25000K, and the colour temperature of the white point was 6659K.

5.3.7 Results

First, during the experiment, participants selected related colours easily and relatively quickly, which suggests that they could easily found related colours for specific words; this, in itself, is some evidence that strong associations exist from words to colours. However, the data from the experiment were analysed by visual analysis and similarity measurement.

Visual analysis:

For each sample word, every participant selected three related colours so that 90 (3 colours × 30 observers) related colours were collected for each word and organised into 90-colour palettes (Figure 5-9).

Figure 5-9 The presenting visual data of each word

It is evident that there are systematic differences between the colours that were selected for each of the words; the colours that were selected are intuitively what one might expect. In many cases, a clear colour trend can be seen in the palettes, which means some specific colours are near and significantly associated with those words, and it could evidence the strong associations from those words to some specific colours. In other words, note the predominance of pink for ‘love’, the predominance of light colour for ‘rice’, the predominance of blue for ‘cold’; and compare these to the low saturation colours that are associated with ‘probably’, even when the colours that were collected were less obviously intuitive (such as ‘ask’, ‘at’) there is evidence of some systematic relationship between word and colour (Figure 5-10).

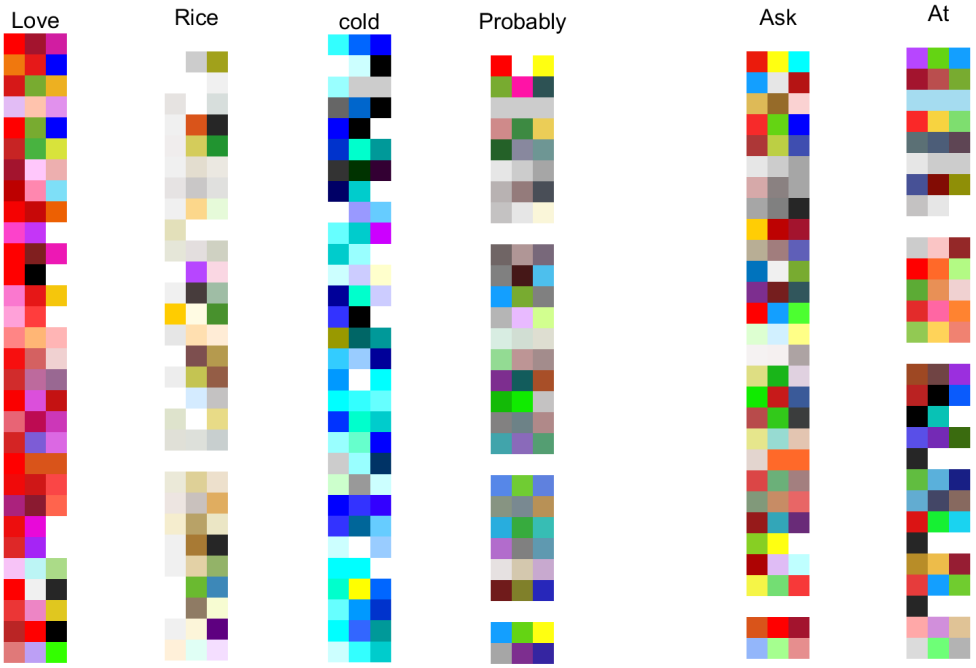


Figure 5-10 The predominance of pink for ‘love’; the predominance of light colour for ‘rice’; the predominance of blue for ‘cold’; the low saturation colours associated with ‘probably’. On the contrary, less obviously colour trend of ‘ask’ and ‘at’.

It is also noticed that concrete nouns, proper nouns, and adjectives perform better than other groups. Most of the words in these three groups presented evident colour trends. On the contrary, verbs and function words were less obviously a colour trend, and the colours are colourful. It could be considered that participants did not have clear related colours for these words, and these words are weakly associated with colours.

Similarity Measurement:

To analyse the characteristic of each palette in detail, the PCC value was used to measure the similarity of the colour in each colour palette for each sample word (Table 5-3). The PCC value is closer to 1, the higher correlation and the PCC value is closer to 0, the lower correlation.

Overall, it can be seen that the PCC value for most of the 70 words (70%) was above 0.6 and in some cases even reach 0.8 (‘rice’), which means the correlation level of most of the palettes are ‘strong’ or ‘very strong’. Only a few of them are below 0.6 but still above 0.5. Thus, for 70 sample words, the complementary colour palette presented a strong similarity or an evident colour trend; it indicated that a strong association exists between these words to the colours.

Besides, a significant difference was presented between different word classes. First, as Table 5-3 shows, the mean of PCC value in each word class was provided. The mean of Adjectives shows the highest PCC values (0.701), and Concrete nouns are also high (0.690). Conversely, Function words show the lowest mean value (0.587) of the seven classes. The similarity of associated colours for Adjectives are higher than other word classes, and Function words are the weakest word class of the association with colours.

Specifically, the statistical dispersion of every similarity data for each word was carried out to compare seven classes of sample words. The boxplot shows (Figure 5-11) the minimum, maximum and median of each similarity value for each word. The higher position and the smaller dispersion represented the larger similarity of the colours in each palette. Obviously, the words from Adjective performance best than other groups. Note, although some words (‘Hand’, ‘Rice’) show a strong similarity that is not from the Adjective group, adjectives' performance best and every word present a strong similarity of Adjectives.

Table 5-3 The similarity measurement of sample words.

Concrete nouns	PCC Value	Abstract nouns	PCC Value	Proper nouns	PCC Value	Verbs	PCC Value	Adjectives	PCC Value	Adverbs	PCC Value	Function words	PCC Value
Cat	0.65	***Ability***	0.60	***London***	0.64	***Ask***	0.61	***Active***	0.63	***More***	0.56	***A***	0.56
Dog	0.71	***Confidence***	0.55	***Google***	0.68	***Buy***	0.56	***Clean***	0.79	***Still***	0.65	***This***	0.59
Jewelry	0.63	***Friendship***	0.63	***Tom***	0.58	***Become***	0.61	***Cold***	0.74	***Actually***	0.54	***It***	0.65
Shoes	0.62	***Goal***	0.57	***Maria***	0.60	***Begin***	0.63	***Dead***	0.74	***Probably***	0.68	***Two***	0.61
Eyes	0.68	***Life***	0.62	***China***	0.66	***Call***	0.62	***Fresh***	0.76	***Recently***	0.59	***And***	0.59
Hand	0.72	***Hope***	0.70	***Burberry***	0.63	***Can***	0.52	***Hot***	0.69	***Usually***	0.65	***Or***	0.60
apple	0.73	***Skill***	0.55	***Subway***	0.70	***Come***	0.55	***Natural***	0.71	***Suddenly***	0.55	***No***	0.50
Rice	0.80	***Sleep***	0.60	***June***	0.73	***Feel***	0.64	***Rich***	0.65	***Better***	0.61	***My***	0.57
Car	0.63	***Love***	0.58	***Christmas***	0.72	***Find***	0.58	***Safe***	0.66	***Quickly***	0.58	***At***	0.56
Stone	0.72	***Information***	0.64	***Monday***	0.58	***Look***	0.65	***Young***	0.64	***Simply***	0.62	***Although***	0.62
Mean:	0.690		0.604		0.652		0.598		0.701		0.601		0.587

The mean of Adjectives is the highest than others, Concrete noun is the second, Function words is the lowest group.

**PCC: Statistics method- Pearson Correlation Coefficient.*

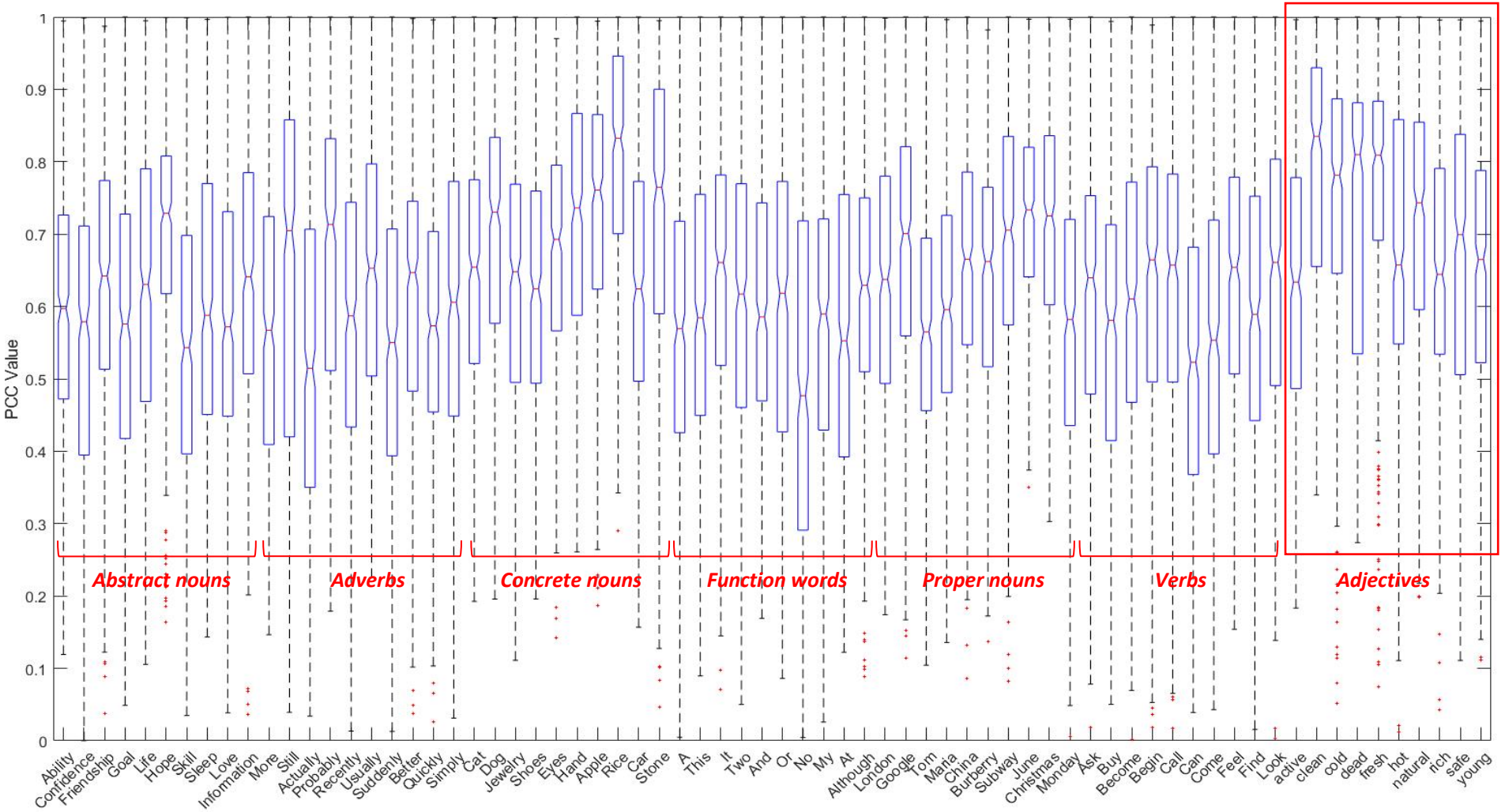


Figure 5-11 The dispersion of every similarity value for each word. The words which from Adjective performance best than other groups.

Overall, strong associations were evidenced from specific words to colours in this experiment. Generally, the associated colours for each word were highly self-similar. Participants selected similar colours for a word. This study also indicated that different word classes have different degrees of associations with colours. Adjectives were considered to be the strongest words most strongly associated with colours in this study. On the contrary, Verbs showed the weakest associations with colours. In the next section, an online survey was introduced to provide supplementary information to support these results.

5.4 Online Survey: Questionnaire

An online survey (questionnaire) was conducted which was completed by one hundred participants, each with a design background. The purpose of this was to ascertain the designers' view of which types of words are usually used in design to select colours. These results will then be integrated with the first psychophysical experiment to indicate the characteristics of practicable words as the concept keywords in colour-selection of design. This Questionnaire also provides supplementary information to support the earlier interview study (Chapter 4).

5.4.1 Survey Structure

An online survey was carried out to collect ideas from designers about which types of words are practically and frequently used as concept words in colour-selection in design. It could provide supplementary information to be compared with the earlier experimental results. In Chapter 4, an interview study was conducted to collect ideas from designers, but the number of participants was relatively small. Saunders (1997) suggested that the questionnaire is an efficient data collection method for gathering responses from a large number of participants. Therefore, a questionnaire study was carried out in this chapter to collect more responses from designers. It collected data from a large group of participants to provide supplementary information to support the interview study (Chapter 4) and gather the ideas of design keywords from designers.

The self-administered questionnaire method was chosen instead of the Interviewer administered method because of the requirement of large numbers of participants (Saunders e*t al.*, 1997:282). A web-based questionnaire was used over postal or other types due to the higher response rate and faster completion (Robson, 2011). Many websites exist that provide questionnaire collection, and Google Forms was selected as the data collection tool.

5.4.2 Preparation of Survey

5.4.2.1 Question Design

Based on the participants' experience of the research, the time and the number of questions have been considered to find the best arrangements. An initial pilot test was carried out with two PhD students with a design background at the University of Leeds. The final version of the questionnaire contains five ordered questions, and the time is around 5 minutes to complete. Five questions were presented in the questionnaire (Table 5-4).

Table 5-4 Questionnaire Description

Question Type	***Question***	***Selection***	***Purpose***
Open question	***1 Which country do you work in?***	-Answering	Participants' information
Category question	***2 Which type of design do you work in?***	-Graphic Design -Interior Design -Product Design -Fashion Design -UI/UX Design -Architectural Design -Information Design -Landscape Design -Colour Design -Service Design -Others	Participants' design background

Rating question	***3 When you are given a design project or a topic. Do you refine the keyword(s) of the topic to provide design ideas?***	-Yes -No -Maybe	The ideas of design process.
Rating question	***4 Did you choose the design colour according to these keywords?***	-Yes -No -Maybe	The ideas of colour selection.
List question	***5 Generally, these keywords are (multiple):***	-Concrete Nouns -Abstract Nouns -Proper Nouns -Verbs -Adjective -Adverb -Function Words -Others	Which types of words are closely associated with colours and are practicable to collect colours.

5.4.2.2 Participant Recruitment

This study collects a large amount of primary data from designers; the target participants should have design working experience or a design educational background. The research took two months to collect the responses, and in total, one hundred responses were gathered in this study. The participants are from different countries and different design disciplines.

The recruitment of participants was through three approaches: 1) using personal contacts; 2) distributing leaflets on the campus (University of Leeds); 3) sending recruiting e-mails in the School of Design from the administration office (University of Leeds).

5.4.3 Survey Procedure

To simplify the survey procedure, the online questionnaire was distributed *(https://docs.google.com/forms/d/e/1FAIpQLSdHFVjOCJQPXknD26SgAFa4ViQyZAvAGodKivRySqpu-ExN9g/viewform)* and was available to be opened on the mobile

phone, computer or any other electronic equipment. Participants were presented with a short introduction to the survey and then the five questions (see Figure 5-12). Without any contact with the researcher, each participant could complete the questionnaire by themselves in a fast and efficient way.

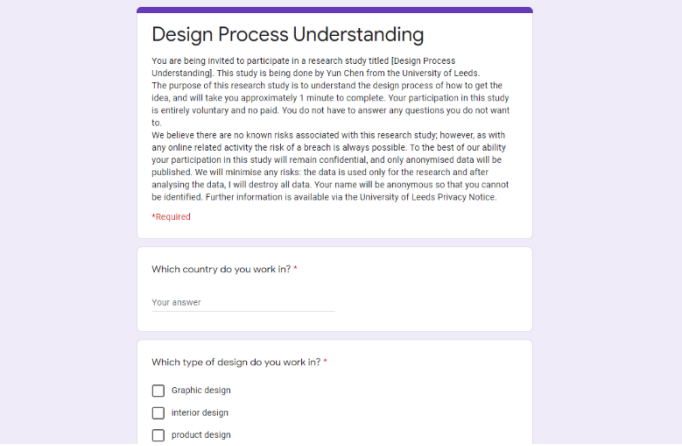


Figure 5-12 Image capture of the online questionnaire

5.4.4 Results

Question 1: Which country do you work in?

Question 2: Which type of design do you work in?

The first two questions are about the participant information as the responses shows that 32 Chinese, 21 South Korean, 14 Japanese, 18 British, 3 American, 6 Mexican, 2 African, 1 French and 3 Arabian. They are in different design areas. The result is presented in Figure 5-13.

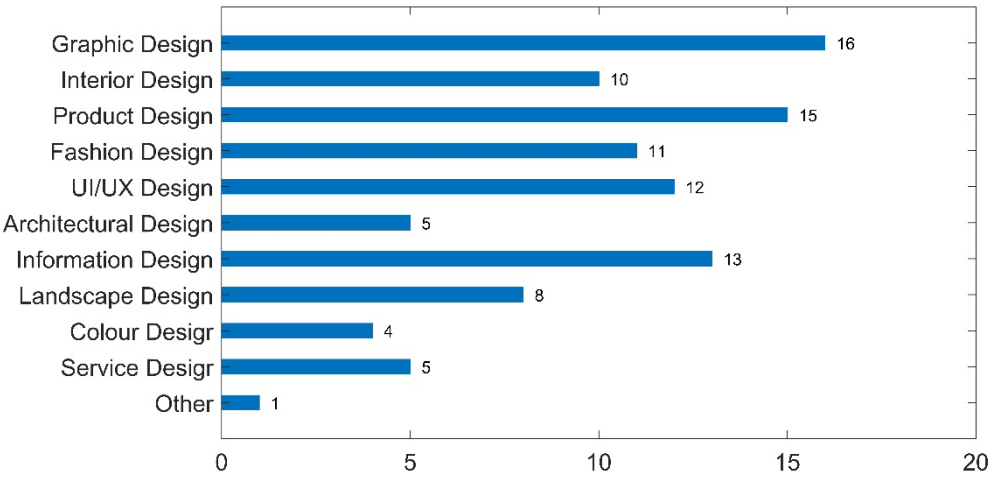


Figure 5-13 Participants design categories collection

Question 3: When you are given a design project or a topic. Do you refine the keyword(s) of the topic to provide design ideas?

Question 4: Did you choose the design colour according to these keywords?

The purpose of these two questions is to collect ideas of the design process and colour selection related to the previous interview study (Chapter 4). The results of question 3 and question 4 are summarised in Figure 5-14 and show: 1) most of the participants (77%) are refining the keywords of the design topic or design concepts; 2) most of the participants choose the design colour according to these keywords.

In the previous interview study, a three-step colour-selection method was deduced from the twenty designers that contain the following steps: 1) topic decision; 2) related concepts; 3) colour selection. In this questionnaire, 100 designers' opinions were collected, and the results show that they are used to refine the keywords of the design topic or design concepts after the topic confirmed, then choose the design colour according to these keywords. This process is the same as the three-step colour-selection method, which means this method is evidential and widely used in the design. This finding compensated for the deficiency of the interview and provided large numbers of additional evidence to support it.

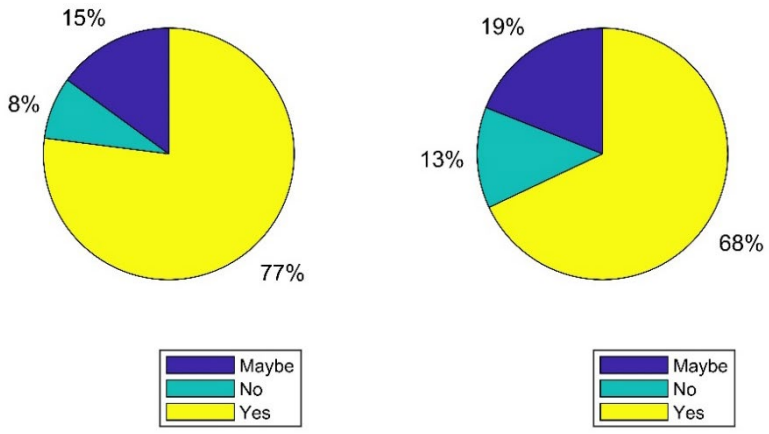


Figure 5-14 Question 3 (left): When you are given a design project or a topic. Do you refine the keyword(s) of the topic to provide design ideas? Question 4 (right): Did you choose the design colour according to these keywords?

Question 5: Generally, these keywords are (multiple)：

The purpose of this question is to gather the ideas of design keywords from designers. Participants were asked to choose the specific word class of the keyword they usually used. Obviously, adjective (N=93) is the most frequent word class for the design keywords in colour selection (Figure 5-15) and is far more frequently than others. Nouns (N=81) are the second-highest frequency group.

This result shows that adjectives are the most used words in design keyword, which means adjectives are more practicable than others and more comfortable collecting related colours for them in design colour selection. It corresponds to the last experiment results: adjectives were indicated as the strongest words associated with colours, and concrete nouns are followed.

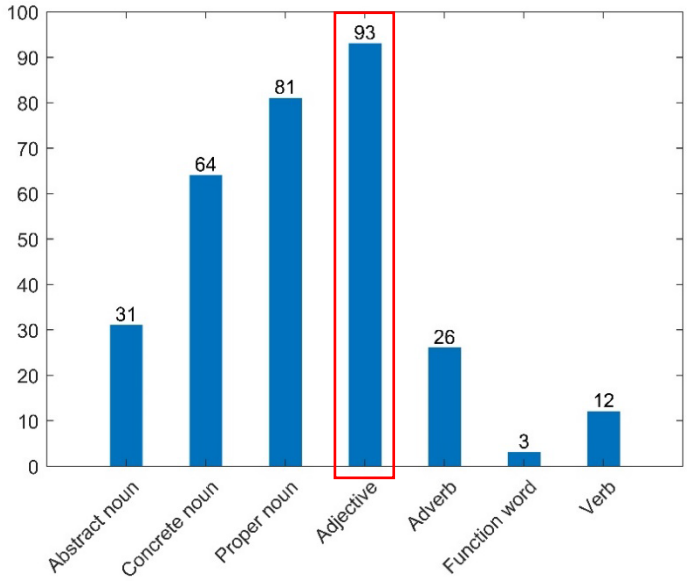


Figure 5-15 Word frequency of different word class collection

5.4.5 The Survey Results Discussion

This online questionnaire collected large numbers of ideas from different design fields. It includes one hundred participants to collect reliable and sufficient ideas from designers.

First, it collected the ideas from a design point of view: adjectives are the most frequent words used as a keyword to select colours in design. This result corresponds to the first psychophysical experiment that adjectives were considered the strongest words associated with colours. Thus, it is reasonable to summarize that adjectives are the most practicable words recommended as the concept keywords in the design colour-selection process.

The result shows that these one hundred designers are used to refine the keywords of the design topic or design concepts after the topic confirmed, then choose the design colour according to these keywords. This process corresponds to the three steps colour-selection method, which collected from the interview study (Chapter 4): 1) topic decision; 2) related concepts; 3) colour selection. It provides more evidence that the valuable and practicable of the three steps colour-selection method, which compensated for the deficiency of the interview and provided large numbers of supplementary data to support it.

5.5 Discussion and Conclusion

The main propose of this study was to explore whether strong associations exist from words to colours and to explore the characteristic between different types of words. A psychophysical experiment was carried out with different classes of 70 target words used to identify the colours that participants associate with each word. Then, an online survey was introduced to provide supplementary data to integrate with the experiment.

5.5.1 Key Insights

It has been noted that people associate blue with calming, depressing, peaceful, quiet, serious, and nostalgic (Gage, 1999); associate yellow with serene, gay and softly exciting (Goethe, 2006), or warm and sunny; associate green with envy, red with passion, black with death, yellow with

cowardice, blue with loyalty (Caivano, 1998). Cherry (2015) has explored the link between colour and mood. Conversely, the discussion from specific concepts to colour is rarely to be mentioned. Understanding these word to colour associations is essential for the effective use of colour in art and design (Chapter 4).

Therefore, the main contribution of this study is: it identified and evidenced that strong associations exist from specific words to colours (RQ 2). A psychophysical experiment is carried out first and used 70 target words (from different classifications of words) and participants to identify the colours they associate with each word. The strong similarity of the associated colours for each word was presented. It means different people selected similar related colours for a word. Some specific colours are closely and significantly associated with the word, which indicated the strong associations from these words to colours (RQ 2.1).

This study also indicated that different word classes have different degrees of associations with colours (RQ 2.2). Adjectives were considered the strongest words associated with colours in the experiment. On the contrary, Verbs showed the weakest associations with colours. An online survey was introduced to provides supplementary information to support these results. It collected the ideas from a design point of view: adjectives are the most frequent words used as a keyword to select colours in design. This result corresponds to the psychophysical experiment that adjectives were considered the strongest words associated with colours. Thus, it is reasonable to summarize that adjectives are the most practicable words recommended as the concept keywords in the colour-selection process in design (RQ 2.3).

Besides, this study provides more supplementary data to support the interview study (Chapter 4). In the previous work (Chapter 4), an interview study was conducted to collect ideas from designers, and the critiques of the interview study were summarised that is the limit of interview participants

number (20 participants). The online survey provides more evidence that the valuable and practicable of the three steps colour-selection method compensated for the deficiency of the interview and provided large numbers of supplementary data to support it.

5.5.2 Critique of the Study and the Next Step

This study introduced the discussion of the relationship from words to colours on a macroscopic level and provided evidence that strong associations from a word to colours. Although the associations from different types of words to colours were compared and discussed, the specific characteristic of the association from a word to colours did not include.

Therefore, in the next step of the research, another psychophysical experiment will be introduced to provide more data to supplement and explore this problem: The association from word to colour will be discussed at a micro-level. The specific characteristic will be analysed summarised.

Chapter 6

Study 3: The characteristic of the associations from word to colour.

6.1 Introduction

Chapter 5 explored associations from word to colour. A new psychophysical experiment was introduced to identify and evidence that strong associations exist from specific words to colours. It was also shown that adjectives are the word class with the strongest associations with colours and are recommend as practicable words in helping with the colour-selection process in design. Therefore, the specific characteristics of the association from adjectives to colours is now explored further in this chapter.

There is a wealth of literature that has explored the characteristic of associations from colour to concept or specific words. Cherry (2015) has explored links between colour and mood. Cool colours are linked with calm, serene and comfortable. Conversely, warm colours are relevant to stressful and exciting moods. Hemphill (1996) showed that bright colours are linked with positive emotions like happiness, joy and hope. Likewise, Elliot and Maier (2007) consider brighter colours as friendly, cultured, pleasant and beautiful. Conversely, dark colours are associated with negative concepts such as boredom and sadness (Camgöz *et al.*, 2002). It is clear that colours generate associations and responses to concepts (Elliot and Maier, 2007). However, the characteristic of the link from word to colour is an interesting topic waiting to be explored.

Chapter 5 introduced a new methodology for studying associations from specific words to colours, which starts with a word and asks participants to select colours associated with this word. This novel approach is an efficient and practicable way to explore word-->colour associations. This approach is explored in this chapter. A psychophysical experiment was carried out in which 30 adjectives were employed, and participants were asked to identify three colours associated with each word. The experimental procedure was slightly different from the previous experiment: each participant was asked to choose the most related colour before selecting two further related colours. The purpose was: 1) to analyse the characteristics of the associated colours for each word. 2) to test the relationship between colour similarity and the associations from word to colour. A K-means clustering method is employed in this study to analyse the characteristics of the associated colours for each word. Figure 6-1 is a visual summary of the research process.

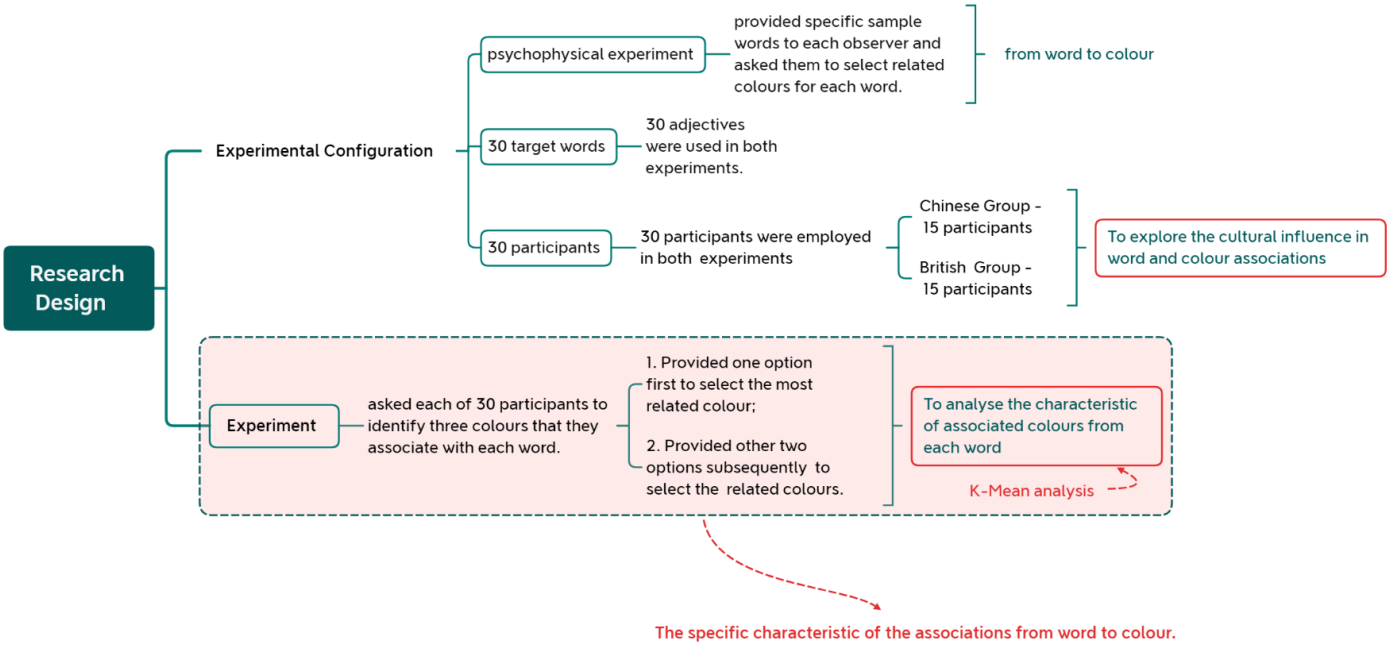


Figure 6-1 A visual summary of the research process in this chapter

6.2 Research Questions and Objective

In this chapter, one main research question and two sub-research questions are considered (see Table 6-1). The research objectives are summarised according to the research questions: 1) to gather the specific characteristic of the association from a word to colours; 2) to explore a measurement method of the characteristics of associations.

Table 6-1 Research questions for this study

Main research question	***Sub-research questions***
RQ 3: Are there significate characteristics in the associations from word to colour?	**RQ** 3.1: What is the characteristic of the associations between words and colours?
	RQ 3.2: How to measurement the characteristic of associations from word to colour?

6.3 Experiment Details: Experiment 2

A psychophysical experiment was carried out and conducted according to the University's code of ethical practice. An application was made to the ethical review committee and was accepted (reference number LTDESN-100).

6.3.1 Experimental Samples

In this study, 30 target words were selected and provided for participants as prompts to choose colours. Based on the findings of the last chapter, in this study, the 30 target words were all adjectives.

In consideration of the motivation of participants and the experimental length, 30 adjectives were employed in Experiment 2 to explore the characteristic of associations from word to colour. The 30 adjectives chosen were amongst the

most frequent words from the words frequency websites: http://www.wordfrequency.info/ (see Table 6-2).

Table 6-2 The list of words used in the experiment.

Number	*Words*	*Number*	*Words*	*Number*	*Words*
1	Active	**11**	Good	**21**	Poor
2	Bad	**12**	Healthy	**22**	Powerful
3	Clean	**13**	Hot	**23**	Religious
4	Cold	**14**	Lucky	**24**	Rich
5	Cultural	**15**	Male	**25**	Safe
6	Dangerous	**16**	Married	**26**	Sweet
7	Dead	**17**	Medical	**27**	Traditional
8	Female	**18**	Modern	**28**	Unlucky
9	Fresh	**19**	Natural	**29**	Urban
10	Future	**20**	Old	**30**	Young

6.3.2 Experiment Structure

Participants were instructed to select three colours that are associated with each word. However, each participant was asked to choose the most related colour before selecting two further related colours. This will enable a subsequent analysis to be carried out using the three colours selected for each word or the most associated colour.

To restrict the experiment to a reasonable length (it took each participant approximately 30 minutes to complete each time) and avoid participant fatigue, only 30 target words were used. The display part of the design required the development of a GUI, and this was done by writing MATLAB code for Experiment 2. A uniform grey (L*=50) was used as the background (see Figure 6-2). The words were presented one at a time (and in a different random order for each participant) on the computer monitor. There were three

buttons below each word, and by clicking, each of the participants could select a colour from a colour palette.

Figure 6-2 The GUI for the experiment.

Initially, only the first button was visible to the participants; once this was used to select a colour, the other two buttons appeared to select two further related colours. It is a slight change to the instructions that informed participants to select the most relevant colour first in this study, and this was reinforced by having the option to select the second and third colours only appearing after the first colour had been selected.

6.3.3 Participant Recruitment & Experimental Procedure

Following the experiment configuration in the last chapter, 30 participants were recruited in this experiment (15 female and 15 male; all students or staff at the University of Leeds; all aged above 18 with normal colour vision). Besides, to conduct a cross-cultural aspect of this study and explore the cultural influence of associations from word to colour, participant recruiting is limited to British and Chinese. Thirty participants consisted of two groups: 15 British participants and 15 Chinese participants.

The experiment took place in the Experience Design Laboratory at the School of Design (University of Leeds) with controlled viewing conditions, lighting conditions and display technology. The viewing distance was about 40 inches from the observers' eyes to the display. All observers had a Colour Blindness Test before the experiment started. It generally took around 30 minutes for each participant, and the experimental procedure was: 1) Setting up; 2) Introduction; 3) Agreement signature and a Colour Blindness Test; 4) Main body of experiment. (For further details, refer to the experiment in the last chapter, Section 5.3.5 of Chapter 5)

Note a slight difference in the main body of the experiment. The participants were asked to select the most related colour first, then choose another two colours related to the word (note, however, that participants could choose to select the same colour in all three selections if they preferred).

6.3.4 Data Analysis Method

In this study, two data analysis methods were employed: the Pearson Correlation Coefficient(Chapter 5) and K-Means Clustering Analysis (Na *et al.*, 2010).

6.3.4.1 Pearson Correlation Coefficient (PCC)

Pearson Correlation Coefficient (PCC) was introduced in Chapter 5 to measure the colour difference within a colour palette. In this experiment, each word was asked to select the most related colours and another two, and thus, for each word, there are two colour palettes after the experiment, which is the most related colour palette and the other two colours palette. The PCC method was employed again to measure the self-similarity of the palettes for each word, to compare the extent of colour similarity between the most

related colour palette and the other two colours palette. To test the relationship between colour similarity and the strength of associations.

6.3.4.2 K-Means Clustering Analysis

K-Means Clustering Analysis is used to explore the specific characteristic of associations from word to colour. Cluster analysis is a mathematical technique that can find the centres or representative points of clusters in data and is illustrated schematically in Figure 6-3. Figure 6-3 (a) shows a set of 29 data points in a 2-D space. Cluster analysis that seeks a single cluster will find the centre of gravity for the 29 points. This is shown in Figure 6-3 (b), where a single cluster is shown (red). Figures 6-3 (c) and 6-3 (d) show the result of seeking 2 and 3 clusters, respectively. In Figure 6-3 (d), the three centroids show the positions of the three clusters that the data naturally fall into. This clustering method can be applied to data with more than 2-dimensions; for example, in this study, the data are 3-dimensional because three numbers define each colour patch in each colour palette (CIELAB L*, a* and b*). K-Means Clustering partition data into *k* mutually exclusive clusters to present the characteristic of the objects.

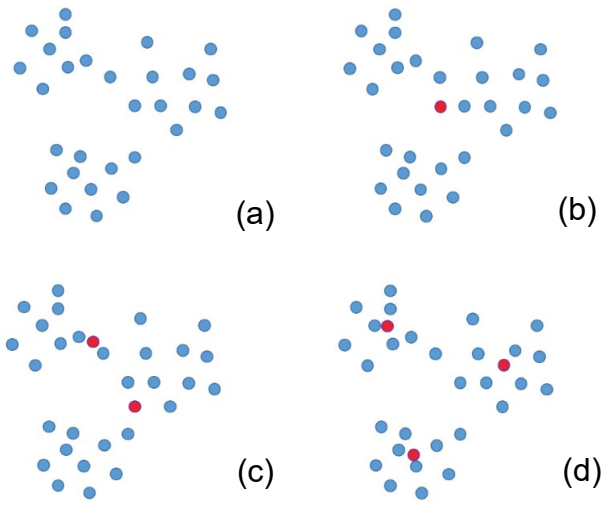


Figure 6-3 It shows a set of 29 data points in a 2-D space (a) using cluster analysis that seeks a single cluster(b) will find the centre of gravity for the 29 points. (c) and (d) show the result of seeking 2 and 3 clusters, respectively.

The processing of computing the K-Means Clustering in CIELab depends on the Euclidian Distance (Section 5.3.4 in Chapter 5):

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

Eqn 6

During the caculation, the number of the centroids in each cluster should be determined and the centroids are placed randomly in CIELab space. Then, computing the distance between each point and the centroids respectively, categoring each point into the cluster which has relatively small distance than others. Averaging the coordinate of all points in each cluster, which is the centroids of the second iteration, the details could be described as:

$$LC_{n+1}^{m} = \frac{1}{|C_n^m|} \sum_{L_i \in C_n^m} L_i$$

$$aC_{n+1}^{m} = \frac{1}{|C_n^m|} \sum_{a_i \in C_n^m} a_i$$

$$bC_{n+1}^{m} = \frac{1}{|C_n^m|} \sum_{b_i \in C_n^m} b_i$$

$$Centroid_{n+1}^{m} = [LC_{n+1}^{m}\ aC_{n+1}^{m}\ bC_{n+1}^{m}]$$

Eqn 11

Where n is number of iteration times, m is the number of centroids, $Centroid_{n+1}^{m}$ is the coordinate of the mth centroids in the $(n+1)$th iteration. C_n^m is the the mth clusters in the nth iteration. $|C_n^m|$ is the colour point numbers in the mth clusters in the nth iteration. L_i , a_i and b_i is the value of each colour point.

The iterative process is calculated repeatly until the averaged distances between the clustered points and the each cluster reach a relative minimum value.

For each word, a colour palette of 90 colour patches (30 participants x 3 colours) was collected (in the case where all three selected colours were considered). K-Means Clustering was carried out to partition all the colour patches into several exclusive clusters and identify the centroids which represent the characteristic of this palette. The analysis follows three steps:

1) **All the colour data are organized into different colour palettes by each word.**

   Thirty colour palettes of 90 patches were collected, each of which corresponds to one of the 30 target words. For each palette, the colour patches were defined in CIELAB space.

2) **Determining the correct number of clusters for each palette.**

   Every colour palette was divided into a different number of clusters. A silhouette value was used to analyse the results of different k-means clustering solutions. The silhouette represents a measure of how close each point in one cluster is to points in the neighbouring clusters. To compare the performance of a different number of clusters, the mean silhouette values of each cluster were collected. The larger the value, the better performance of this number of clusters. For example, the plot (Figure 6-4) shows that the highest silhouette value occurs at 2 clusters, suggesting that the optimal number of clusters is 2.

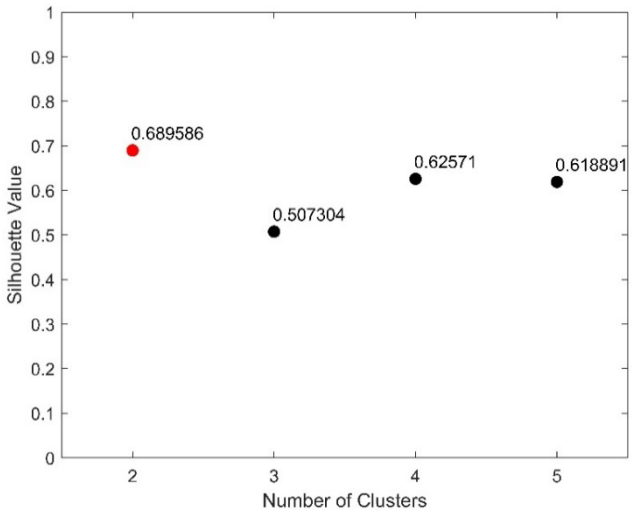


Figure 6-4 It shows the highest silhouette value occurs at 2 clusters, suggesting that the optimal number of clusters is 2

3) Analysis of the characteristic of each palette by K-Means Clustering.

All the patches of a palette were defined in CIELAB space in *Step 1*(Figure 6-5 left), and the optimal number of clusters was calculated in *step 2*. In this step, all the patches were partitioned into several exclusive clusters and centroids identified for each cluster (Figure 6-5 right).

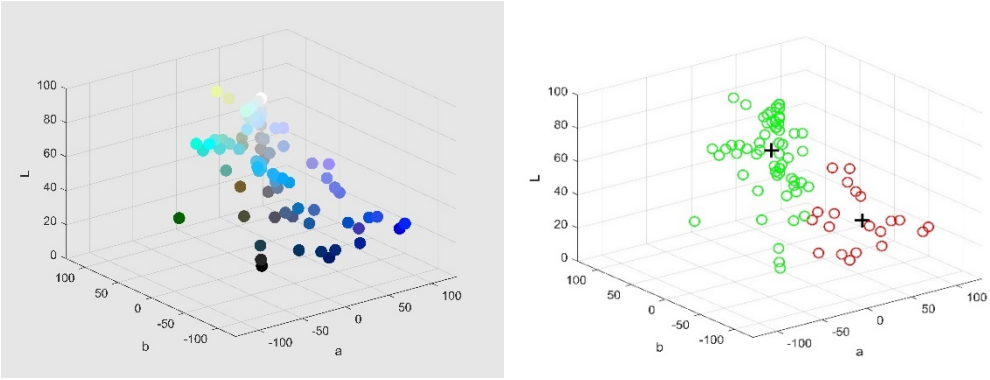


Figure 6-5 (a) All the colour patches of a palette were pointed in CIELAB space; (b) They were partitioned into two exclusive clusters, and the centroids of each cluster were presented by '+'.

To analyse the characteristics of a specific palette, the number of clusters and the weight of each cluster were collected:

- **the number of clusters** represents the colour distribution of a palette. It indicates how many main colour clusters within this palette. For instance (Figure 6-5), there are two main colour clusters of this palette: this word is associated with two main colour categories.
- **the weight of each cluster** represents the colour tendency of a palette. A large weight for a colour cluster means obvious colour tendency within a palette. It indicates a specific colour tendency is associated with the word.

Therefore, for each colour palette, the related colour distribution and related colour tendency were obtained to obtain the specific characteristic of the association.

6.3.5 Results

This experiment was performed in the laboratory, displayed on an HP DreamColor LP2480zx Professional Display (24-inch Diagonal LCD Backlit Monitor). The colours displayed in the experiment were defined by RGB values; however, they were measured using a Konica Minolta CS-2000 spectroradiometer to obtain CIELAB values (with reference to the white display point: CIE x = 0.3116, y = 0.3184) after the experiment. The data from thirty participants were organized into 30 colour palettes by every 30 words (Figure 6-6). Note that the first column corresponds to the most related colours; the other two columns correspond to the other two related colours.

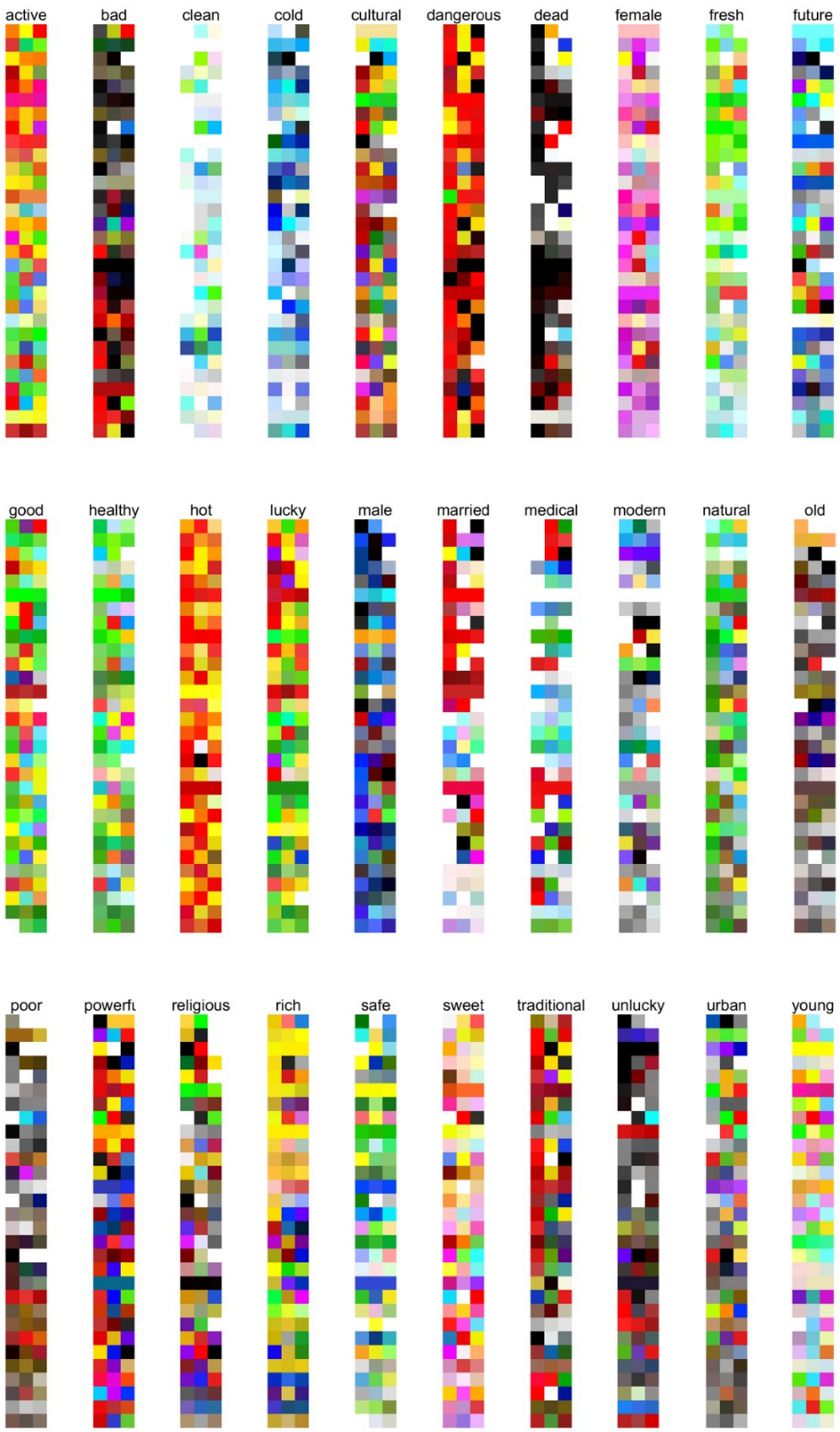


Figure 6-6 The presenting visual data of each word. In each palette, the first column corresponds to the most related colours; the left two columns correspond to the other two related colours.

6.3.5.1 Colour similarity comparison

In Experiment 2, each word was asked to select the most related colours and another two, and thus, for each word, there are two colour palettes after the experiment, which is the most related colour palette (Palette 1) and the other two related colours palette (Palette 2). The self-colour similarity of both palettes for each word was measured by PCC values (Table 6-3) for the most-related colour (Palette 1) and the other two related colours (Palette 2).

Table 6-3 The self-colour similarity of each palette by PCC values.

Word	Palette 1*	Palette 2*	Word	Palette 1	Palette 2
Active	0.74	0.73	***Married***	0.74	0.73
Bad	0.74	0.64	***Medical***	0.81	0.74
Clean	0.93	0.85	***Modern***	0.74	0.72
Cold	0.76	0.75	***Natural***	0.89	0.70
Cultural	0.67	0.63	***Old***	0.73	0.70
Dangerous	0.90	0.66	***Poor***	0.74	0.65
Dead	0.88	0.73	***Powerful***	0.68	0.63
Female	0.76	0.67	***Religious***	0.64	0.66
Fresh	0.82	0.77	***Rich***	0.86	0.68
Future	0.63	0.68	***Safe***	0.68	0.64
Good	0.84	0.77	***Sweet***	0.65	0.64
Healthy	0.87	0.71	***Traditional***	0.79	0.68
Hot	0.72	0.72	***Unlucky***	0.70	0.69
Lucky	0.83	0.80	***Urban***	0.73	0.64
Male	0.73	0.64	***Young***	0.62	0.67

Only three words which the PCC of Palette 1 is less than Palette 2.

**Palette 1: the most related colour palette;*

Palette 2: the other two related colours palette.

The PCC value is larger, the higher correlation and the larger similarity of the palette. For most of the words (90%), the similarity value of Palette 1 is larger than Palette 2; in only three cases, the similarity value of Palette 1 is less than Palette 2, and these are marked in the table. A histogram (Figure 6-7) was carried out to present a clear visual comparison between each set of Palette 1 and Palette 2. It is evident that, for many cases, the colour similarity value of Palette 1 is much larger than Palette 2 (such as ‘clean’, ‘dangerous’, ‘dead’, ‘natural’ and ‘rich’). On the contrary, in the three exceptional cases (marked by red colour in the figure), the colour similarity value of Palette 1 is slightly less than Palette 2.

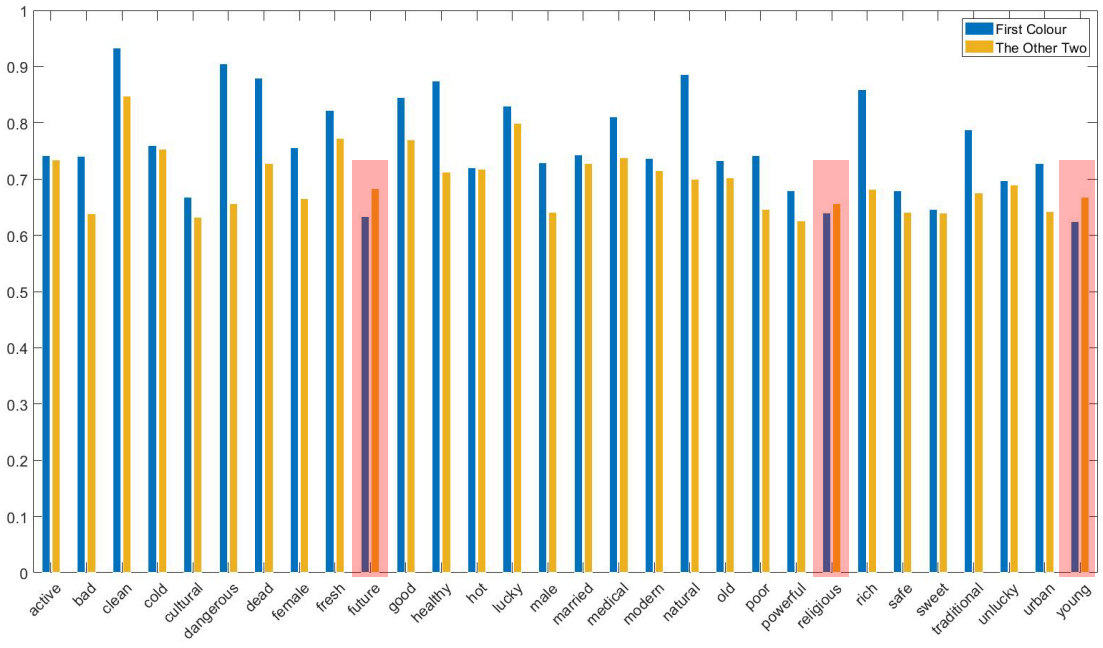


Figure 6-7 The comparison between each set of Palette 1 and Palette 2. For each word, the right column(blue) corresponds to the colour similarity value of Palette 1; the left column(yellow) corresponds to the colour similarity value of Palette 2

Therefore, this result indicated that the colour of the most related colour palette is more similar than the other two related colours palette for most of the words (90%). Note, the subjective strength of the association between each set of Palette 1 and Palette 2 is obtained: the participants were asked to

select the most corresponding colour and another two related colours. That is, for each word, the strength of association for Palette 1 is stronger than Palette 2. Thus, it is reasonable to consider the stronger association from the word to colour, the larger colour similarity of the related colours. The results also support the ideas in Chapter 5.

6.3.5.2 The characteristic of associations

In this part, K-Means Clustering Analysis was employed to explore the specific characteristic of the associations from word to colour. The most related colour and the other two related colours were organized into a single palette for each word. Thus, 90 related patches were collected from each palette for each word. Each of the palettes was analysed by K-Means Clustering to partition each of 90 colour patches and collected the characteristic. For instance, the analysis of the word ‘active’ is(Figure 6-8):

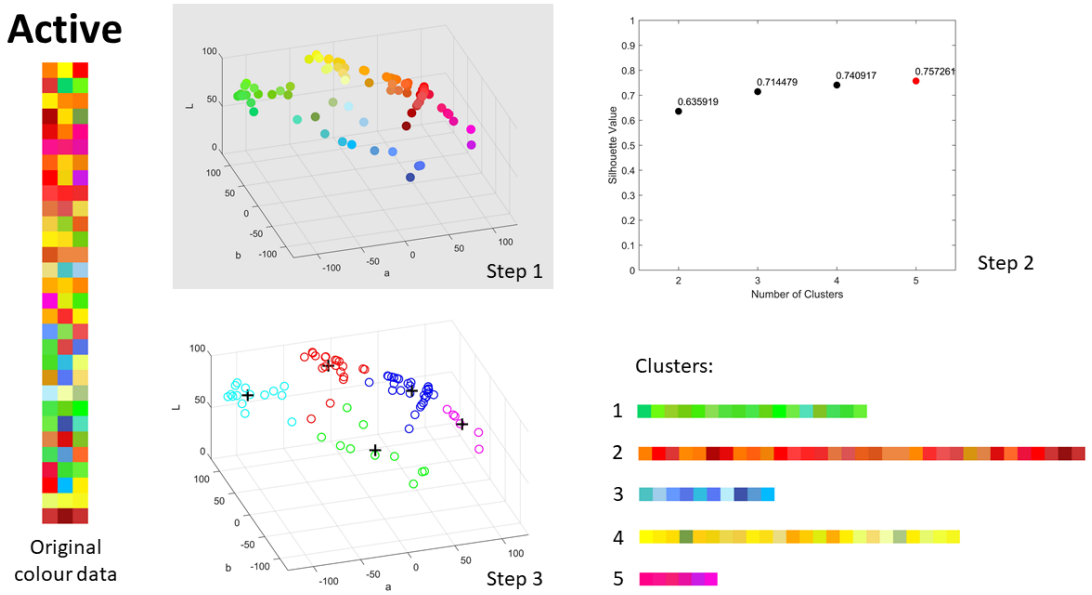


Figure 6-8 The analysis process of ‘active’.

Step 1: 90 related colour patches of ‘active ’were pointed in CIELAB space;

Step 2: highest silhouette value occurs at 5 clusters, suggesting that the optimal number of clusters is 5;

Step 3: 90 colours were partitioned into 5 clusters.

The weight of each cluster was collected (Table 6-3).

Table 6-4 The description of all clusters for ‘active’

Active					
	Cluster 1	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
Colours:	17	33	10	24	6
Weight:	0.189	0.367	0.111	0.267	0.067

To summary the characteristic of the association for ‘active’, the number of clusters and the weight of each cluster were collected (Table 6-3):

- **Related Colour distribution:**

  In this palette, there are five colour clusters. Thus, ‘active’ is associated with five main colour categories in this study.

- **Related colour tendency:**

  The weights of each cluster were collected. The largest weight of the clusters is Cluster 2 (33 colours and weight 0.367), which means the obvious colour tendency of this palette is red and orange colours. It indicates ‘active’ is closely associated with red and orange colours.

Each colour palette of each word was analyzed following this process one by one. The related colour distribution and related colour tendency were collected as the specific characteristics of each association from word to colours in this study. All the results of 30 words were presented in Table 6-5.

Table 6-5 The description of clusters for each word.

Word		Clusters				
Active	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.189	0.367	0.111	0.267	0.067
Bad	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.222	0.189	0.533	0.056	
Clean	N=2	***Cluster 1***	***Cluster 2***			
	Weight:	0.911	0.089			
Cold	N=2	***Cluster 1***	***Cluster 2***			
	Weight:	0.767	0.233			
Cultural	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.167	0.322	0.267	0.122	0.122
Dangerous	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.644	0.144	0.200	0.011	
Dead	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.278	0.600	0.022	0.022	0.078
Female	N=3	***Cluster 1***	***Cluster 2***	***Cluster 3***		
	Weight:	0.411	0.467	0.122		
Fresh	N=3	***Cluster 1***	***Cluster 2***	***Cluster 3***		
	Weight:	0.122	0.489	0.389		
Future	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.544	0.067	0.256	0.133	
Good	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.356	0.189	0.233	0.067	0.156
Healthy	N=3	***Cluster 1***	***Cluster 2***	***Cluster 3***		
	Weight:	0.300	0.178	0.522		
Hot	N=3	**Cluster 1**	**Cluster 2**	**Cluster 3**		
	Weight:	0.056	0.633	0.311		
Lucky	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.267	0.100	0.233	0.400	
Male	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.322	0.067	0.289	0.233	0.089
Married	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***

	Weight:	0.311	0.389	0.144	0.100	0.056
Medical	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.556	0.056	0.211	0.178	
Modern	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.578	0.100	0.111	0.111	0.100
Natural	N=2	***Cluster 1***	***Cluster 2***			
	Weight:	0.567	0.433			
Old	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.067	0.367	0.089	0.078	0.400
Poor	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.222	0.511	0.211	0.056	
Powerful	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.211	0.156	0.233	0.367	0.033
Religious	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.178	0.144	0.067	0.167	0.444
Rich	N=2	***Cluster 1***	***Cluster 2***			
	Weight:	0.722	0.278			
Safe	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.189	0.378	0.278	0.156	
Sweet	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.311	0.244	0.267	0.178	
Traditional	N=5	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
	Weight:	0.100	0.367	0.100	0.089	0.344
Unlucky	N=3	***Cluster 1***	***Cluster 2***	***Cluster 3***		
	Weight:	0.733	0.178	0.089		
Urban	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.133	0.133	0.189	0.544	
Young	N=4	***Cluster 1***	***Cluster 2***	***Cluster 3***	***Cluster 4***	
	Weight:	0.122	0.233	0.433	0.211	

**N: the number of clusters;*

Weight: the weight of each cluster in the palette.

From this analysis, two main characteristics of associations from word to colour were summarized:

1) The related colour distribution of word:

For different words, the related colours have different numbers of the colour cluster. Some words associated with two main colours (such as ‘clean’, ‘cold’, ‘rich’); some words associate with three main colours (such as ‘female’, ‘fresh’, ‘health’) and some words associated with more main colours (such as ‘active’, ‘cultural’, ‘dead’).

2) The related colour tendency of the word:

Different words are associated with different colour tendency. It could divide into two categories by the weight of each cluster: a word have a single colour tendency of the associated colours (one cluster presents a much larger weight than other clusters); a word has several colour tendencies of associated colours (more than one clusters present a much larger weight than others). For example, the words ‘dead’ and ‘modern’, they associated with a single colour tendency obviously; on the contrary, ‘female’ and ‘fresh’, they associated with more than one colour tendencies (Figure 6-9).

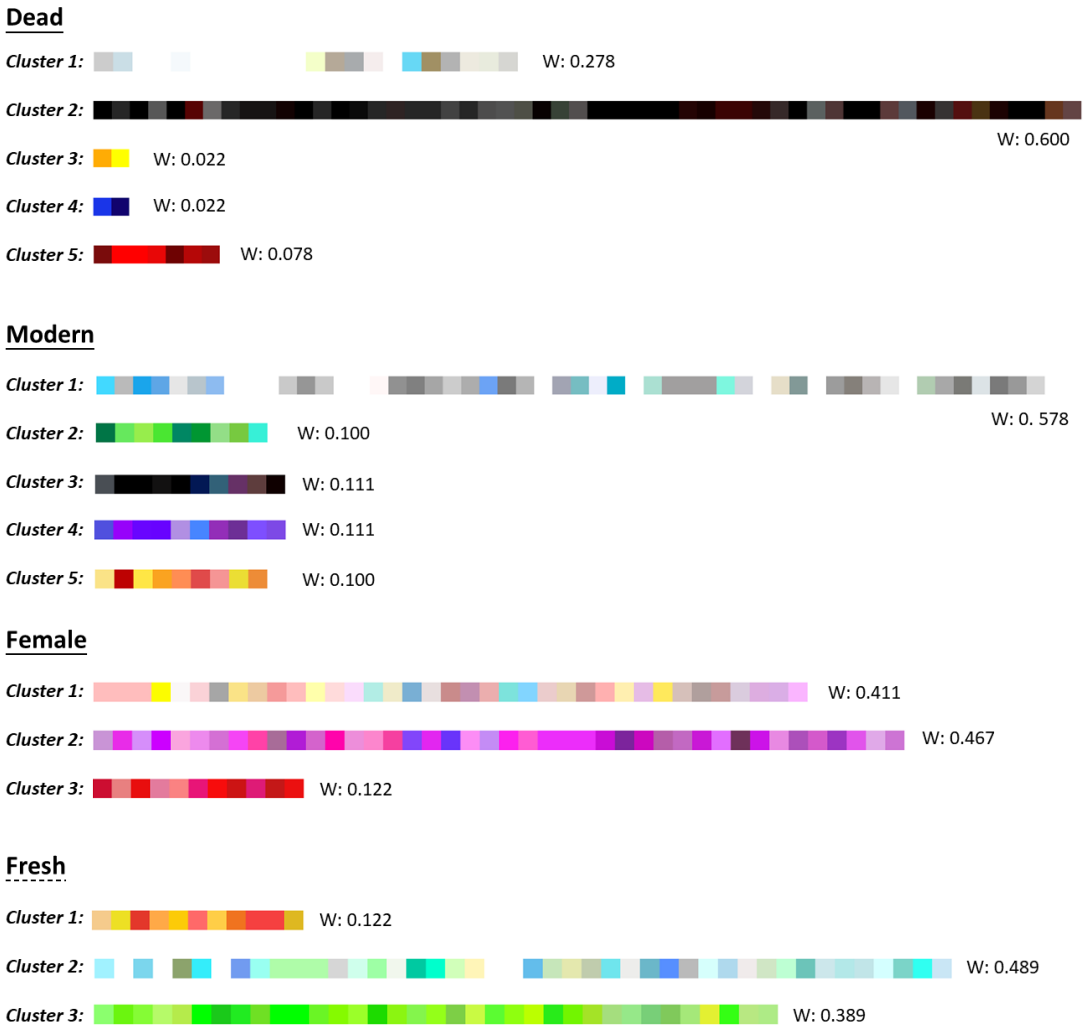


Figure 6-9 The clusters of ‘dead’, ‘modern’, ‘female’ and ‘fresh’. The words ‘dead’ and ‘modern’ they associated with a single colour tendency obviously; on the contrary, ‘female’ and ‘fresh’, they associated with more than one colour tendencies；

6.3.5.3 Conclusion of the characteristic of word and colours associations

This study explored the characteristics of associations from word to colours. An analysis method of the associations was introduced, and this method applies to these 30 sample words and any other words to investigate the specific characteristic of the associations from word to colours. Also, three main points of the associations were summarised in this study:

- **The extent of the association:**

  The stronger association from the word to colour, the larger colour similarity of the related colours.

- **The related Colour distribution of word:**

  For different words, the related colours have a different number of colour cluster.

- **The related colour tendency of the word:**

  Different words are associated with different colour tendencies. These can be divided into two categories by the weight of each cluster: words that have a single associated colour; words that have several associated colours.

In Chapter 5, it was mentioned that the similarity of selected colours for each word by different people corresponds to the extent of associations from each word to colours. If different people selected similar related colours for a word, some specific colours are near and significantly associated with this word and could evidence the strong associations from this word to some specific colours. In this study, this idea was further evidenced.

6.3.6 Culture Aspect Comparison

To conduct a cross-cultural aspect of this study, the data from the 15 British and 15 Chinese participants were analysed separately. In this section, the results of the British group and Chinese group were considered separately to allow a comparative study between British and Chinese cultures to explore whether any cultural similarities or differences in word and colour associations. The visible results from the British and Chinese participants are illustrated in

Figures 6-10 and 6-11, respectively. For each of the 30 words in each Figure, 45 colours patches (3 colours ×15 observers) are shown.

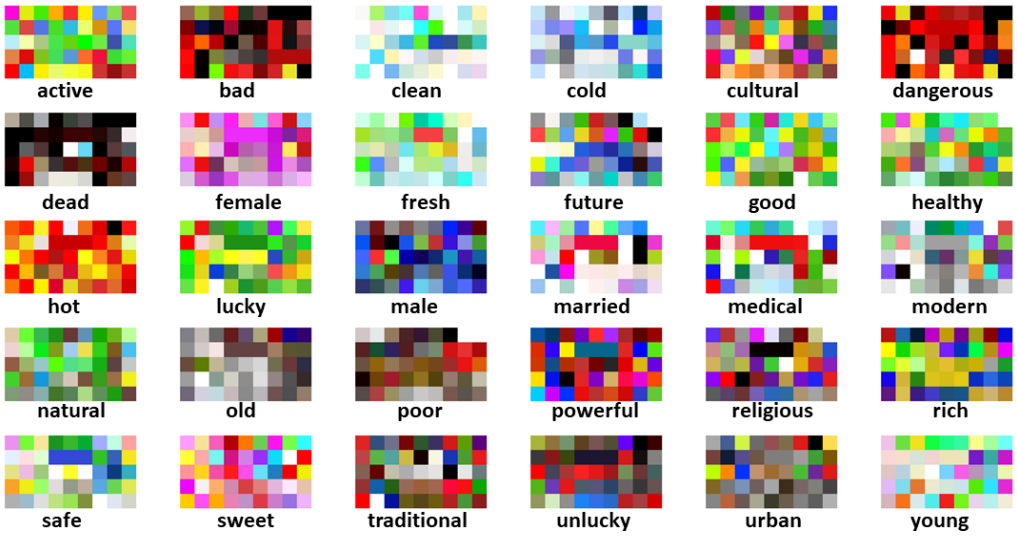


Figure 6-10 The experimental results of British participants.

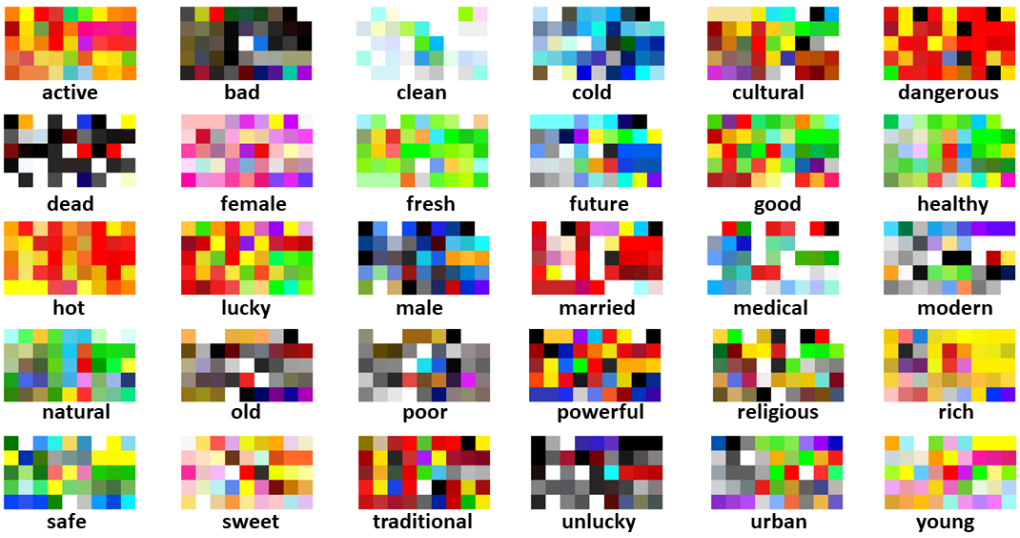


Figure 6-11 The experimental results of Chinese participants.

From the whole view:

'Large similarity between the British and Chinese group.'

Generally, a casual visual analysis of Figures 6-10 and 6-11 reveal more similarities than differences between British and Chinese palettes. In other words, broadly speaking, they are quite similar, reinforcing the evidence for a

word-colour relationship. Note, for example, the similarity in colours chosen by British and Chinese participants for the words clean, hot, healthy, natural etc.

In some specific cases:

'Culture differences influenced associated colours.'

For some specific words, it is clear that some difference exists between the two cultures. For example, red is used much more by Chinese participants in association with traditional and married. Another interesting difference between the colours associated with the words bad and lucky (Figure 6-12). In the UK (and in many western societies), the colour green is generally associated with positive meanings such as good luck or energy and the colour red is associated with some negative meanings such as dangerous and blood (Crozier, 1999; Adams and Osgood, 1973). However, in China, it is the colour red (not the colour green) associated with good luck (Tao *et al.*, 2016; Kommonen, 2011). Due to these cultural characteristics, many British participants selected red, which was associated with the word bad, and just a few red colours appeared, which were associated with the word lucky. On the contrary, red is selected much more by Chinese participants in association with the word lucky and few Chinese participants associate red with the word bad.

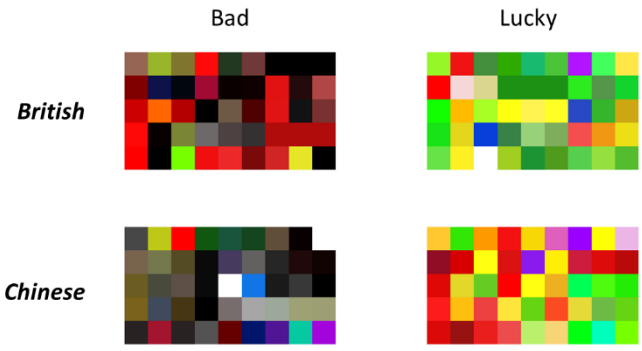


Figure 6-12 The colours associated with bad (left) and lucky (right) by British (upper row) and Chinese (lower row) participants.

Overall, in this study, although the primary observation is that actually there is more similarity than difference when we compare British and Chinese results, some interesting cultural differences can be found in these data. This indicates that cultural influence in word and colour associations cannot be ignored and needs to be explored systematically in the following work.

6.4 Discussion and Conclusion

The main propose of this study was to explore the specific characteristic of the association from a word to colours. A psychophysical experiment (Experiment 2) was employed to collect data on word and colour associations. Then, an analysis method was introduced to investigate the specific characteristics of the associations from word to colours, and three key points were summarised based on this study.

6.4.1 Key Insights

Widely academic studies explore the relationship from colour to concepts or a specific word. The characteristic of this relationship has discussed as colour emotion, colour meaning or colour semiotic (Ou *et al.*, 2004; Kauppinen-Räisänen & Jauffret, 2018). Such as people always associate blue with calming, depressing, peaceful, quiet, serious, and nostalgic (Gage, 1999); associate yellow with serene, gay and softly exciting (Goethe, 2006), or warm and sunny. Conversely, the discussion from specific concepts to colour is rarely to be mentioned. Understanding these word to colour associations is important for the effective use of colour in art and design (Chapter 4).

It has been noted that strong associations exist from specific words to colours (Chapter 5). Therefore, the main contribution of this study is to explore the specific characteristic of the association from a word to colours, and three main points of the associations were summarised:

(RQ 3.1, RQ 3.2)

- **The extent of the association:**

  The stronger the association from the word to colour, the larger the colour similarity of the associated colours.

- **The related Colour distribution of word:**

  For different words, the related colours have different numbers of colour clusters.

- **The related colour tendency of the word:**

  Different words are associated with different colour tendencies. Some words have a single colour tendency, whereas other words have several colour tendencies of the associated colours.

An analysis method of the associations was introduced, which is based on K-means, and this method applies to not only the sample words in this study but also any other words to investigate the specific characteristic of the associations from word to colours. In this study, the experiment only used 30 samples words. However, the conclusion of characteristic categorizing and the analysis method was also practicable for any other words in the related research. This work presents a meaningful and clear method in analysis the associations from word to colours.

6.4.2 Critique of the study and the next Step

The cultural influences of the associations from words to colours are a non-negligible part of the characteristic discussion. Some analyses have suggested that social groups that share common purposes around colour are relatively small and specialised (Kress & Van Leeuwen, 2006). Other (more empirical observations) have noted that there are more similarities than differences between cultures in terms of colour meanings (Lucassen *et al.*, 2010). The extent to which words and colours associations are shared between cultures, therefore, remains an open question.

In this study, the cultural influence of associations from word to colours was discussed. Two cultures (British and Chinese) were carried out to make a comparison, and it indicated the cultural influence in word and colour associations is significant and cannot be ignored in some specific cases.

However, the cultural influence was only based on these 30 participants and with a casual visual analysis. The specific characteristic of the cultural influence in word and colour associations was not mentioned, which is an important part of the association investigation. Thus, in the next part, another study will be introduced, focusing on the culture discussion in word and colour associations. More association data will be collected, and the cultural influence will be analysed systematically and deeply.

Chapter 7

Study 4: The effect of culture on word to colour associations.

7.1 Introduction

In chapter 6, the specific characteristics of the associations from word to colour were discussed, and three key ideas were summarised. A cross-culture study (British and Chinese) revealed some obvious cultural influences on word and colour associations though there were also many similarities. In this chapter, the cultural influence on word and colour associations is discussed further.

Associations from colour to word are not restricted to the English language (Al-Adaileh, 2012; Kommonen, 2011). Some analyses have suggested that social groups that share common purposes around colour are relatively small and specialised (Kress & Van Leeuwen, 2006). Even when people are exposed to the same colour, how they perceive colour, and the meanings and emotions of the same colour, are different among people due to gender, age, educational and culture, childhood association and others (Scott-Kemmis, 2013). Some studies have discussed colour associations among different cultures, and cross-cultural differences in colour associations have been identified (Philbrick, 1976; Trueman, 1979). Other (more empirical observations) have noted that there are more similarities than differences between cultures in terms of colour meanings (Lucassen *et al.*, 2010). Equally, the cultural influences on the associations of words and colour is a question that needs to be addressed.

Chapter 6 introduced some data for British and Chinese cultures to explore word and colour associations. In this chapter, the British and Chinese cultures continue to be studied. A further psychophysical experiment is carried out using the same experimental procedure but with a different set of 15 British and 15 Chinese participants. The experiment uses the same 30 target words as before to allow it to be compared with Experiment 2 (Chapter 6). The main purpose of this work is 1) to explore the cultural influence of word and colour associations, if this experiment presents the characteristic of the results in two cultural groups, which is similar to the last experiment, it will prove that specific influence is existing in word and colour associations by different cultures; 2) to provide more robust results between these two cultures, in order to better understand the effect of culture on word and colour associations. Overall, this study carries out an in-depth analysis of cultural influence in word and colour associations. It presents an efficient cultural discussion approach for the samples (British and Chinese cultures) and any different two cultures. Besides, an evaluation system of cultural influence is established and introduced. It categorises the characteristic of difference in two cultures and provides a quantised cultural influence in word and colour associations.

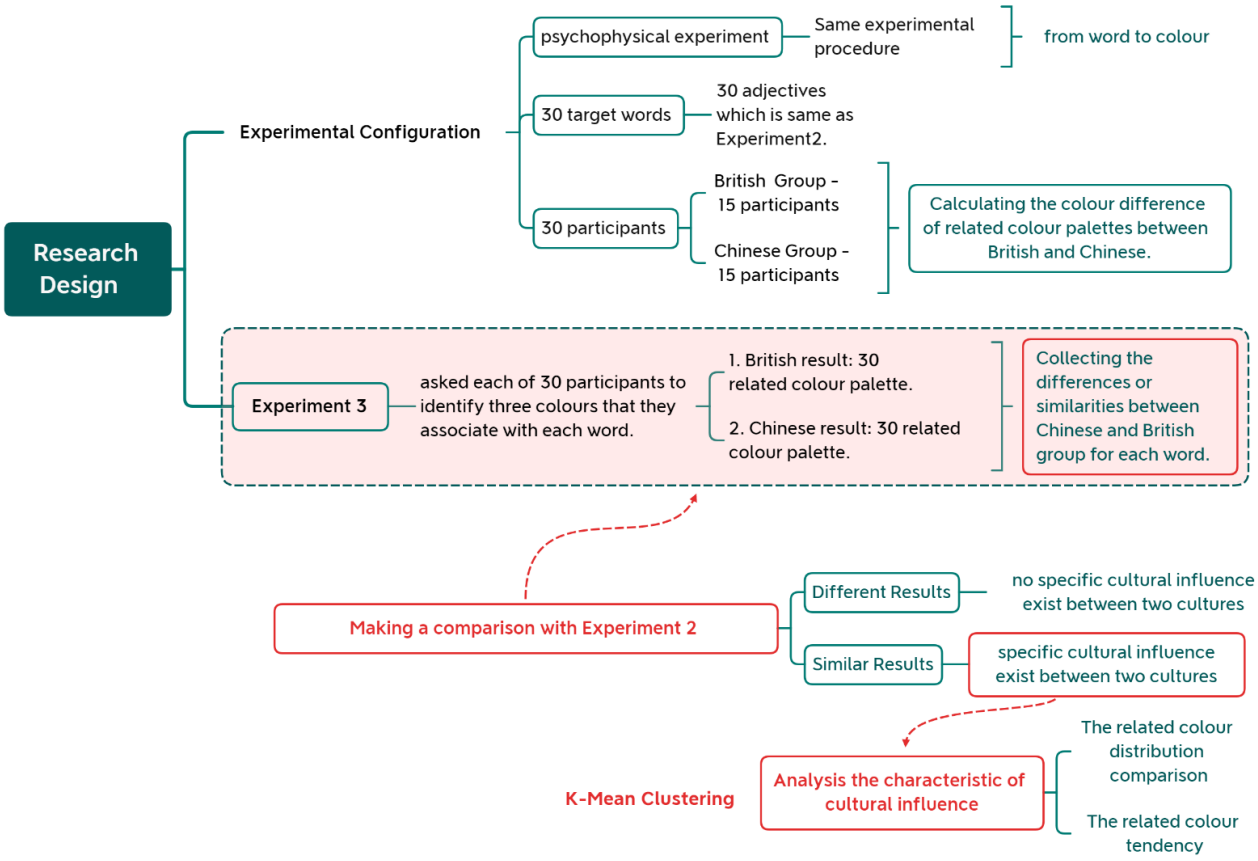


Figure 7-1 A visual summary of the research process in this chapter

7.2 Research Questions and Objective

In this chapter, one main research question and two sub-research questions are considered (see Table 7-1). The research objectives are summarised according to the research questions: 1) to determine the cultural influence on word and colour associations; 2) to analyse the characteristic of cultural influences on word and colour associations; 3) to explore a practical approach to compare differences in word and colour associations between different cultures.

Table 7-1 Research questions for this study

Main research question	*Sub-research questions*
RQ 3: Are there significant cultural influences on the associations from word to colour?	**RQ** 3.1: What is the characteristic of the cultural influence in the associations from words to colours?
	RQ 3.2: How to measure the characteristics of cultural influences on associations from word to colour?

7.3 Experiment Configuration

In the previous study (Chapter 6), Experiment 2 employed two groups (British and Chinese) to collect the associated colours by different cultural backgrounds. To explore whether any specific characteristic between two different cultures of colour associations, another experiment (Experiment 3) is carried out: a repeating experiment. It used to collect more research data in the cultural aspect and compare it with the previous experiment.

The experiments were conducted according to the University's code of ethical practice. A successful application was made to the ethical review committee (reference number LTDESN-071).

7.3.1 Participant Recruitment & Experimental Samples

Following the previous study's experiment configuration, an additional 30 participants, all aged above 18 with normal colour vision, were recruited in this experiment. To conduct a cross-cultural aspect of this study and explore the cultural influence of associations from word to colour, the participants were

limited to being British or Chinese. The thirty participants consisted of two groups: 15 British participants and 15 Chinese participants.

The same 30 target words were continued employed in this study as previously used and were provided to participants to choose colours related to each word. The 30 target words were translated into Chinese (Table 7-2). The British participants viewed English words, and the Chinese participants viewed Chinese words. A similar typeface was used for the English and Chinese words (that is, typefaces with similar emotional characteristics were used to avoid introducing additional factors).

Table 7-2 The list of words used in the two experiments

Number	***Words***	***Chinese***	***Number***	***Words***	***Chinese***	***Number***	***Words***	***Chinese***
1	Active	**积极的**	**11**	Good	**好的**	**21**	Poor	**贫穷的**
2	Bad	**坏的**	**12**	Healthy	**健康的**	**22**	Powerful	**强大的**
3	Clean	**干净的**	**13**	Hot	**热的**	**23**	Religious	**宗教的**
4	Cold	**冷的**	**14**	Lucky	**幸运的**	**24**	Rich	**富有的**
5	Cultural	**文化的**	**15**	Male	**男性的**	**25**	Safe	**安全的**
6	Dangerous	**危险的**	**16**	Married	**婚姻的**	**26**	Sweet	**甜的**
7	Dead	**死亡的**	**17**	Medical	**医学的**	**27**	Traditional	**传统的**
8	Female	**女性的**	**18**	Modern	**现代的**	**28**	Unlucky	**不幸的**
9	Fresh	**新鲜的**	**19**	Natural	**自然的**	**29**	Urban	**城市的**
10	Future	**未来的**	**20**	Old	**年老的**	**30**	Young	**年轻的**

* *Lanting Hei (兰亭黑) was chosen for the Chinese typeface.*

7.3.2 Experimental Procedure

The experimental procedure was as before: each participant was asked to select three related colours for each word. The display part of the design required the development of a GUI, and this was done by writing MATLAB code for the experiment. A uniform grey (L*=50) was used as the background (see Figure 7-2). The words were presented one at a time (and in a different random order for each participant) on the computer monitor. There were three buttons below each word and, by clicking, each of the participants could select a colour from a colour palette. The British participants viewed English words, and the Chinese participants viewed Chinese words.

Figure 7-2 The GUI for the experiment. The British participants viewed English words, and the Chinese participants viewed Chinese words.

The experiment took place in the Experience Design Laboratory at the School of Design (University of Leeds) with controlled viewing conditions, lighting conditions and display technology. The viewing distance was about 40 inches from the observers' eyes to the testing screen samples. All observers had a

Colour Blindness Test before the experiment started. It generally took around 30 minutes for each participant, and the experimental procedure is: 1) Setting up; 2) Introduction; 3) Agreement signature and a Colour Blindness Test; 4) Main body of experiment. (For further details, refer to the experiment in Section 5.3.5 of Chapter 5.)

7.3.3 Results Collection

This experiment was performed in the laboratory, displayed on an HP DreamColor LP2480zx Professional Display (24-inch Diagonal LCD Backlit Monitor). The colours displayed in the experiment were defined by RGB values, and they were measured using a Konica Minolta CS-2000 spectroradiometer and converted to CIELAB values (with reference to the displayed white point: CIE x = 0.3116, y = 0.3184) after the experiment. The selected colours were organised into 30 colour palettes, one for each of the 30 words in each group. The visible results from the British and Chinese groups are illustrated in Figures 7-3 and 7-4. In each Figure, and for each of the 30 words, 45 colours patches (3 colours × 15 observers) are shown.

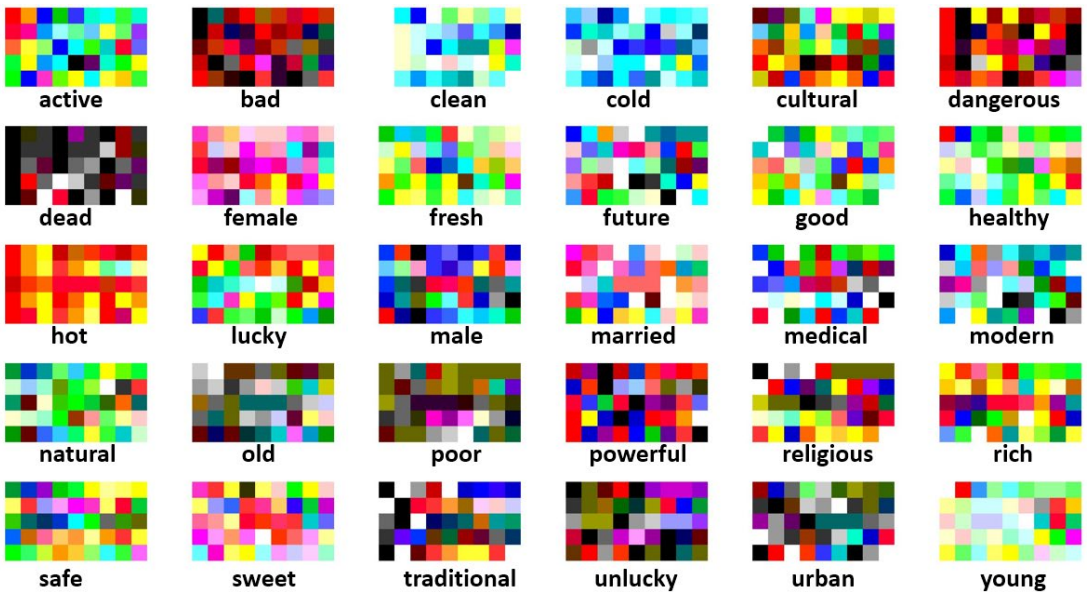


Figure 7-3 The experimental results of British participants.

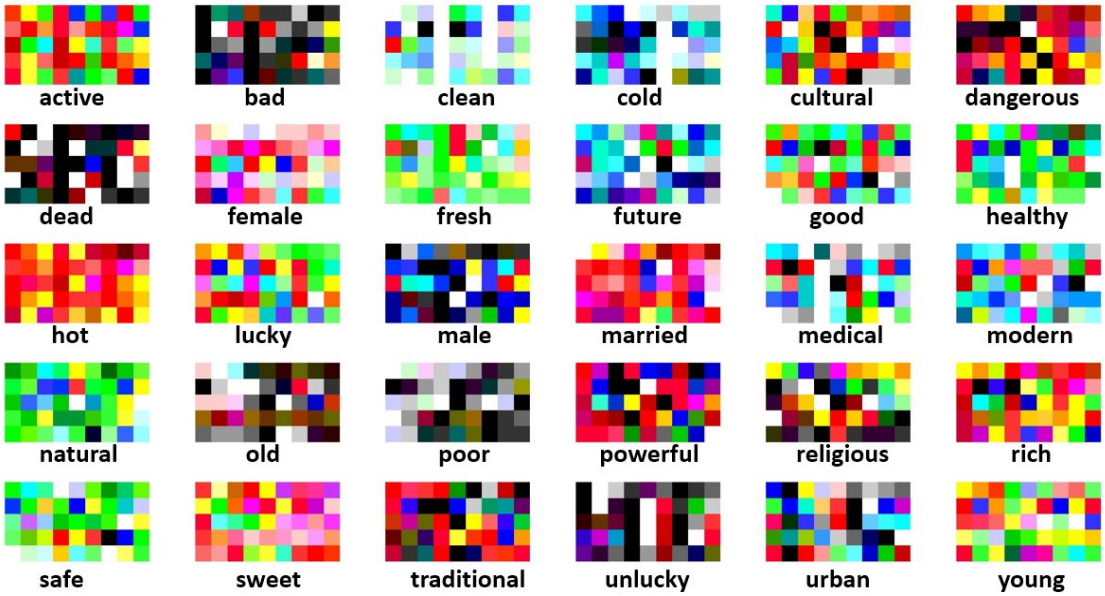


Figure 7-4 The experimental results of Chinese participants.

7.4 Experimental Results Analysis

The analysis of the data consists of two steps. First, a comparison with Experiment 2 (Chapter 6) explores whether the specific cultural influence exists of the word to colour associations. Second, analyse the characteristic of cultural influence in Experiment 3 and explore a systematic approach in the cultural discussion of the word to colour associations.

7.4.1 Step 1: The comparison with Experiment 2

In Experiment 2, some interesting cultural influences on word-colour associations were noted, but these were only based on a visual analysis of colour without any quantitative analysis. Thus, in this study, the data from Experiment 2 will be analysed more carefully and compared with Experiment 3.

7.4.1.1 Data Analysis Method

The first step is to compare the British results and Chinese results. If the same cultural differences are observed in Experiment 2 and Experiment 3, this will provide strong evidence for a cultural effect on word-colour associations.

In each experiment, there are two related colour palettes of each sample word which correspond to British and Chinese results. The colour difference between each set of colour palettes (British and Chinese results of each word) will be analysed, representing the cultural influence of the colour associations for each sample word directly. The larger the colour difference between the British palette and the Chinese palette for a given the word, the stronger the cultural influence on this word.

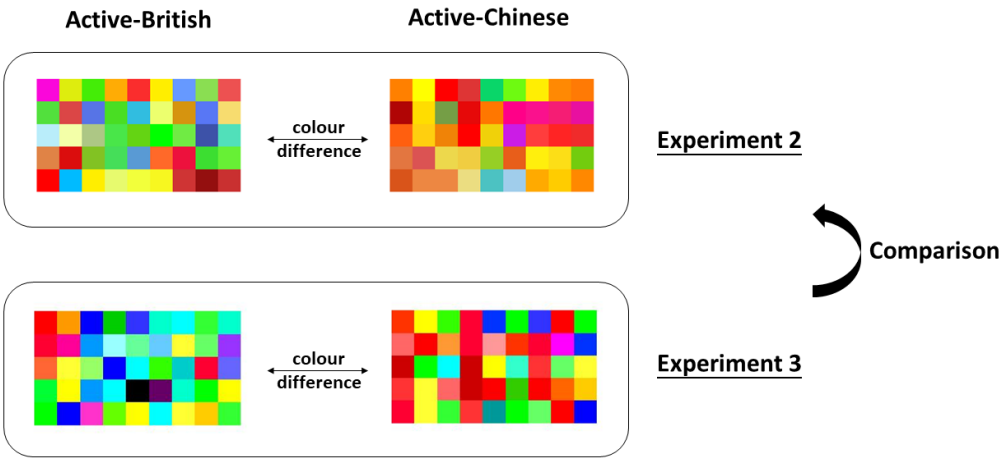


Figure 7-5 The results analysis process.

To measure the colour difference between each set of two colour palettes, ΔE^*_{ab} formulate is carried out in this study which is a basic method in the general colour difference computation between two colours (Hunt and Pointer, 2011:57-58), as shown in Eqn 6 (Section 5.3.4 in Chapter 5):

$$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

Eqn 6

Each colour palette includes 45 colour patches (15 participants x 3 colours). The algorithm's concept is to compare each patch's colour in one palette with every other colour patch in the second palette, then take an average of these colour differences. The details are described thus:

1. Each colour in one palette can form a colour pair with every colour in the second palette. Thus, each colour in one palette will form 45 colour pairs with 45 colours in the second palette. This will result in 45 x 45 = 2025 colour pairs.
2. Calculating the colour difference between each colour pair by ΔE^*_{ab} Formulate which will result in a set of 2025 colour difference values.
3. Averaging the 2025 colour difference values to represent the colour difference between two colour palettes.

7.4.1.2 Results Analysis

For Experiment 2 and Experiment 3, each word's strength of cultural influence was collected as the colour difference value between each British palette and Chinese palette set. Thus, the colour difference between each 30 sample words was calculated respectively (Table 7-3 shows the colour differences between the Chinese and British colour palettes for each word and each experiment). Mean ΔE^*_{ab}: the colour difference between British results and Chinese results. A larger value means a larger colour difference. The order of words depends on the value of the colour difference (sort descending). The top 10 large value words and the last ten small value words were marked with the red and blue frames.

Table 7-3 The colour differences between Chinese and British palettes. The data are sorted for each Experiment, with the greatest differences being displayed at the top.

Experiment 2			*Experiment 3*		
Number	**Words**	**MeanΔE^*_{ab}**	**Number**	**Words**	**MeanΔE^*_{ab}**
1	*Active*	117.14	1	*Lucky*	115.65
2	*Good*	105.49	2	*Powerful*	113.07
3	*Lucky*	105.13	3	*Active*	110.68
4	*Rich*	102.28	4	*Good*	110.03
5	*Cultural*	101.91	5	*Rich*	109.13
6	*Safe*	101.66	6	*Cultural*	101.81
7	*Male*	101.61	7	*Religious*	101.28
8	*Powerful*	95.77	8	*Safe*	99.75
9	*Medical*	95.59	9	*Young*	98.49
10	*Future*	94.87	10	*Future*	97.64
11	*Religious*	94.57	11	*Medical*	96.34
12	*Young*	94.46	12	*Healthy*	96.31
13	*Traditional*	94.14	13	*Traditional*	96.03
14	*Married*	93.58	14	*Fresh*	93.87
15	*Sweet*	92.99	15	*Married*	93.55
16	*Healthy*	92.63	16	*Urban*	92.08
17	*Natural*	90.61	17	*Natural*	91.57
18	*Modern*	89.83	18	*Sweet*	91.01
19	*Urban*	87.85	19	*Male*	90.20
20	*Female*	84.71	20	*Bad*	77.81
21	*Fresh*	84.66	21	*Modern*	77.54
22	*Dangerous*	79.97	22	*Dangerous*	76.84
23	*Cold*	76.88	23	*Unlucky*	73.01
24	*Unlucky*	76.30	24	*Female*	72.23
25	*Bad*	74.06	25	*Cold*	67.75
26	*Clean*	67.79	26	*Poor*	62.63
27	*Hot*	63.56	27	*Dead*	62.13
28	*Poor*	61.33	28	*Hot*	59.34
29	*Old*	61.16	29	*Old*	58.75
30	*Dead*	58.02	30	*Clean*	48.54

The order of 30 words depends on the value of MeanΔE^*_{ab} (sort descending). Larger values indicate larger colour differences which represent stronger cultural influences on the word. In the table, the top 10 largest value words and the last ten smallest value words were marked with red and blue frames, respectively. First, the results indicated that the cultural difference influenced the related colours for these 30 words in both experiments. Some words presented a strong impact, and some words were influenced slightly.

Comparing the results of Experiment 2 and Experiment 3, it is noticed that 80% of the largest value words (eight words of ten, marked as red) are coincident in both experiments. Also, 80% of the smallest value words (eight words of ten, marked as blue) are the same. This suggests a strong similarity between Experiment 2 and Experiment 3 for cultural influence. Although they are two independent experiments differently and employed different participants, the evident similarity of the cultural influence on the related colours between British and Chinese cultures is presented. Besides, a strong correlation (R-value = 0.9131) exist between two experiments.

This result indicates the cultural background of the participant influences the word-colour association. Thus, in the following work, it will discuss the characteristic of the cultural influence in word and colour associations and explore a practical approach to compare the word-colour associations between different cultures.

7.4.2 Step 2: The characteristic of cultural influence

In this part, the data from Experiment 3 is further analysed. The associated colours of each word for British and Chinese participants were compared to summary the characteristic of cultural influence in this study. An efficient and systematic cultural comparison approach for word and colour associations was developed. An evaluation system of cultural influence was established and introduced that categorises the characteristics of the difference in two cultures and provides a quantised cultural influence in word and colour associations.

7.4.2.1 Data Analysis Method

K-Means Clustering Analysis was introduced in the last chapter to analyse the specific characteristic of associations from word to colour (Section 6.4.2 of Chapter 6). This method uses the same approach to present the colour distribution and tendency of related colours for each word.The related colour distribution and related colour tendency were collected for each word in both groups using K-Means Clustering Analysis:

- **the number of clusters** represents the colour distribution of a palette. For each sample word, the number of clusters in the British and Chinese groups was collected separately to compare the related colour distribution between these two cultures.
- **the weight of each cluster** represents the colour tendency of a palette. The colour clusters' large weight was gathered from each word in both groups to compare the related colour tendency between the British and Chinese groups.

Thus, the comparison of the related colour distribution and the tendency of each word in British and Chinese were collected one by one. An evaluation

system was established to categorise each set of word (British and Chinese) and provide a quantised cultural influence of the word.

7.4.2.2 Results Analysis: The related colour distribution comparison

First, the cultural groups' comparison is in terms of colour distribution. The number of clusters and the centroid of each cluster was compared between British and Chinese related colour palettes for each word. For instance, the first word 'active' presented five clusters of related colours in both British results and Chinese results. To compare the colour distribution of 'active' in two groups, every colour patches were pointed in CIELAB space (black dots represent the results from the British group; red dots represent the results from the Chinese group), and the centroid of each cluster was marked ('**+**' was carried out to represent the centroid) (Figure 7-6). Obviously, five centroids in British and five centroids in Chinese were in pairs with very close positions. It means the five clusters as pairs and overlap between British and Chinese results. Thus, the word 'active' has the same distribution of related colours between the British and Chinese groups.

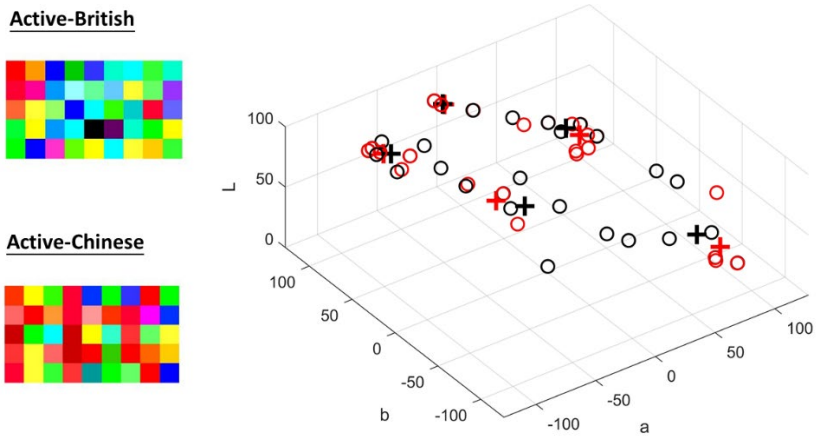


Figure 7-6 The related colour distribution of 'active'.

Black dots represent the results from the British group; red dots represent the results from the Chinese group. '**+**' was carried out to represent the centroid of each cluster.

A comparison of colour distribution between British and Chinese group for 30 words is presented in Table 7-4. The number of clusters in both groups was provided for each word. Besides, the number of matched clusters for each word were collected. It is noticed that only four words (marked in red) have the same number of clusters between British and Chinese groups. However, the case of only one cluster did not match; there are 14 words (marked in blue colour). Thus, the small part of 30 words, the related colour distribution presented a large difference (12 words). These results indicated that, in terms of related colour distribution of these 30 words, the similarity is larger than the difference between the British group and the Chinese group of the word and colour associations.

Table 7-4 The number of clusters for each word.

Number	Word	British	Chinese	Matched*
1	Active	5	5	5
2	Bad	3	3	3
3	Clean	2	5	2
4	Cold	2	2	2
5	Cultural	2	5	1
6	Dangerous	4	5	4
7	Dead	4	5	3
8	Female	5	4	3
9	Fresh	2	3	2
10	Future	5	2	2
11	Good	5	4	4
12	Healthy	5	4	4
13	Hot	2	3	2
14	Lucky	5	5	5
15	Male	4	5	3
16	Married	4	5	4
17	Medical	5	5	4
18	Modern	5	4	4

19	***Natural***	4	3	3
20	***Old***	5	5	4
21	***Poor***	2	3	2
22	***Powerful***	5	5	4
23	***Religious***	5	5	4
24	***Rich***	5	4	3
25	***Safe***	2	5	1
26	***Sweet***	4	4	3
27	***Traditional***	5	4	2
28	***Unlucky***	5	5	2
29	***Urban***	5	5	3
30	***Young***	3	5	2

* ***Matched:*** the number matched clusters between the British group and Chinese group.

Red: same number of clusters and matched between British and Chinese.

Blue: only one cluster did not match between the British and Chinese.

7.4.2.3 Results Analysis: The related colour tendency comparison

Then, the cultural groups' comparison is in terms of colour tendency. The number of main colours was compared between British and Chinese related colour palettes for each word. For instance, the first word 'active' (Figure 7-7) presented five average related colours in the British palette; in the Chinese palette, it showed one main colour tendency and four sub-colours of the related colours. It indicated that the word 'active' is specifically associated with red colours in the Chinese background. On the contrary, in the British background, 'active' is associated with green colours, dark blue colours, light blue colours, red colours and yellow colours, averagely without any significant main colours.

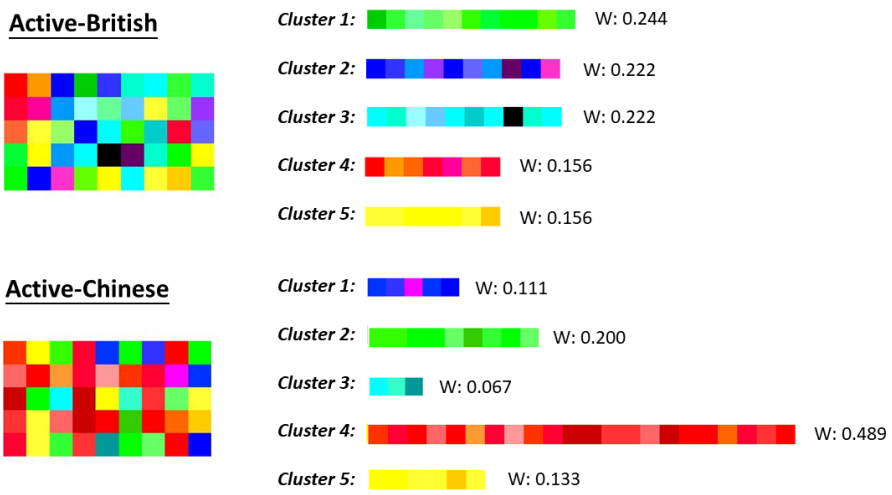


Figure 7-7 The related colour tendency of 'active'. It has five average related colours in British; in Chinese, it has one main colour tendency and four sub-colours in the related colours.

Thus, the number of large weight clusters and small weight clusters were collected for each word in two cultural groups (Table 7-5). In the table, 's' means the small weight clusters (the cluster which less than 10 colour patches); 'b' means the big weight clusters (the cluster which more than 10 colour patches). It is noticed that only five words which have the same number of small weight clusters and big weight clusters between British and Chinese. These results indicated that, in terms of these 30 words' colour tendency, the difference is larger than the similarity between the British group and the Chinese group of the word and colour associations.

Table 7-5 The number of large weight clusters and small weight clusters.

Number	Word	British	Chinese
1	***Active***	5s	1b 4s
2	***Bad***	2b 1s	1b 2s
3	***Clean***	1b 1s	1b 3s
4	***Cold***	1b 1s	1b 1s
5	***Cultural***	1b 1s	3b 2s
6	***Dangerous***	2b 2s	2b 3s

7	***Dead***	1b 3s	1b 4s
8	***Female***	2b 3s	1b 3s
9	***Fresh***	1b 1s	1b 2s
10	***Future***	1b 4s	2b
11	***Good***	2b 3s	3b 1s
12	***Healthy***	2b 3s	2b 2s
13	***Hot***	1b 1s	1b 2s
14	***Lucky***	2b 3s	2b 3s
15	***Male***	2b 2s	2b 3s
16	***Married***	3b 1s	1b 4s
17	***Medical***	2b 3s	1b 4s
18	***Modern***	1b 4s	1b 3s
19	***Natural***	2b 2s	1b 2s
20	***Old***	2b 3s	2b 3s
21	***Poor***	1b 1s	2b 1s
22	***Powerful***	2b 3s	2b 3s
23	***Religious***	1b 4s	2b 3s
24	***Rich***	2b 3s	2b 2s
25	***Safe***	1b 1s	2b 3s
26	***Sweet***	4s	4s
27	***Traditional***	3b 2s	2b 2s
28	***Unlucky***	3b 2s	2b 3s
29	***Urban***	2b 3s	1b 4s
30	***Young***	2b 1s	3b 2s

* ***b***: the big weight of cluster (the cluster which more than 10 colour patches);

s: the small weight of cluster (the cluster which less than 10 colour patches).

'***2b 1s***' means there are two big weight clusters and one small weight clusters for a word.

Red: the number of larger weight clusters and small weight clusters is matched between British and Chinese.

7.4.2.4 Cultural Influence Evaluation

British and Chinese groups' cultural influence was analysed by comparing the related colours for the same word. In analysing the above results, each word's

cultural influence was measured by two aspects separately: ***colour distribution*** and ***colour tendency***. To discuss the specific characteristic of cultural influence on each word, a Two-Aspect model and an evaluation system of culture influence were developed.

7.4.2.4.1 Two-Aspect Cultural Influence Model

Each word's related colour characteristic under British and Chinese cultural influence was collected by ***colour distribution*** and ***colour tendency***. In particular, to analyse the cultural influence, these two aspects should be considered together for each word. The Two-Factor theory (also known as Herzberg's motivation-hygiene theory) is worthy of reference in developing a two-aspects system (Herzbery, 1959). This theory proposes a two-factor model which is used to analyse the complex problem (individual working enthusiasm) by two factors and categories the problem into four possible situations to analyse (Herzbery and Frederick, 1966) (Table 7-6).

Table 7-6 Two-Factor theory (Herzbery, 1959).

Two-Factor model
➢ ***Motivators***   ➢ ***Hygiene factors***
Classification the problem into four possible situations to analyse: 1. **High** Hygiene + **High** Motivation   2. **High** Hygiene + **Low** Motivation   3. **Low** Hygiene + **High** Motivation   4. **Low** Hygiene + **Low** Motivation

Thus, a two-aspect cultural influence model is developed, which references the Two-Factor theory. It provides the cultural influence analysis from two aspects: ***colour distribution*** and ***colour tendency***, classification of the cultural influence into four types in word and colour associations between two

different cultures(Table 7-7). This model categorised the specific characteristic of cultural influence and is practical not only for British and Chinese cultural comparison but also for any other two cultures. It provides a theoretical approach in cultural influence discussion and is efficient to indicate different cultural influence levels in word and colour associations.

Table 7-7 Two-Aspect cultural influence model.

Two aspects
➢ ***Colour Distribution*** ➢ ***Colour Tendency***
Classification the cultural influence into four types: **1. Similar Colour Distribution + Similar Colour Tendency:** The cultural influence is negligible. **2. Different Colour Distribution + Similar Colour Tendency:** The cultural influence is appeared and affected the related colour distribution of the word. **3. Similar Colour Distribution + Different Colour Tendency:** The cultural influence is appeared and affected the related colour tendency of the word. **4. Different Colour Distribution + Different Colour Tendency:** The cultural influence is obvious.

7.4.2.4.2 Cultural Influence Evaluation System

According to this Two-Aspect cultural influence model, an evaluation system was developed to quantise each case's cultural influence into a specific level. The cultural influence is scored by a specific scale rule which consists of ***colour distribution*** influence level and ***colour tendency*** influence level. This evaluation system of cultural influence is formed as a two-dimensional coordinate axis (Figure7-8). It categorises the cultural influence on each word's related colours from colour distribution (X-coordinate) and colour

tendency (Y-coordinate) between two cultures. For each specific word, the smaller X value, the larger cultural influence on the related colour distribution; the smaller Y value, the larger cultural influence on the related colour tendency.

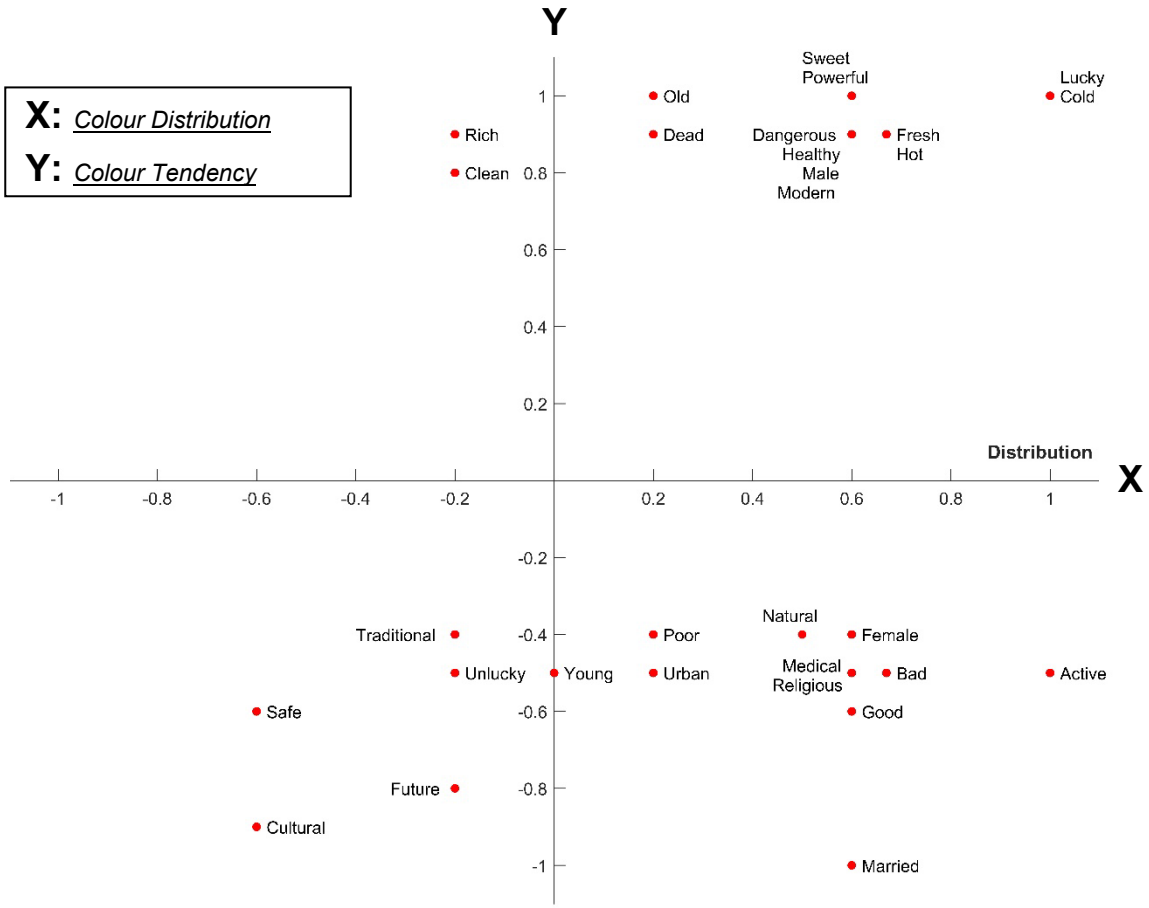


Figure 7-8 The evaluation system of cultural influence. It categorises the difference between two cultures for each word from colour distribution and colour tendency. For each specific word, the smaller X value, the larger cultural influence on the related colour distribution; the smaller Y value, the larger cultural influence on the related colour tendency.

In particular, each word's cultural influence was quantified as two scores and corresponded to a point in the coordinate. Identifying the specific X value and Y value in the system by measuring the difference of colour distribution and

colour tendency between two cultures (K-means clustering analysis, Section 6.4.2.2, Chapter 6). The details are described thus:

- **X-coordinate which corresponds to colour distribution;**

The X value is measured for each word following this evaluation sheet (Figure 7-9). A specific score will be provided by matching the number of clusters between two cultures, the X value. It includes three steps:

Step 1: determining the number of clusters of the related colours in British and Chinese results for the word. In the evaluation sheet, finding the corresponding position of the pairs of clusters number.

Step 2: Comparing the centroids' location between two cultures in CIELAB space and counting the number of adjacent pairs of centroids. Following step 1, in the corresponding position in the sheet, finding the matching level by colours: Green: the pair of centroids is adjacent which is matched; Red: the pair of centroids is not adjacent which is not matched; Yellow: the centroids are unpaired.

Step 3: each matching level corresponds to a specific score, the X value for the word.

For example, word 1 has five clusters of related colours in both two cultures; if the five clusters in the British results match the five clusters in the Chinese results, the score is 1; if only four pairs of clusters are matching, the score is 0.6; if only three pairs of clusters are matching, the score is 0.2. The related colour distribution of each word was compared between British results and Chinese results. The specific score was collected for each word by the number of clusters and matching extent (Table 7-4, section 7.4.2.2).

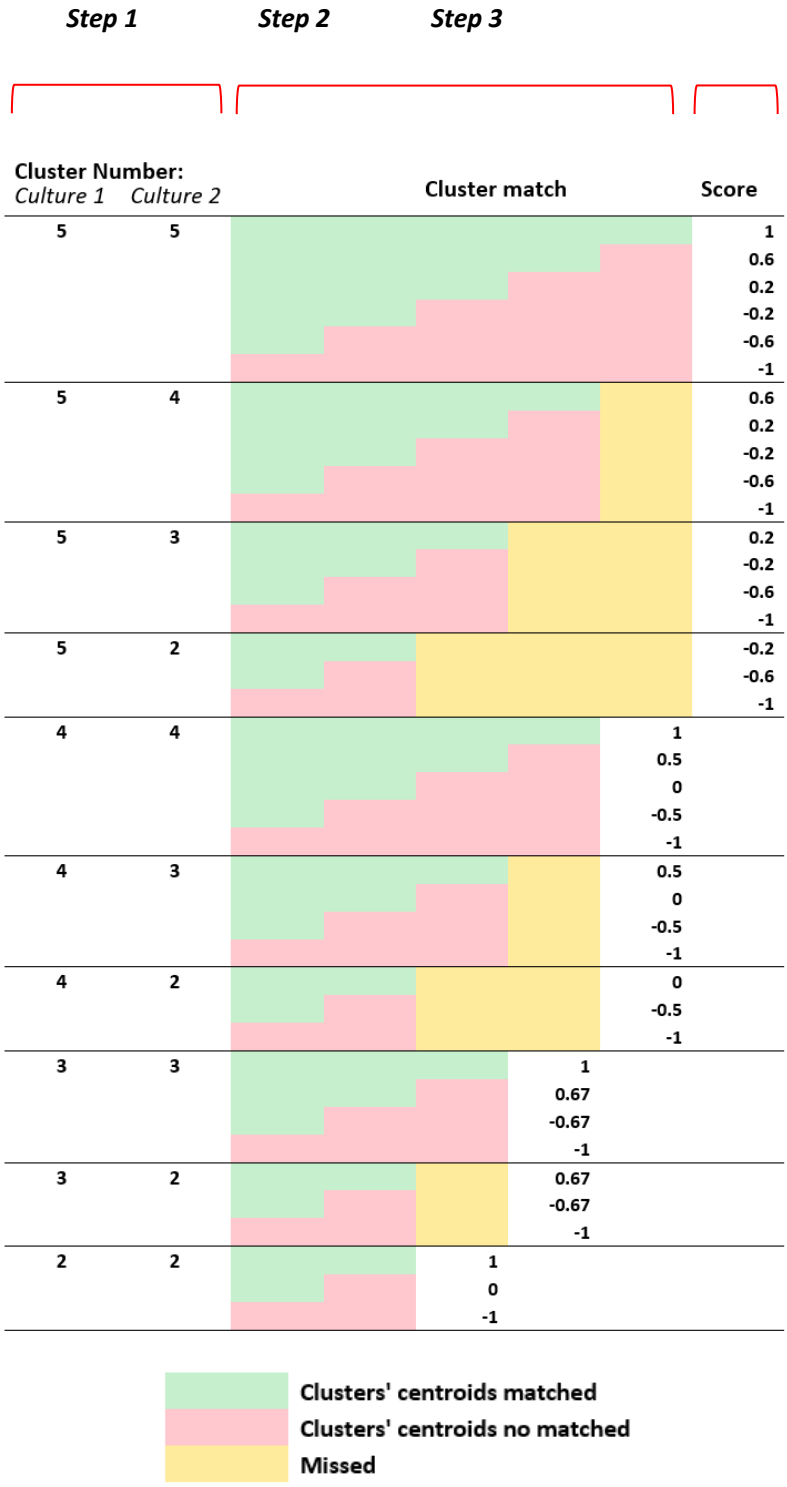


Figure 7-9 The evaluation sheet of the value of x-coordinate.

A specific score will be provided by the matching number of clusters between two cultures.

- **Y-coordinate, which corresponds to colour tendency (cluster weight).**

For each word, the Y value corresponds to the difference of colour tendency in two cultures. In section 7.4.2.3, Table 7-5, the number of big weight clusters (b) and small weight clusters (s) were collected for each word in two groups. The Y value is collected by comparing the number of 'b' and 's' between two cultures: the difference of a 'b' correspond to 0.4 points, and the difference of an 's' corresponds to 0.1 points. Thus, a specific score corresponds to the different number of 'b' and 's' for each word. For example, the first word 'active' (Figure 7-10), has five average related colours in British, which is five number of 's'; in Chinese, it has one main colour tendency and four sub-colours in the related colours which are 1 'b' and four number of 's'. The difference between '5s' and '1b 4s' is the Y value score, which is -0.5.

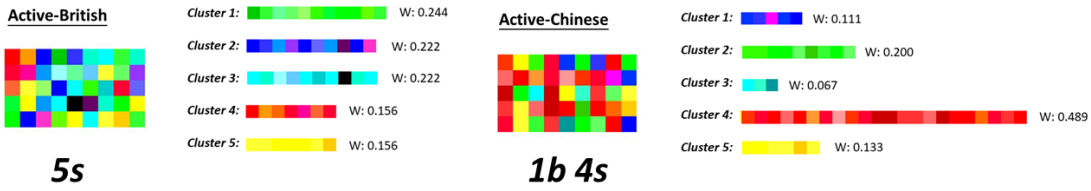


Figure 7-10 The measuring of the Y value for the word ‘active’:

Step1: Active {British\China + China\British} = 1b1s

Step2: Y value of ‘active’ = 0 - 1b1s = 0 - 0.4 - 0.1= -0.5

.

Therefore, the specific X and Y values were collected for each word and placed into the evaluation system. In this system (Figure 7-11), the cultural influence of words is categorised into four classes by four quadrants which also corresponds to the four types of cultural influence in the Two-Aspect cultural influence model:

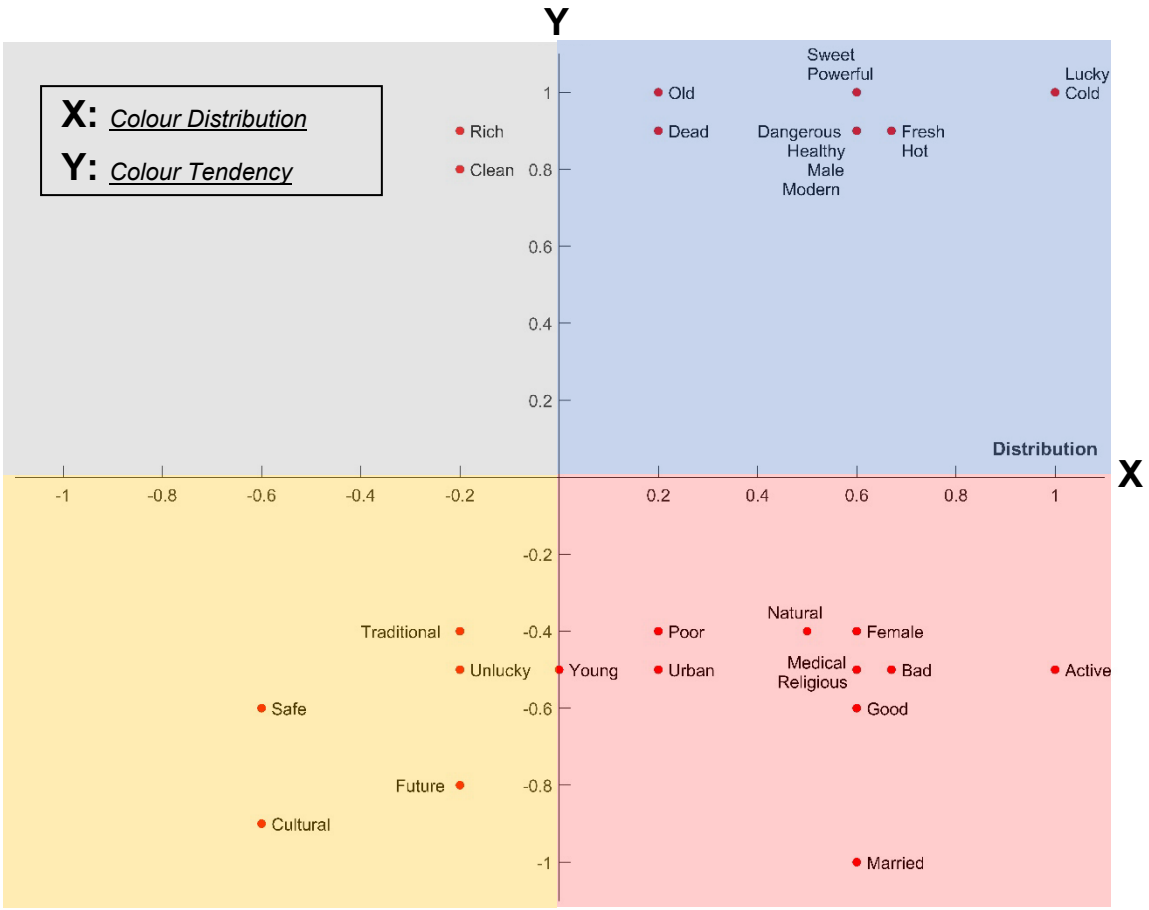


Figure 7-11 Four classes of the cultural influence of the evaluation system.

1) **Similar Colour Distribution + Similar Colour Tendency**
   No obvious influence by culture: Quadrant 1 (blue)

   For the words in Quadrant 1, it means no obvious influence by culture in these words. The related colours of these words present a large similarity between the two cultures. Such as 'lucky', 'cold'.

2) **Different Colour Distribution + Similar Colour Tendency**
   Cultural influence in colour distribution: Quadrant 2 (grey)

   For the words in Quadrant 2, it means the cultural influence is appeared and affected the related colour distribution of the word. Such as 'rich', 'clean'.

3) **Different Colour Distribution + Different Colour Tendency**
Obvious influence by culture: Quadrant 3 (yellow)

For the words in Quadrant 3, it means obvious influence by culture in these words. The related colours of these words present a large difference between the two cultures. Such as 'cultural', 'safe'.

4) **Similar Colour Distribution + Different Colour Tendency**
Cultural influence in colour tendency: Quadrant 4 (red)

For the words in Quadrant 4, it means the cultural influence is appeared and affected the related colour tendency of the word. Such as 'married', 'good'.

7.5 Discussion and Conclusion

This study's purpose was to explore the cultural influence on word→colour associations. British and Chinese participants took part in a psychophysical experiment (Experiment 3) using the same sample words (and the same experimental procedure) as in the previous study (Experiment 2).

7.5.1 Key Insights

Some studies have discussed colour associations among different cultures, and the cross-cultural difference in colour associations was indicated and evidenced (Philbrick, 1976; Trueman, 1979). Academic studies have explored the cultural influence on the associations in terms of colour to word, such as Osgood's (1973) colour emotion study among 20 countries; Thomas's (1999) colour meaning study was between 8 areas; and so on. However, it is noticed that cultural influence discussion from word to colour is rarely mentioned. In the previous chapters, the importance of colour associations from word to colour was indicated and identified. Thus, the discussion and investigation in

the cultural influence of the colour associations from word to colour are indispensable in this thesis.

In the last chapter (Chapter 6), the cultural influence was simply identified, and some interesting differences between British and Chinese colour palettes were revealed. In this study, another psychophysical experiment (Experiment 3) was employed to introduce a thorough exploration of cultural influence on the associations from word to colours:

- ***The cultural influence is specific and obvious.*** (RQ 3)

Comparing the experimental results with Experiment 2 indicated a similar cultural influence even though the two experiments were independent (different participants). It means the cultural influence is specific and noticeable; the strength of the influence varies for different words on the associations from word to colour.

- ***Four classes of the characteristic of cultural influence.*** (RQ 3.1)

In the second step, the characteristic of the cultural influence was analysed thoroughly. From the results of Experiment 3, the difference and similarity between the two cultural groups were collected and analysed. A Two-Aspect cultural influence model (Table 7-8) was established, presenting a theoretical model discussing the cultural influence on word and colour associations. This model categorised the specific characteristic of cultural influence into four types and is practical not only for British and Chinese cultural comparison but also for any other two cultures. It provides a theoretical approach in cultural influence discussion and is efficient to indicate different cultural influences on word and colour associations.

Table 7-8 Two-Aspect cultural influence model.

Two aspects
➢ ***Colour Distribution***   ➢ ***Colour Tendency***
Classification the cultural influence into four types: **1. Similar Colour Distribution + Similar Colour Tendency:**   The cultural influence is negligible.   **2. Different Colour Distribution + Similar Colour Tendency:**   The cultural influence is appeared and affected the related colour distribution of the word.   **3. Similar Colour Distribution + Different Colour Tendency:**   The cultural influence is appeared and affected the related colour tendency of the word.   **4. Different Colour Distribution + Different Colour Tendency:**   The cultural influence is obvious.

Subsequently, based on the theoretical model, an evaluation system was developed to provide a quantised cultural influence of each word. Each word's cultural influence was quantised as two values in the system and corresponded to a specific point in the coordinate. It is clear to present the different strength of cultural influence on each word and easy to make a comparison between different words. Although only 30 sample words were carried out in this study, any other words could be analysed using this evaluation system. It provides a visual and quantised analysis of the cultural influence of word and colour associations (RQ 3.2).

7.5.2 Critique of the study

This study indicated the cultural influence on word and colour associations and discussed the characteristic of cultural influence. By considering the practical operability, it has only employed British and Chinese cultures as the sample to investigate. In the future, it would be meaningful to involve more

cultures to make a wider exploration. It is worth comparing all the world's main cultures to make cultural influence discussion and summarise on colour associations. It would provide a guideline for cross-cultural design work or academic research.

Chapter 8
Discussion

At the end of the thesis, this chapter summarises all the studies and the overall conclusions of the main findings from this research. A conclusion of the research contributions, the limitations of this research, and the future work recommendations are described.

8.1 Summary

In summary, the research addressed in this thesis is motivated by 1) a current lack of research on colour associations, specifically in the direction from concept→colour; 2) the critical role of colour in design and the importance of colour associations in colour selection. Therefore, this research focuses on discussing the word→colour associations in design, with the long-term goal of aiding colour selection in the design process. It is hoped that this research could attract more attention to the colour association discussion, especially the discussion of the colour association from concept→colour.

This research explores colour associations, specifically from words to colours, useful and relevant in the colour selection process in design. This research has presented an in-depth discussion of the word→colour associations in design. To achieve this research aim, several specific objectives were outlined (Table 8-1). According to each specific objective, five research activities, including an interview, an online survey, and three laboratory experiments, were carried out to collect quantitative and qualitative data.

Table 8-1 The research objectives.

Chapter	Research Objectives
2	To provide a review of some fundamental concepts and definitions related to the research topic: - the basic knowledge of colour theories; - the significance and potential advantages of the role of colour in design; - a critical overview of colour associations. *Based on this review, the research topic has been developed.*
3	To develop the research methodologies and design the research plan, which includes the framework, the specific research activities, data collection and analysis methods. *Following this plan, four studies are carried out.*
4	To understand the colour selection process of designers and identify the meaning and application of word-colour associations in design.
5	To evidence that strong associations exist from word→colour and find out which types of words are associated with colours stronger than others.
6	To analyse the characteristics of word→colour associations.
7	To explore the cultural influence of word→colour associations.

The research has outlined a current lack of research on colour associations from concept→colour and has highlighted the critical role of colour in design and the importance of colour associations in colour selection. The research has been conducted through four studies:

Study 1 - Methods used by designers to choose colour (Chapter 4)

This study explored the design process and used an interview to collect new data on this topic. It identified a three-step colour selection method used by designers for selecting the colour in their design work. The importance of concept-->colour (as opposed to colour-->concept) was also highlighted (Figure 8-1). That is, finding associated colours for specific concepts or design topics is important in colour design. It identified the meaning and application of word→colour associations in design.

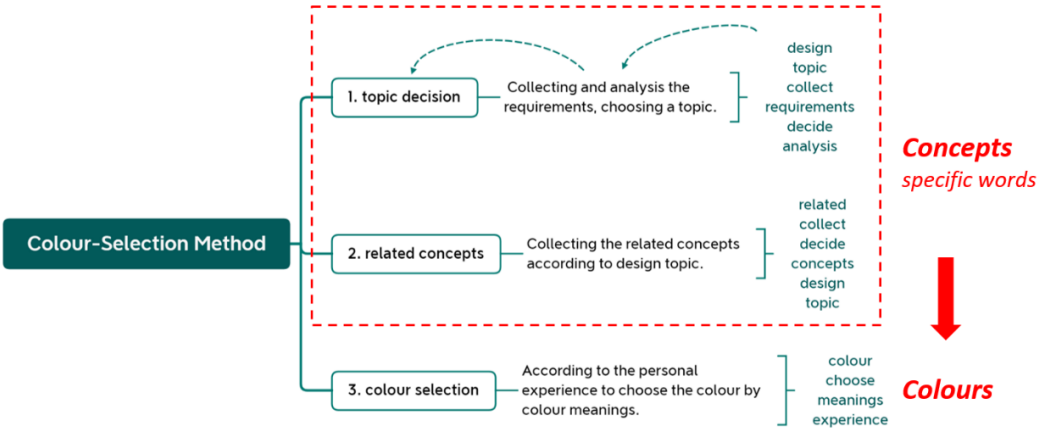


Figure 8-1 The analysis of the three-step colour selection method

Study 2 - Evidence for strong associations exist from word to colour (Chapter 5）

To discuss word→colour associations, the first step is to identify whether strong associations exist. This chapter evidenced word→colour associations through a psychophysical experiment (*Experiment 1*) and revealed that different word classes have different degrees of association with colours. Adjectives were found to be most strongly associated with colours in the experiment. On the contrary, verbs showed only weak associations with colours.

An online questionnaire was carried out to integrate the results with *Experiment 1*. It collected ideas from practical design perspectives; adjectives are identified as the most frequent words used as cues to select colours in the design. This result corresponds to the psychophysical experiment that found that adjectives were found to be most strongly associated with colours. Thus, it is reasonable to summarise that adjectives are the most practicable words recommended as the concept keywords in the colour-selection process in design. This provides more supplementary data to support the interview study (Study 2, Chapter 4).

Study 3 - The characteristic of the associations from word to colour (Chapter 6)

After concluding that word→colour associations exist, this chapter discusses the characteristics of the associations from word to colour. An analysis method for studying these associations was introduced, and three main findings were summarised from a psychophysical experiment (*Experiment 2*):

- **The extent of the association:**

  The stronger the association from word to colour, the larger the colour similarity of the related colours.

- **The related colour distribution of word:**

  For different words, the related colours have a different number of colour cluster. In other words, the number of colours found to be related to a word varies depending upon the word.

- **The related colour tendency of the word:**

  Different words are associated with different colour tendencies. It could divide into two categories by the weight of each cluster: a word have a single colour tendency of the associated colours; a word has several colour tendencies of associated colours.

The associations were explored through K-means cluster analysis. This method applies to the sample words in this study and any other words to investigate the associations' specific characteristic from word to colours. In this study, the experiment only used 30 samples words. However, the conclusion of characteristic categorising and the analysis method was also practicable for any other related research words. This work presents a meaningful and clear method in analysis the associations from word to colours.

Study 4 - The cultural influence of the associations from word to colour (Chapter 7)

In the last step of discussing word-colour associations, the effect of culture on the associations from word→colour was explored. In *Experiment 3*, it was evidenced that the cultural influence is specific and noticeable; the characteristic of the cultural influence is summarised as four main categories, and a theoretical model was developed (Table 8-2).

Table 8-2 Two-Aspect cultural influence model.

Two aspects
➢ ***Colour Distribution***   ➢ ***Colour Tendency***
Classification the cultural influence into four types: **5. Similar Colour Distribution + Similar Colour Tendency:**   The cultural influence is negligible.   **6. Different Colour Distribution + Similar Colour Tendency:**   The cultural influence is appeared and affected the related colour distribution of the word.   **7. Similar Colour Distribution + Different Colour Tendency:**   The cultural influence is appeared and affected the related colour tendency of the word.   **8. Different Colour Distribution + Different Colour Tendency:**   The cultural influence is obvious.

Subsequently, based on the theoretical model, an evaluation system was developed to provide a quantised cultural influence of word→colour associations. Each word's cultural influence was quantised as two values in the system and corresponded to a specific point in the coordinate. It is clear to present the different strength of cultural influence on each word and easy to make a comparison between different words. Although only 30 sample words were carried out in this study, any other words could analyse the evaluation system's cultural influence. It provides a visual and quantised analysis of the cultural influence of word and colour associations.

8.2 Research limitations

Each step of the research had its limitations in this study. Some of the limitations have already been discussed and improved in this thesis. From the overview of the research, several limitations were outlined and discussed:

- ***Lim. 1***

  First, in the colour selection process investigation, which is in Study 1, the findings might lack generalisability to each specific design fields. There are numbers of design fields currently, and new design categories have arisen. From the public perception, the categorisation within design fields does not have clear delineation boundaries (Margolin, 1989); it depends on individual accumulated knowledge and particular cultural settings (Cantor and Mischel, 1979; Forgas, 1983). The colour selection of different design fields has different requirements and focuses. Although this study is carried out to collect the general colour selection process and the interviewees are from different design fields, the results still carried any limitations, especially for some specific design fields.

- ***Lim. 2***

  Second, this research focuses on discussing the associations from words to colours. The discussion of different languages is not strong enough. Although it employed two languages (English and Chinese) and made some comparisons, other languages are still worth investigating in the word-colour associations' research.

- ***Lim. 3***

  Third, the other influence elements of word-colour associations did not discuss in this research. In the word-colour association's investigation, the influence elements are required to discuss. In the thesis, the influence of different categories of words and the cultural influence was explored. However, some other elements might influence the word-colour associations, such as the groups of participants, gender preference, or the related colours collection method.

- ***Lim. 4***

  Fourth, the weak of the psychophysical experiment in this study. The small number of sample words and participants. Although it has provided some value findings from these experiments, employing more sample words and recruiting more participants is still worth to conduct in further work.

8.3 Future work

A current lack of research on colour associations from concept→colour was observed. This research is started to explore these associations, but much more work is needed in this area. Based on the research findings and limitations, some further work can be planned and implemented in the future. Table 8-3 lays out further research recommendations.

Table 8-3 Further research recommendations.

Limitation	Research Recommendation
Lim. 1 The lack of generalisability of some specific design fields.	To conduct another in-depth interview that focuses on each specific design fields. Moreover, to collect the colour selection information from different design fields.
Lim. 2 The discussion of different languages is not strong enough.	To broaden the sample languages, such as Spanish, Arabic, Russian etc.
Lim. 3 The other influence elements of word-colour associations did not discuss in this research.	To employ several further experiments: - Exploring the influence of different ages or genders of the participants. - Changing the experimental method to collect related colours.
Lim. 4 The weak of the psychophysical experiment in this study.	To recruit more participants and sample words and to provide stronger results.
Others: - Finding a practical method that could replace the laboratory experiment to collect related colours for specific words. - Developing an automatic method in word-colour associations collection, building a system that includes plenty of words or languages and provides the related colours for each word.	

List of References

A

1. Aaronson BS (1970), Some affective stereotypes of color, International Journal of Symbology, 2 (1), 15-27.
2. Abbott, M., Holland, R., Giacomin, J., Shackleton, J. J. J. o. P., & Management, B. (2009). Changing affective content in brand and product attributes. 18(1), 17-26.
3. Adams, E. (2013) The Elements and Principles of Design: A Baseline Study. International Journal of Art & Design Education, 32(2), 157–175.
4. Adams, Francis M. and Charles E. Osgood. (1973). A Cross-Cultural Study of the Affective Meanings.
5. Adams, R. J. (1987). An evaluation of color preference in early infancy. Infant Behavior and Development, 10(2), 143-150.
6. Aghdaie, S. F. A., and Honari, R. (2014). Investigating the Psychological Impact of Colors on Process of Consumer Shopping Behavior. International Review of Management and Business Research, 3(2), 1244-1253.
7. Ahmed, S. (2000). PhD Thesis: Understanding the Use and Reuse of Experience in Engineering Design. Cambridge, Cambridge University Engineering Department.
8. Ahmed, S., Wallace, K.M. and Blessing, L.S. (2003). Understanding the Differences between How Novice and Experienced Designers Approach Design Tasks. Research in Engineering Design. 14, pp.1-11.
9. Aizawa, Akiko (2003). "An information-theoretic perspective of tf–idf measures". Information Processing and Management. 39 (1): 45–65.
10. Al-Adaileh, B.A., (2012). The Connotations of Arabic Colour Terms. Linguistica online, (13).
11. Albers, J.J., Wahl, P.W., Cabana, V.G., Hazzard, W.R. and Hoover, J.J., (1976). Quantitation of apolipoprotein AI of human plasma high density

lipoprotein. Metabolism, 25(6), pp.633-644.

12. Ambrose, G. & Harris, P. (2005a) Basics Design 05: Colour. AVA Publishing.
13. Ambrose, G. & Harris, P. (2005b) Basics Design 05: Colour. AVA Publishing.
14. Amsteus M, Al-Shaaban S, Wallin E and Sjöqvist S (2015), Colors in marketing: A study of color associations and context (in) dependence, International Journal of Business and Social Science, 6 (3), 32-45.
15. Ares G and Deliza R (2010), Studying the influence of package shape and colour on consumer expectations of milk desserts using word association and conjoint analysis, Food Quality and Preference, 21 (8), 930-937.
16. Aslam MM (2006), Are you selling the right colour? A cross‐cultural review of colour as a marketing cue, Journal of Marketing Communications, 12 (1), 15-30.
17. Attiah, D. Y., Cheung, V., Bromilow, D., & Westland, S. (2014, September). Colour planning in the interior design process. In Proceedings of The Second Conference of Asia Color Association (pp. 187-191).

B

18. Baek, E. et al. (2018) Using warmth as the visual design of a store: Intimacy, relational needs, and approach intentions. Journal of Business Research, 88, 91–101.
19. Ballard, K. (2013) The Frameworks of English: Introducing Language Structures. Macmillan International Higher Education.
20. Bannan-Ritland, B. (2003). The Role of Design in Research: The Integrative Learning Design Framework. Educational Researcher. 32(1), pp.21-24.
21. Bartram L, Patra A and Stone M (2017). Affective color in visualization. Paper presented at: Proceedings of the 2017 CHI Conference on Human

Factors in Computing Systems, 1364–1374. ACM.

22. Baxter, M. (1995) Product Design. CRC Press.
23. Beach, L., Wise, B.K. and Wise, J.A., (1988). The human factors of colour in design: A critical review. Moffet Field.
24. Beck, J., (1978). Additive and subtractive color mixture in color transparency. Perception & Psychophysics.
25. Bellizzi JA, Crowley AE, Hasty RW (1983), The effects of color in store design, Journal of Retailing, 59 (1), 21-45.
26. Bengtsson, A., & Grahn, P. (2014). Outdoor environments in healthcare settings: A quality evaluation tool for use in designing healthcare gardens. Urban forestry & urban greening, 13(4), 878-891.
27. Benesty, J., Chen, J., Huang, Y. and Cohen, I., (2009). Pearson correlation coefficient. In Noise reduction in speech processing (pp. 1-4). Springer, Berlin, Heidelberg.
28. Berlin B and Kay P (1999), Basic Color Terms: Their Universality and Evolution, CSLI Publications.
29. Bernard, H. R. (2002). Research Methods in Anthropology: Qualitative and Quantitative Approaches. (3rd Edition). Walnut Creek, CA: AltaMira Print.
30. Berns, R. J. B., & Saltzman's Principles of Color Technology. (2000). CMC colour difference. 117-118.
31. Best, J. (2017) Colour Design: Theories and Applications. Woodhead Publishing.
32. Bhowmik, A. K. J. A. T. o. S., & Processing, I. (2017). Sensification of computing: adding natural sensing and perception capabilities to machines. 6.
33. Birren F. (1978). Color & Human Response. New York: Wiley. p 9–11.
34. Birren, F., (1981). JC Le Blon, discoverer and developer of the red‐yellow‐blue principle of color printing and color mixture. Color Research & Application, 6(2), pp.85-92.

35. Blaikie, N. W. H. (2000). Designing social research : the logic of anticipation. Cambridge ;: Polity Press.

36. Blessing, L., Chakrabarti, A. and Wallace, K. (1995). A Design Research Methodology. Proceedings of the 10th International Conference on Engineering Design (ICED 95), pp 50-55. Praha, Czech Republic.

37. Bottomley, P. A., & Doyle, J. R. (2006). The interactive effects of colors and products on perceptions of brand logo appropriateness. Marketing Theory, 6(1), 63-83.

38. Bryman, A., Teevan, J.J. (2005). Social Research Methods: Canadian Edition. Oxford, Don Mills, ONTARIO.

39. Burchett, K.E., (1991). Color harmony attributes. Color Research & Application, 16(4), pp.275-278.

C

40. Cai H. et al. (2018) The Change of Government Functions in the On-line Fundraising Development -- Qualitative Analysis Based on 30 Personal Interviews. In: Atlantis Press, 2018 3rd International Conference on Humanities Science, Management and Education Technology (HSMET 2018). Nanjing, China, 2018. Nanjing, China: Atlantis Press. Available at: doi:10.2991/hsmet-18.2018.75 [Accessed: 26 February 2020].

41. Caivano JL (1998). Color and semiotics: A two-way street, Color Research and Application, 23 (6), 390-401.

42. Calver, G. (2004). What is Packaging Design? Switzerland: Rotovision.

43. Camgöz, N., Yener, C. and Güvenç, D., (2002). Effects of hue, saturation, and brightness on preference, Color Research and Application, 27 (3), 199-207.

44. Capko, J. (2003) Five Steps to a Performance Evaluation System. Family Practice Management, 10(3), 43.

45. Cardoso, C. (2005). PhD Thesis: Design for Inclusivity: Assessing the Accessibility of Everyday Products. Cambridge: Cambridge University, the Department of Engineering and Design.

46. Case, D.O. (2008). Looking for information: A survey of research on information seeking, needs and behavior. Amsterdam: Academic Press.

47. Castree, N., Kitchin, R. and Rogers, A. (2015). A Oxford Dictionary of Human Geography[online]. Oxford: Oxford University Press.

48. Chen Y, Yang J, Pan Q, Vazirian M and Westland S (2019), A method of exploring word-colour associations, Color Research and Application, 45 (1), 85-94.

49. Cherry, K. (2015). Color psychology: How colors impact moods, feelings, and behaviors. About Education.

50. Chevreul, M.E. (1967). The principles of harmony and contrast of colors, and their applications to the arts. New York: Reinhold

51. Ching, F. (1987) Interior Design Illustrated. Australia, Van Nostrand Reinhold Company Inc.

52. Choungourian, A., (1969). Color preferences: A cross-cultural and cross-sectional study. Perceptual and Motor Skills, 28 (3), 801-802.

53. Chuang MC, Ou LC. (2001). Influence of a holistic color interval on color harmony. Color research and application. 26(1):29-39.

54. Chun Tie, Y. et al. (2019) Grounded theory research: A design framework for novice researchers. SAGE Open Medicine, 7. [Accessed: 26 February 2020].

55. Cifter, A. S. (2011). PhD Thesis: An Inclusive Approach Towards Designing Medical Devices for Use in the Home Environment, London: Brunel University School of Engineering and Design.

56. Creswell, J.W. (1998). Qualitative Inquiry and Research Design: Choosing among Five Traditions. London: Sage.

57. Cross, N. (1999). Design Research: A Disciplined Conversation. Design Issues Vol. 15, Issue. 2, pp 5-10.

58. Crozier, W.R. (1999) The meanings of colour: preferences among hues. Pigment & Resin Technology, 28(1), 6–14. MCB UP Ltd.

59. Cyr, D. et al. (2010) Colour appeal in website design within and across

cultures: A multi-method evaluation. International Journal of Human-Computer Studies, 68(1–2), 1–21.

D

60. D.Attiah, (2016), PhD Thesis, University of Leeds.
61. Dalke H, Little J, Niemann E, Camgoz N, Steadman G, Hill S, et al. (2006). Colour and lighting in hospital design. Optics and Laser Technology. 38(4–6): 343–65 p.343.
62. Darrodi, M. (2012). Models of Color Semiotics. The University of Leeds School of Design.
63. De Bortoli, M. and Maroto, J., (2001). Colours across cultures: Translating colours in interactive marketing communications. European Languages and the Implementation of Communication and Information Technologies.
64. DeCuir-Gunby, J.T. et al. (2011) Developing and Using a Codebook for the Analysis of Interview Data: An Example from a Professional Development Research Project. Field Methods, 23(2), 136–155.
65. Demirbilek, O. & Sener, B. (2003) Product design, semantics and emotional response. Ergonomics, 46(13–14), 1346–1360. Taylor & Francis.
66. Diane, T. and Cassidy, T., (2009). Colour forecasting. John Wiley & Sons.
67. Ding, M. and Dong, W., (2020). Multiemotional product color design using gray theory and nondominated sorting genetic algorithm - III. Color Research & Application, 45(1), pp.142-155.
68. Dong, H. (2004). PhD Thesis: Barriers to Inclusive Design in the UK. Cambridge: Cambridge University Department of Engineering.
69. Dorcus, R.M. (1926). Color Preferences and Color Associations. Pedagogical Seminary and Journal of Genetic Psychology. 33, pp.399-434.
70. Dorcus, R.N. (1926). Colour preferences and colour associations. J. Genet. Psychol. 33, 399–434.

71. Dorst, K. & Cross, N. (2001) Creativity in the design process: co-evolution of problem–solution. Design Studies, 22(5), 425–437.

E

72. Ebner, M. (2007). Color constancy (Vol. 7): John Wiley & Sons.
73. Elliot, A. J., & Maier, M. A. (2007). Color and psychological functioning. Current directions in psychological science, 16(5), 250-254.
74. Elm, N. (2012) How color affects customer perception. Iran's industrial design.
75. Eysneck, H.J. (1941). A Critical and Experimental Study of Colour Preferences. American Journal of Psychology. 40(3), pp.563-581.

F

76. Fallman, D. (2008). The interaction design research triangle of design practice, design studies, and design exploration. Design Issues, 24(3), 4.
77. Fehrman, K. and Fehrman, C., (2000). Color: The secret influence. Prentice Hall.
78. Feisner, E.A., (2006). Colour: How to use colour in art and design. Laurence King Publishing.
79. Fidel, R. and Green, M. (2004). The Many Faces of Accessibility: Engineers' Perception of Information Sources. Information Processing and Management.
80. Francis, M., 1987. Urban open spaces. Advances in environment, behavior, and design, 1(7).
81. Frayling, C. (1993). Research in Art and Design. Royal College of Art Research Papers 1, 1 pp 1-5.

G

82. Gage, J. (1999). Colour and Meaning: Art, Science and Symbolism. London: Thames and Hudson.

83. Gao X-P, Xin JH, Sato T, Hansuebsai A, Scalzo M, Kajiwara K, Guan S-S, Valldeperas J, Lis MJ and Billger M (2007). Analysis of cross-cultural color emotion, Color Research and Application, 32 (3), 223-229.

84. García PA, Huertas R, Melgosa M and Cui G. (2007). Measurement of the relationship between perceived and computed color differences. J. Opt. Soc. Am. A, 24, 1823–1829.

85. Garrett, J.C. and Brooks, C.I., (1987). Effect of ballot color, sex of candidate, and sex of college students of voting age on their voting behavior. Psychological Reports, 60(1), pp.39-44.

86. Gegenfurtner, K. R., & Kiper, D. C. (2003). Color vision. Annual review of neuroscience, 26(1), 181-206.

87. Genetti, C. (2018) How Languages Work: An Introduction to Language and Linguistics. Cambridge University Press.

88. Goethe, J. W. V., & Eastlake, C. L. (2006). Theory of colours. Dover.

89. Gómez-Polo, C. et al. (2016a) Comparison of the CIELab and CIEDE2000 color difference formulas. The Journal of Prosthetic Dentistry, 115(1), 65–70.

90. Gómez-Polo, C. et al. (2016b) Comparison of the CIELab and CIEDE2000 color difference formulas. The Journal of Prosthetic Dentistry, 115(1), 65–70.

91. Granville, W.C., (1987). Color harmony: What is it?. Color Research & Application, 12(4), pp.196-201.

92. Green‐Armytage, P. (2006) The value of knowledge for colour design. Color Research & Application, 31(4), 253–269.

93. Gregory, S.A. (2013) The Design Method. Springer.

94. Grieve, K.W., (1991). Traditional beliefs and colour perception. Perceptual and motor skills, 72(3_suppl), pp.1319-1323.

95. Grossman, R. P. and Wisenblit J. Z. (1999), What we know about consumers' color choices. Journal of Marketing Practice , 5 (3), pp. 78-90.

96. Guest, G., Bunce, A. and Johnson , (2006). How Many Interviews Are Enough? An Experiment with Data Saturation and Variability. Field Methods . 18(1), pp.59 82.

97. Guilford JP. (1931). The prediction of affective values. Am J Psychol. 43:469–478.

98. Guilford JP. (1934). The affective value of color as a function of hue, tint, and chroma. Journal of experimental psychology. 17(3):342.

99. Guilford, J.P. and Smith, P.C. (1959). A System of Color-Preferences. The American Journal of Psychology. 72(4), pp.487-502.

100. Gump, J.E., (2001). The readability of typefaces and the subsequent mood or emotion created in the reader. Journal of education for business, 76(5), pp.270-273.

101. Gupta, S. (2007). PhD Thesis: Design and Delivery of Medical Devices for Home-Use: Drivers and Challenges. Cambridge: Cambridge University Department of Engineering.

H

102. Hagtvedt, H. (2016). The Influence of Product Color on Perceived Weight and Consumer Preference. In Marketing Challenges in a Turbulent Business Environment (pp. 25-25). Springer, Cham.

103. Hailman JP. (1977).Optical signals: animal communication and light. Indiana U Press.

104. Haller, K., (2017). Colour in interior design. In Colour Design (pp. 317-348). Woodhead Publishing.

105. Hamid, P.N. and Newport, A.G., (1989). Effect of colour on physical strength and mood in children. Perceptual and Motor skills, 69(1), pp.179-185.

106. Hanson, A.R. (2012). What Is Colour? In: Best, J. ed. Colour Design: Theories and Applications. Oxford: Woodhead, pp.3-23.

107. Hanss, D., Böhm, G., and Pfister, H.-R. (2012). Active red sports car and relaxed purple–blue van: affective qualities predict color

appropriateness for car types. Journal of Consumer Behaviour, 11(5), 368-380.

108. Harris, M., (1766). The natural system of colour.

109. Hauke J and Kossowski T (2011). Comparison of values of Pearson's and Spearman's correlation coefficients on the same sets of data. Quaestiones geographicae, 30 (2), 87-93.

110. Hemphill, M., (1996). A note on adults' colour–emotion associations, The Journal of Genetic Psychology, 157 (3), 275-280.

111. Henn, M., Weinstein, M., and Foard, N. (2006). A Critical Introduction to Social Research. Wiltshire: Sage Publications.

112. Herzberg, Frederick (1966). Work and the Nature of Man. Cleveland: World Publishing. OCLC 243610.

113. Herzberg, Frederick (January–February 1964). The Motivation-Hygiene Concept and Problems of Manpower. Personnel Administration (27): 3–7.

114. Herzberg, Frederick; Mausner, Bernard; Snyderman, Barbara B. (1959). The Motivation to Work (2nd ed.). New York: John Wiley. ISBN 0471373893.

115. Hidefi, M. (2017). Understanding and forecasting colour trends in design. In Colour Design (pp. 285-298): Elsevier.

116. Hiler, H., (1942). Color harmony and pigments. Favor, Ruhl.

117. Hogg J. (1969). A principal component analysis of semantic differential judgements of single colors and color pairs. J Gen Psychol. 80:129–140.

118. Hogg J. (1969). The prediction of semantic differential ratings of color combinations. J Gen Psychol. 80:141–152.

119. Holbrook, A.L., Green, M.C. and Krosnick, J.A. (2003). Telephone versus Face-To-Face 248 Interviewing of National Probability Samples with Long Questionnaires: Comparisons of Respondent Satisficing and Social Desirability Response Bias. American Association for Public Opinion Research. 67, pp.79-125. Research method for business

studentS saunders et al., 1997

120. Holtzschue, L. (2012). Understanding Color: An Introduction for Designers. New Jersey: John Whiley and Sons.

121. Holbrook, A. L., Green , M.C. and Krosnick , J. (2003). Telephone versus Face To Face Interviewing of National Probability Samples with Long Questionnaires: Comparisons of Respondent Satisficing and Social Desirability Response Bias. American Association for Public Opinion Research . 67, pp.79 125.

122. Hope, A. and Walch, M., (1990). The color compendium.

123. Hsiao, S.-W. (1995a) A systematic method for color planning in product design. Color Research & Application, 20(3), 191–205.

124. Hsiao, S.-W. (1995b) A systematic method for color planning in product design. Color Research & Application, 20(3), 191–205.

125. Huang, L., and Lu, J. (2013). When color meets health: The impact of package colors on the perception of food healthiness and purchase intention. In S. Botti & A. Labroo (Eds.), Advances in Consumer Research (Vol. 41, pp. 625-626). Duluth, MN: Association for Consumer Research

126. Hunt RWG and Pointer MR (2011). Measuring colour. John Wiley & Sons.

127. Hurlbert AC, Ling Y. (2007). Biological components of sex differences in color preference. Curr Biol. 17:623–625.

128. Hurlbert, A. and Ling, Y. (2012). Understanding Colour Perception and Preference. In: Best, J. ed. Colour Design: Theories and Applications. Oxford: Woodhead, pp.129-157.

129. Hurlbert, A. and Ling, Y., (2007). Biological components of sex differences in color preference, Current Biology, 17 (16), R623-R625.

130. Hynes, N. (2009) Colour and meaning in corporate logos: An empirical study. Journal of Brand Management, 16(8), 545–555.

I

131. Ioffe S and Szegedy C (2015). Batch normalization: Accelerating deep network training by reducing internal covariate shift. arXiv preprint arXiv:1502.03167.

132. Itten J. (1961). The Art of Color. Cincinnati: Van Nostrand Reinhold.

J

133. J.W. von Goethe, Zur Farbenlehre, (1810), see Argan's introduction to italian translation, edited by R. Troncon, Milano, 1981.

134. Jackson, L., (2007). Twentieth-century pattern design. Princeton Architectural Press.

135. Jacobs L, Keown C, Worthley R and Ghymn KI (1991), Cross‐cultural colour comparisons: global marketers beware!. International Marketing Review, 8 (3), 21-30.

136. Jacobson, E., Granville, W.C., Foss, C.E. and MacAdam, D.L., (1950). Color Harmony Manual. Physics Today, 3, p.34.

137. Jiang L, Cheung V, Westland S, Rhodes P, Shen L and Xu L (2020), The impact of color preference on adolescent children's choice of furniture, Color Research and Application, 45 (4), 754-767.

138. JL Nasar, editor. (1992). Environmental Aesthetics: Theory, Research and Applications. New York: Cambridge University Press.

139. Joel G (2015). Data Science from Scratch. Sebastopol, CA: O'Reilly, 99-100.

140. Jordan, B. and Henderson, A. (1995). Interaction Analysis: Foundations and Practice. The Journal of the Learning Sciences, 4, pp 39-103.

141. Judd, D. B. (1952). Color in business, science and industry.

142. Judd, D.B. and Wyszecki, G. (1963). Color in Business, Science and Industry. New York: Wiley.King, N. 2012. Doing Template Analysis. In: Gillian, S. and C. Cassell, ed. Qualitative Organizational Research: Core

Methods and Current Challenges. London: Sage, pp.426-450.

143. Juszczak P, Tax D and Duin RP (2002). Feature scaling in support vector data description. Proc. ASCI. 95-102.

K

144. Kahneman, D., (1973). Attention and effort (Vol. 1063). Englewood Cliffs, NJ: Prentice-Hall.

145. Kandinsky, W. J. M. S. (1977). Concerning the Spiritual in Art, trans. 19.

146. Kaplan S. (1992). Where cognition and affect meet: a theoretical analysis of preference. In: JL Nasar, editor. Environmental Aesthetics: Theory, Research and Applications. New York: Cambridge University Press, 56– 63.

147. Kareklas, I., Brunel, F. F. and Coulter, R. A. (2014). Judgment is not color blind: The impact of automatic color preference on product and advertising preferences. Journal of Consumer Psychology, 24, 87-95.

148. Kauppinen‐Räisänen H and Luomala HT (2010). Exploring consumers' product‐specific colour meanings, Qualitative Market Research: An International Journal, 13 (3), 287-308

149. Kauppinen-Räisänen, H. and Jauffret, M.N., (2018). Using colour semiotics to explore colour meanings. Qualitative Market Research: An International Journal.

150. Kobayashi, S., (1981). The aim and method of the color image scale. Color research & application, 6(2), pp.93-107.

151. Koller, V., (2008). Not just a colour': pink as a gender and sexuality marker in visual communication. Visual communication, 7(4), pp.395-423.

152. Kommonen, K. (2011) Narratives on Chinese colour culture in business contexts: The Yin Yang Wu Xing of Chinese values. Cross Cultural Management: An International Journal, 18(3), 366–383.

153. Kopacz, J., (2017). Enhancing design using colour. Colour Design:

Theories and Applications, p.243.

154. Kress G and Van Leeuwen T (2006), Reading images: The grammar of visual design, Routledge.

155. Kress, G. and Van Leeuwen, T., (2002). Colour as a semiotic mode: notes for a grammar of colour. Visual communication, 1(3), pp.343-368.

156. Kress, G.R. and Van Leeuwen, T., (1996). Reading images: The grammar of visual design. Psychology Press.

157. Kuehni, R.G. (1997). Color: An Introduction to Practice and Principles. New York; Chichester: John Wiley.

158. Kwak, Y., Lee, S.D., Choe, W. and Kim, C.Y., (2005), January. Optimal chromaticities of the primaries for wide gamut 3-channel display. In Color Imaging X: Processing, Hardcopy, and Applications (Vol. 5667, pp. 319-327). International Society for Optics and Photonics.

L

159. Lamb, T. and Bourriau, J. eds., (1995). Colour: Art and science (Vol. 7). Cambridge University Press.

160. Landa, R. (2010) Graphic Design Solutions. Cengage Learning.

161. Lang J. (1992). Symbolic aesthetics in architecture: toward a research agenda. In: JL Nasar, editor. Environmental Aesthetics: Theory, Research and Applications. New York: Cambridge University Press, 11–26.

162. Larman, C. (2005). Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and Iterative Development. Upper Saddle River, New Jersey: Prentice Hall Professional Technical Reference.

163. Lavendel L and Kohler T (2008). The story of a color advisor, Sixth Color Imaging Conference: Color Science, Systems and Applications, volume 6, pp228–229, Scottsdale (Arizona)."

164. Lee, C.J. and Andrade, E., (2010). The effect of emotion on color preferences. ACR North American Advances.

165. Li, D. 2017, Private Communication.

166. Lightfoot, C. and Gerstman, R. (1998) ‘Brand Packaging’, in S. Hart and J. Murphy (eds) Brands: the New Wealth Creators, pp. 46–55. Basingstoke: Macmillan.

167. Lindner, A. and Süsstrunk, S., (2013). Automatic color palette creation from words, in Proceedings of the Twenty-Third Color and Imaging Conference, pp. 69-74, Society for Imaging Science and Technology.

168. Lucassen MP, Gevers T and Gijsenij A (2010), Texture affects color emotion, Color research and application, 36 (6), 426 ‐ 436.

169. Luo MR, Cui G and Rigg B (2001). The development of the CIE 2000 colour-difference formula: CIEDE2000. Color Res Appl., 26 (5), 340-350.

170. Luo, M.R. & Cui, G. (n.d.) A Colour Design Tool Based on Empirical Studies. 17.

171. Lupton, E. & Phillips, J.C. (2008) Graphic Design: The New Basics. Princeton Architectural Press.

172. Luscher, M. and Scott, (2003) The Luscher color Test, Random House, New York, Ny.

M

173. Maciaszek, L.A. (2001). Requirements Analysis and System Design: Developing Information Systems with UML. Harlow: Addison Wesley.

174. Madden TJ, Hewett K and Roth MS (2000), Managing images in different cultures: A cross-national study of color meanings and preferences, Journal of International Marketing, 8 (4), 90-107.

175. Maguire, M.C. (2011) Guidelines on Website Design and Colour Selection for International Acceptance. In: Marcus, A. (ed.) Design, User Experience, and Usability. Theory, Methods, Tools and Practice Lecture Notes in Computer Science. [Online]. Berlin, Heidelberg: Springer Berlin Heidelberg. Available at: doi:10.1007/978-3-642-21675-6_19 [Accessed: 14 September 2020].

176. Margolin, V. ed., (1989). Design discourse: history, theory, criticism.

University of Chicago Press.

177. Marshall, G. and Jonker, (2011). An Introduction to Inferential Statistics: A Review and P ractical G uide. Radiography. 17(1), pp.e1 e6.

178. Martell, J. (2020) Things You Must Know About Lucky Red Pockets on New Year. Chinese New Year 2021. Available at: https://chinesenewyear.co/red-pocket/ [Accessed: 22 September 2020].

179. McDonald R (1990). European practices and philosophy in industrial colour-difference evaluation. Color Res Appl, 15(5), 249-260.

180. McLellan, E. et al. (2003) Beyond the Qualitative Interview: Data Preparation and Transcription. Field Methods, 15(1), 63–84.

181. McManus, I.C., Jones, A.L. and Cottrell, J., (1981), The aesthetics of colour, Perception, 10, 651-666.

182. Melgosa M (2000). Testing CIELAB-based color-difference formulas. Color Res Appl., 25(1), 49-55.

183. Mikellides, B. (2012). Colour Psychology: The Emotional Effects of Colour Perception. In: Best, J. ed. Colour Design: Theories and Applications. Oxford: Woodhead, pp.105-128.

184. Milligan, G.W. & Cooper, M.C. (1988) A study of standardization of variables in cluster analysis. Journal of Classification, 5(2), 181–204.

185. Milton, H. (1991) Packaging design, London: The Design Council.

186. Minah, G. (2008) Colour as Idea: The Conceptual Basis for Using Colour in Architecture and Urban Design. 9.

187. Monmonier, M. (1985) Review of Semiology of Graphics: Diagrams, Networks, Maps., , ; The Visual Display of Quantitative Information. Annals of the Association of American Geographers, 75(4), 605–609. [Association of American Geographers, Taylor & Francis, Ltd.].

188. Moon P, Spencer D E, (1944). Area in color harmony. Journal of the Optical Society of America 34 93-103

189. Moretti G and Lyons P (2002). Tools for the selection of colour palettes. Paper presented at: Proceedings of the SIGCHI-NZ

Symposium on Computer-Human Interaction, 13–18, ACM.

190. Morse BS, Thornton D, Xia Q and Uibel J (2007). Image-based color schemes. Paper presented at: IEEE International Conference on Image Processing, IEEE, 3; III-497.

191. Motamed, B., & Tucker, R. (2018). Colourful practice: Is design education informing architects' use of colour?. International Journal of Technology and Design Education, 28(4), 1001-1017.

192. Munsell A.H. (1969). A grammar of color. New York: Van Nostrand Reinhold.

193. Muratovski, G. (2015). Research for designers: A guide to methods and practice. Sage.2-3.

N

194. Newton, I., (1952). Opticks, or, a treatise of the reflections, refractions, inflections & colours of light. Courier Corporation.

O

195. O'Connor, Z. (2010) Colour harmony revisited. Color Research & Application, 35(4), 267–273.

196. O'Connor, Z., (2011). Colour psychology and colour therapy: Caveat emptor, Color Research and Application, 36 (3), 229-234.

197. Ogden, J. R. Ogden, D. T., Akcay, O., Sable, P. and Dalgin, M. H. (2010), Over the Rainbow- The Impact of Color on Consumer Product Choice, Journal of Business and Behavioral Sciences, 22 (1), pp. 65-72.

198. Ohta, N. and Robertson, A., (2006). Colorimetry: fundamentals and applications. John Wiley & Sons.

199. Olguntürk, N. & Demirkan, H. (2011a) Colour and design: From natural patterns to monochrome compositions. Optics & Laser Technology, 43(2), 270–281.

200. Olguntürk, N. & Demirkan, H. (2011b) Colour and design: From

natural patterns to monochrome compositions. Optics & Laser Technology, 43(2), 270–281.

201. Olguntürk, N. & Demirkan, H. (2011c) Colour and design: From natural patterns to monochrome compositions. Optics & Laser Technology, 43(2), 270–281.

202. Osborne, R. (2012). The history of colour theory in art, design and science. In Colour Design (pp. 309-335): Elsevier.

203. Osgood, C.E., Suci, G.J. and Tannenbaum, P.H., (1957). The Measurement of Meaning. Urbana: University of Illinois Press.

204. Ostwald, W., (1969). The color primer: a basic treatise on the color system of Wilhelm Ostwald. Van Nostrand Reinhold Co.

205. Ou L, Luo MR, Woodcock A, Wright A., (2004c). A study of colour emotion and colour preference. III. Colour preference modelling, Color Research and Application, 29, 381–389.

206. Ou, L., Luo, M.R., Woodcock, A. and Wright, A., (2004b). A study of colour emotion and colour preference. II. Colour emotions for two-colour combinations, Color Research and Application, 29, 292–298.

207. Ou, L., Luo. M.R., Woodcock, A. and Wright, A., (2004a). A study of colour emotion and colour preference. I. Colour emotions for single colours, Color Research and Application, 29, 232–240.

P

208. Palmer SE, Schloss KB, Sammartino J. (2013). Visual aesthetics and human preference. Ann Rev Psychol. 64: 77– 107.

209. Pan Q and Westland S (2018). Comparative evaluation of color differences between color palettes. Proceedings of the IS&T Color and Imaging Conference, 110–115.

210. Parraman, C. (2012). Colour printing techniques. In Colour Design (pp. 497-531): Elsevier.

211. Pile, J. F. (2007). Interior Design, 4th ed. Prentice Hall

212. Pope A. (1944). Notes on the problem of color harmony and the geometry of color space. JOSA. 34(12):759-64.

213. Poulin, R. (2011) The Language of Graphic Design: An Illustrated Handbook for Understanding Fundamental Design Principles. Rockport Publishers.

R

214. Ramollari, E and Dranidis, D. (2007). Student UML: An Educational Tool Supporting Object-Oriented Analysis and Design. Proceedings of the 11th Panhellenic Conference in Informatics (PCI 2007), pp.363-373.

215. Renouf, A. and Sinclair, J., (1991). Collocational frameworks in English. English corpus linguistics, pp.128-143.

216. Ritterfeld, U., (2002). Social heuristics in interior design preferences. Journal of Environmental Psychology, 22(4), pp.369-386.

217. Robson, C. (2002). Real world research : a resource for social scientists and practitioner-researchers (Second edition. ed.). Oxford: Blackwell Publishers.

218. Rocchi, B., & Stefani, G. J. I. J. o. W. M. (2006). Consumers' perception of wine packaging: a case study. 18(1), 33-44.

219. Rodgers, J.L. & Nicewander, W.A. (n.d.) Thirteen Ways to Look at the Correlation Coefficient. 11.

220. Rousseeuw, P.J. (1987) Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. Journal of Computational and Applied Mathematics, 20, 53–65.

S

221. Samara, T. (2007) Design Elements: A Graphic Style Manual. Rockport Publishers.

222. Sandnes, F.E. & Zhao, A. (2015) A Contrast Colour Selection Scheme for WCAG2.0-Compliant Web Designs Based on HSV-Half-Planes. In: IEEE, 2015 IEEE International Conference on Systems, Man and

Cybernetics (SMC). Kowloon, Oct, 2015. Kowloon: IEEE. Available at: doi:10.1109/SMC.2015.220 [Accessed: 14 September 2020].

223. Sato, T., Kajiwara, K., Xin, J., Hansuebsai, A. and Nobbs, J.H. (2003). Numerical expression of colour emotion and its application, Proceedings AIC, Bangkok, 365.

224. Saunders, M., Lewis, P., & Thornhill, A. (2009). Research methods for business students. Pearson education.

225. Schloss, K.B. and Palmer, S.E., (2011). Aesthetic response to color combinations: Preference, harmony, and similarity, Attention, Perception, & Psychophysics, 73, 551–571.

226. Scott-Kemmis, J., (2013). Target Markets – Using color psychology to attract your target markets.

227. Scully, K. and Cobb, D.J., (2012). Colour forecasting for fashion. Laurence King Publishing.

228. Selkirk, E. (2004) The Prosodic Structure of Function Words. In: McCarthy, J.J. (ed.) Optimality Theory in Phonology. [Online]. Oxford, UK: Blackwell Publishing Ltd. Available at: doi:10.1002/9780470756171.ch25 [Accessed: 6 April 2020].

229. Sharma, G. et al. (2005) The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. COLOR research and application, 30(1), 10.

230. Sherin, A. (2012) Design Elements, Color Fundamentals: A Graphic Style Manual for Understanding How Color Affects Design. Rockport Publishers.

231. Srinivasan, R., Lilien, G.L., Rangaswamy, A., Pingitore, G.M. and Seldin, D., (2012). The total product design concept and an application to the auto market. Journal of Product Innovation Management, 29, pp.3-20.

232. Sivik L and Taft C (1994), Color naming: A mapping in the NCS of common color terms, Scandinavian Journal of Psychology, 35, 144-164.

233. Smith, D. (2003). Environmental colouration and/or the design

process. Color Research & Application: Endorsed by Inter‐Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur, 28(5), 360-365.

234. Smith, G. & Whitfield, T.W.A. (2005) Profiling the Designer: a Cognitive Perspective. The Design Journal, 8(2), 3–14.

235. Smith, G., & Whitfield, T. A. (2005). The professional status of designers: A national survey of how designers are perceived. The Design Journal, 8(1), 52-60.

236. Srinivasan, R. et al. (2012) The Total Product Design Concept and an Application to the Auto Market. Journal of Product Innovation Management, 29(S1), 3–20.

237. Sutton, T. & Whelan, B.M. (2017) The Complete Color Harmony, Pantone Edition: Expert Color Information for Professional Color Results. Rockport Publishers.

238. Swirnoff L. (1992). Dimensional color. New York: Van Nostrand Reinhold.

T

239. Taft C. (1996). Color meaning and context: Comparisons of semantic ratings of colors on samples and objects. Color Res Appl. 22:40–50.

240. Talja, S. (n.d.) Analyzing Qualitative Interview Data: The Discourse Analytic Method. 18.

241. Tao, D. et al. (2017) Effects of color on expectations of drug effects: A cross-gender cross-cultural study. Color Research & Application, 42(1), 124–130.

242. Tao, L., Westland, S. and Cheung, V., (2011). Blackness: preference and perception, Proceedings of the IS&T/SID's Nineteenth Color and Imaging Conference, 270-275, San Jose, USA.

243. The Oxford English Dictionary [online]. 2015. Available from:

http://www.oed.com

244. Thornhill A, Saunders M and Lewis P (2009). Research methods for business students. Prentice Hall: London; 127-128.

245. Tofle, R.B., Schwartz, B., Yoon, S., and Max-Royale, A., (2004). Color in healthcare environments: A critical review of the research literature. California: The Coalition for Health Environments Research (CHER).

246. Tracy, S.J., (2019). Qualitative research methods: Collecting evidence, crafting analysis, communicating impact. John Wiley & Sons.

U

247. Ural, S.E. & Yilmazer, S. (2010) The architectural colour design process: An evaluation of sequential media via semantic ratings. Color Research & Application, 35(5), 343–351.

248. Ural, S.E. et al. (2017) Progression of color decision making in introductory design education. Color Research & Application, 42(6), 849–860.

V

249. Valdez, P., and Mehrabian, A. (1994). Effects of color on emotions. Journal of Experimental Psychology: General, 123(4), 394-409.

250. Volkova, S. et al. (2012) CLex: A Lexicon for Exploring Color, Concept and Emotion Associations in Language. 9.

W

251. Webster, M. A. J. N. C. i. N. S. (1996). Human colour perception and its adaptation. 7(4), 587-634.

252. Wei, S.-T. (2014) Colour Harmony and Consumer Expectations. 8(1), 18.

253. Westland, S., 2018. 7. Colour semiotics. Dialogues on Design: Notes on Doctoral Research in Design 2018, p.107.

254. Westland, S., Laycock, K., Cheung, V., Henry, P. and Mahyar, F. (2007). Colour Harmony. Colour: Design and Creativity. 1(1), pp.1-15.

255. Westland, S., Pan, Q. and Lee, S., (2017). A review of the effect of colour and light on non-image function in humans, Coloration Technology, 133 (5), 349-361.

256. Westland, S., Ripamonti, C. and Cheung, V., (2012). Computational colour science using MATLAB. John Wiley & Sons.

257. Weston, C. et al. (2001) Analyzing Interview Data: The Development and Evolution of a Coding System. Qualitative Sociology, 20.

258. White, A.W. (2011) The Elements of Graphic Design: Space, Unity, Page Architecture, and Type. Skyhorse Publishing, Inc.

259. Wierzbicka, A., 1996. The meaning of colour terms and the universals of seeing. Semantics: primes and universals, pp.287-334.

260. Wierzbicka A (2006), The semantics of colour: A new paradigm, in Progress in Colour Studies: Volume I. Language and Culture, Pitchford NJ and Biggam CP (eds.), 1-24, Philadelphia: John Benjamins Publishing Company.

261. Williams JE and Foley Jr JW (1968), Connotative meanings of color names and color hues, Perceptual and Motor Skills, 26 (2), 499-502.

262. Winters NB. (1986). Architecture is elementary: visual thinking through architectural concepts. Salt Lake City: Peregrine Smith Books; p. 23–4, 69–70, 187–90, 205–6.

263. Witt K (1995). CIE guidelines for coordinated future work on industrial colour-difference evaluation. Color Res Appl., 20(6), 399-403.

264. Won S and Westland S (2017), Colour meaning in context, Color Research and Application, 42 (4), 450-459.

265. Won, S. & Westland, S. (2018) Requirements capture for colour information for design professionals. Color Research & Application, 43(3), 387–395.

266. Won, S., (2016). PhD Thesis, University of Leeds.

267. Wong, W.L.P. & Radcliffe, D.F. (2000) The Tacit Nature of Design Knowledge. Technology Analysis & Strategic Management, 12(4), 493–512. Routledge.

268. Wright B, Rainwater L. (1962). The meanings of color. J Gen Psychol.67:89–99.

X

269. Xin JH, Cheng KM, Chong TF, Sato T, Nakamura T, Kajiwara K and Hoshino H (1998), Quantifying colour emotion-what has been achieved, Research Journal of Textile and Apparel, 2 (1), 46–54.

Y

270. Yang J, Chen Y, Westland S. and Xiao K (2020). Predicting visual similarity between colour palettes. Color Res Appl., 45(3), 401-408.

271. Yau, V. (1994) Use of colour in China. The British Journal of Aesthetics, 34(2), 151–163. Oxford University Press.

Z

272. Zelanski, P., & Fisher, M. P. (1999). Colour: Herbert Press.

273. Zeng, H., (2003), January. 3D color separation maximizing the printer gamut. In Color Imaging VIII: Processing, Hardcopy, and Applications (Vol. 5008, pp. 260-267). International Society for Optics and Photonics.

274. Zhang, J.F. (2013) The Application of Color Psychological Effect on Fashion Design, for Available at: doi:10.4028/www.scientific.net/AMR.796.474 [Accessed: 10 June 2020].

275. Zhang, P. & Dran, G.M. von (2000) Satisfiers and dissatisfiers: A two-factor model for website design and evaluation. Journal of the American Society for Information Science, 51(14), 1253–1268.

276. Zwinkels, J. C. J. D. (1996). Colour-measuring instruments and their calibration. 16(4), 163-171.

Appendix A
Publications

This section consists of the published works related to this study.

Study 1 (Chapter 4):

- Chen, Y., Yu, L., Westland, S. and Cheung, V. (2021). Investigation of designers' colour selection process. Color Research & Application. *Accepted in Jan of 2021*.

Study 2 (Chapter 5):

- Chen, Y., Yang, J., Pan, Q., Vazirian, M., & Westland, S. (2020). A method for exploring word-colour associations. Color Research & Application. https://doi.org/10.1002/col.22434
- Ren, S., Chen, Y., Westland, S. and Yu, L. (2020). A comparative evaluation of similarity measurement algorithms within a colour palette. Color Research & Application. https://doi.org/10.1002/col.22591

Future work (Chapter 8):

- Chen, Y., Guo, B., Li, D., Westland, S. and Vazirian, M. (2020). Crowd sourcing word-colour associations. Journal of the International Colour Association, 25, pp.55-64. http://eprints.whiterose.ac.uk/165496/
- Chen, Y., Westland, S., Pan, Q., Yu, L. and Yang, J. (2017). Investigating Cultural Differences in Colour-Word Associations Using Internet Image Search. AIC 2017 Jeju, pp.58-58.

Appendix B
Ethical Approval Certificate

The Secretariat
University of Leeds
Leeds, LS2 9JT Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Yun Chen
School of Design
University of Leeds
Leeds, LS2 9JT

Arts, Humanities and Cultures Faculty Research Ethics Committee
University of Leeds

6 October 2020

Dear Yun,

Title of study: **Understanding Colour in Design**
Ethics reference: **LTDESN-095**

I am pleased to inform you that the above application for light touch ethical review has been reviewed by a representative of the Arts, Humanities and Cultures Faculty Research Ethics Committee and, following receipt of your response to their comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
LTDESN-095 LightTouchEthicsForm.docx	3	29/11/2018
LTDESN-095 Interview.pptx	1	26/11/2018
LTDESN-095 Information Sheet.docx	1	12/11/2018

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as other documents relating to the study. You will be given a two week notice period if your project is to be audited, there is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, the Secretariat
On behalf of Prof Robert Jones, Chair, AHC FREC

CC: Professor Stephen Westland

The Secretariat
University of Leeds
Leeds, LS2 9JT Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Professor Stephen Westland
School of Design
University of Leeds
Leeds, LS2 9JT

Arts, Humanities and Cultures Faculty Research Ethics Committee
University of Leeds

4 June

Dear Stephen,

Title of study: **Colourpedia**
Ethics reference: **LTDESN-100**

I am pleased to inform you that the above application for proportionate (light touch) ethical review has been reviewed by a representative of the Arts, Humanities and Cultures Faculty Research Ethics Committee and I can confirm a favourable ethical opinion as of the date of this letter, provided the answer to C3 is "no". The following documentation was considered:

Document	Version	Date
RE LTDESN-100 application for proportionate ethical review .txt	1	21/05/2019
LTDESN-100 LightTouchEthicsForm..doc	1	20/05/2019

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as other documents relating to the study. You will be given a two week notice period if your project is to be audited, there is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, the Secretariat
On behalf of Prof Robert Jones, Chair, AHC FREC
CC: Faculty Research and Innovation Office

The Secretariat
Level 11, Worsley Building
University of Leeds
Leeds, LS2 9JT
Tel: 0113 343 4873
Email: ResearchEthics@leeds.ac.uk

UNIVERSITY OF LEEDS

Yun Chen
School of Design
University of Leeds
Leeds, LS2 9JT

Faculty of Arts, Humanities and Cultures Research Ethics Committee
University of Leeds

20 November 2017

Dear Yun Chen

Title of study **Comparative investigation in Word-Colour associations**
Ethics reference **LTDESN-071**

I am pleased to inform you that the above research application has been reviewed by a representative of the Faculty of Arts, Humanities and Cultures Research Ethics Committee and I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	*Version*	*Date*
LTDESN-071 LightTouchEthicsForm.docx	1	14/09/17
LTDESN-071 Information Sheet.docx	1	14/09/17
LTDESN-071 Informed Consent for Observers.docx	1	14/09/17

Please notify the committee if you intend to make any amendments to the information in your ethics application as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation and other documents relating to the study, including any risk assessments. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Jennifer Blaikie
Senior Research Ethics Administrator, the Secretariat
On behalf of Prof Robert Jones, Chair, AHC FREC

CC: Student's supervisor

Appendix C
Interview Materials

This section consists of the appendix of Study 1 (Chapter 4).

Appendix C1: The participants recruiting email of the

Hello!

My name is Yun Chen and I am a PhD Design Research student at Leeds University

(under the supervision of Professor Stephen Westland).

I am contacting you in order to get expert opinion in my research as I feel your expertise would add and contribute significantly to the type of research that I am conducting.

My research topic is ‘colour in design’.

And interview is about how designers decide colour in their design process, and what types of concepts they considered.

There is no right or wrong answer to my questions, and the interview would last about 30/40 minutes.

I would be very grateful if you are interested in giving your valuable opinions.

May I expect your reply?

Thanks so much indeed and sorry if my email is bothering you.

Best regards

Yun Chen

Appendix C2: The information sheet of the interview.

INFORMATION SHEET

Before starting to participate in this interview, it is important that you read the following explanation.

About research

This research topic is 'colour in design'.

And the interview is about how designers decide colour in their design process, and what types of types of concepts they considered.

In addition, this activity will help understand the real process of how designers choose colour and a method of colour choosing that will be explored in the following work.

- There is no right or wrong answers to my questions, and the interview would last about 30/40 minutes.

- This interview is to be recorded and used only for the research.

- After analysing the interview data, I will destroy all data.

- So your name and the name of your company will be anonymous so that you cannot be identified.

Appendix C3: The informed consent form of the interview.

Consent to take part in [Colour in Design]

	Add your initials next to the statement if you agree
• I confirm that I have read and understand the information sheet dated [Colour in Design] explaining the above research project.	
• I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question(s), I am free to decline.	
• I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report(s) that result from the research.	
• I agree for the data collected from me to be stored and used in relevant future research in an anonymised form.	
• I understand that other genuine researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	
• I understand that other genuine researchers may use my words in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	
• I understand that relevant sections of the data collected during the study, may be looked at by individuals from the University of Leeds or from regulatory authorities where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.	
• I agree to take part in the above research project and will inform the lead researcher should my contact details change.	

Name of participant:

Participant's signature:

Date:

Name of researcher: Yun Chen

Researcher's signature:

Date: / / 2019

Appendix C4: The interview protocol

RESEARCH PROTOCOL

Time of interview	
Date	
Place	
Interviewer	
Interviewee	

- **Introduction**

Hi <interviewee>. My name is Yun Chen and I am a PhD student in the University of Leeds. I will conduct today's interview on colour in design process.

1. How are you feeling today?
•<respond>

2. Today's interview will help me understand the normal process of colour choosing in design. There are no right or wrong answers. I want you to feel relaxed and comfortable.

3. Are you ready to begin?
•<respond>

4. Today's interview:
•I will begin by asking which aspects you consider in your design process and why you consider them.
•Second I will ask how you decide colour in your general design process.
•Then I will ask you to provide some specific concepts which would influence colour decision.
•Lastly, I will ask your preferences and suggestions about colour choosing.
•This interview is to be recorded and used only for the research. After analyzing this interview data, I will destroy all data.

5. Would you have any questions at this point?
•<respond>

Appendix C5: The interview sheet

PARTICIPANT INFORMATION

Name:

1. Gender:
   - ☐ Male
   - ☐ Female

2. Nationality:

3. Occupation and Field:

4. Years of work experience:
   - ☐ Less than 2 year
   - ☐ 2-4 years
   - ☐ More than 5 years

Email address:

Design process (10 mins)

5. Could you tell me your general design process in your work?
6. Which aspects do you consider in your design process?
7. Is colour an important aspect you need to consider in your design?

Colour decision(10 mins)

8. Is it an easy or difficult process of colour choosing for you?
9. How do you decide colour in your general design process?
10. Do you need a method to help you in selecting colour?

Colour concepts(10 mins)

11. In your design experience, what are important colour factors?
12. Which concepts do you typically consider when choosing colour?

Close

Thank you for your time and contribution. Would you like to ask me any questions at this point?

Appendix D
Experimental Materials

This section consists of the appendix of experimental works.

Appendix D1: Experiment 1 (Chapter 5)

Information Sheet (09/09/2019)

Research title: Colourpedia

You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with the experimenter if you wish. Ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the project?

We will be investigating the strength of the relationship between words and colours (Example in Figure 1).

Figure 1: Example colour palette computationally generated from a word

Why have I been chosen?

Anyone who are British and age above 18 with a normal colour vision can take part in this research.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to read and be asked to sign a consent form and you can still withdraw at any time during the experiment. You do not have to give a reason.

What do I have to do?

This experiment will be conducted on a standard computer screen in our psychophysical laboratory.

Each time a word will be displayed on the computer screen, the participant is asked to pick three colours from a digital colour picker (There are two sections of the colour picker, showed Figure a and b). You are only allowed to choose colour from Figure b.

Figure a: Single Colour Picker

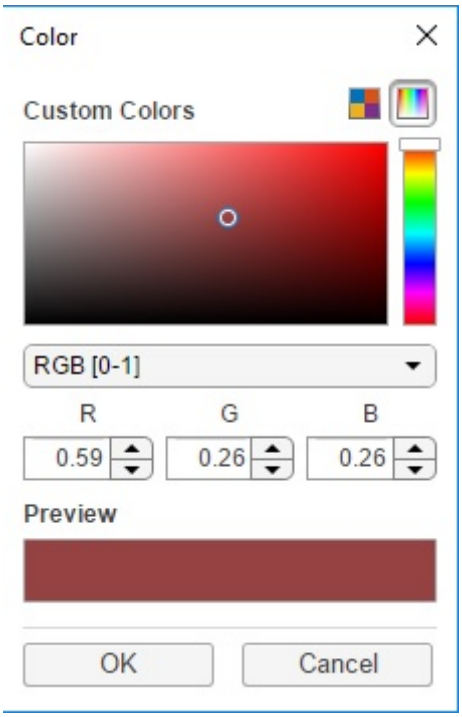


Figure b: Gradient Colour Picker

Reimbursement

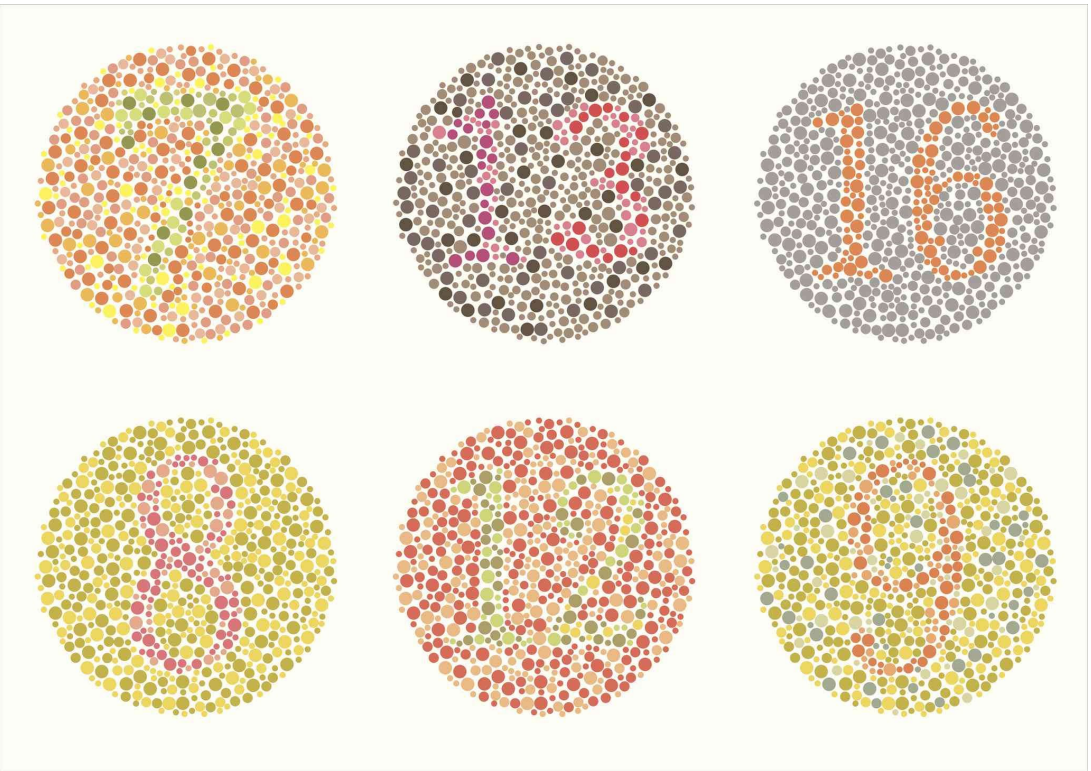
You will be reimbursed with £5 cash at the end of the experiment once you have completed the experiment. You will also be asked to sign on the receipt to confirm that you have received the £10 note for the university finance department purpose.

Other things you might like to know…

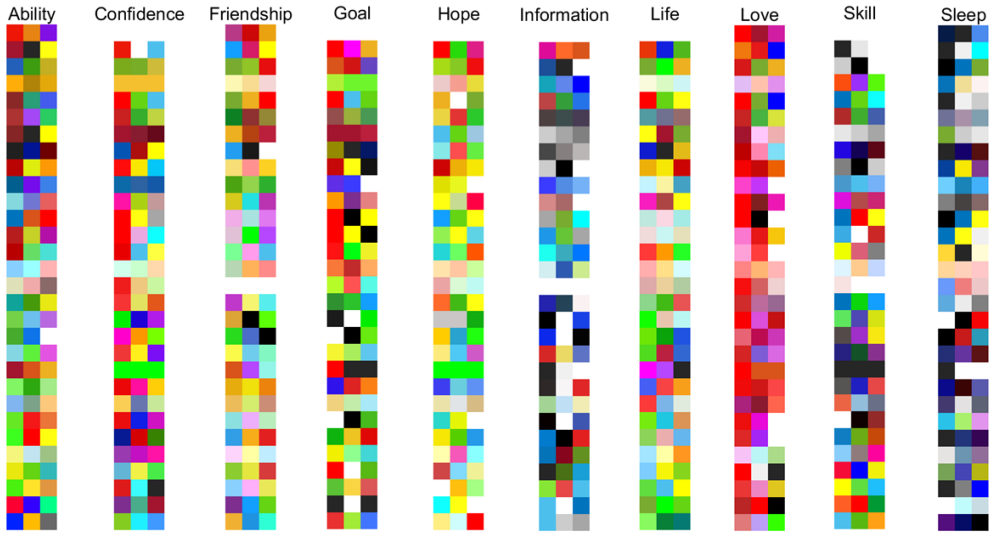
Your participation is anonymous. No personal data from you will be recorded in this study. Reimbursement will be made to you if you successfully completed the participation for reasonable expenses and compensation for time. For further information please contact Yun Chen on 07761297397 or sdyc@leeds.ac.uk. Thank you for taking the time to read through the information.

The Colour Blindness Test

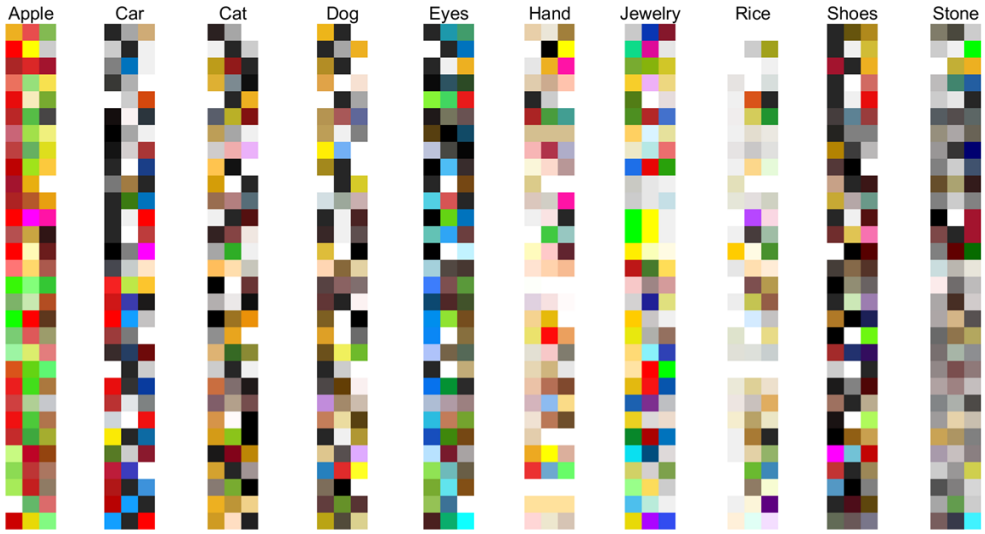
All observers passed a Colour Blindness Test (showed them the a series of specially designed pictures composed of colored dots and asked to look for numbers) before the experiment started (From google image).



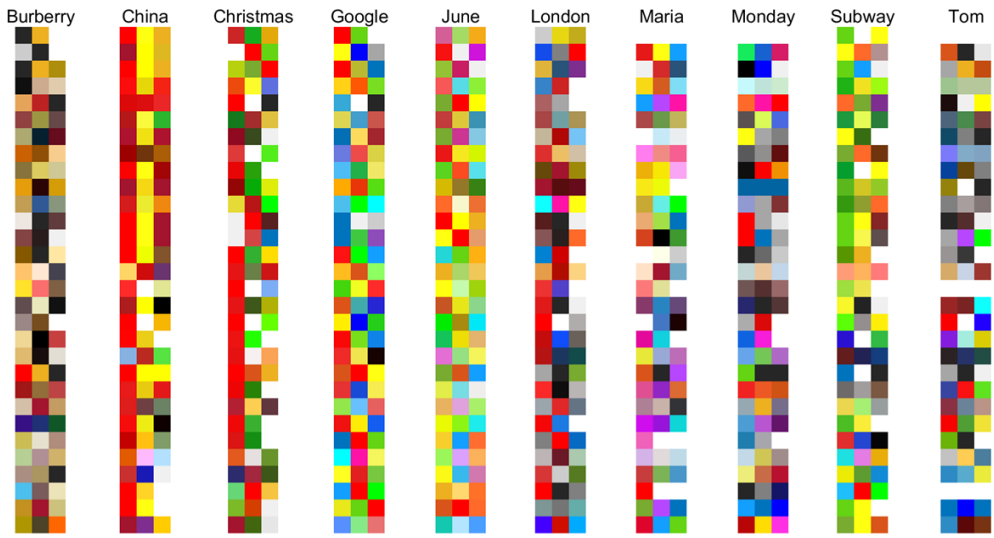
Visual Results of Experiment :



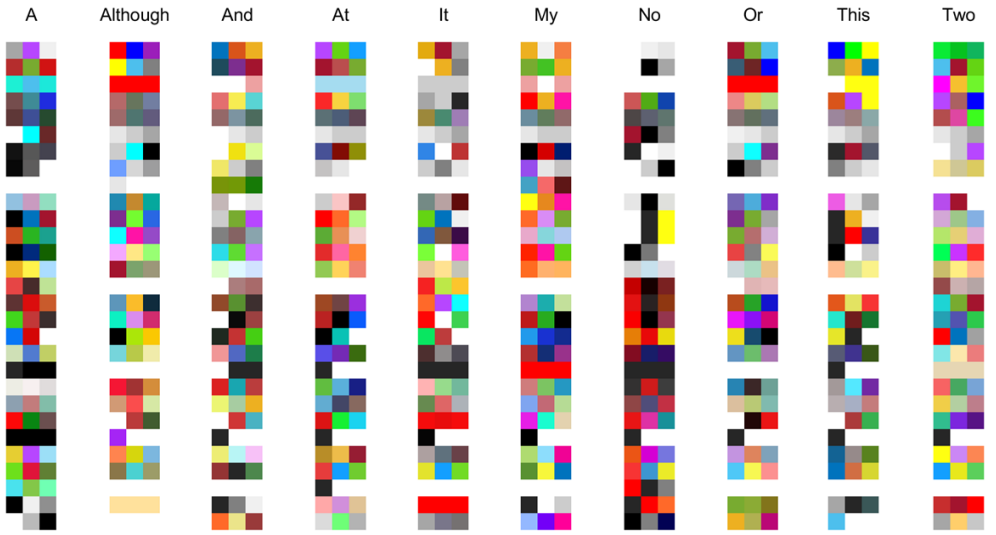
Abstract Noun



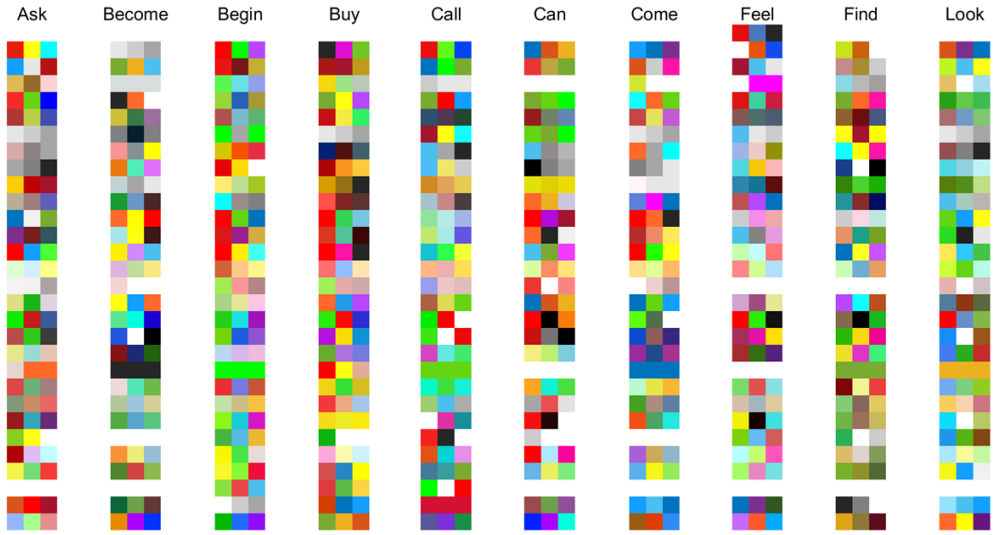
Concrete Noun



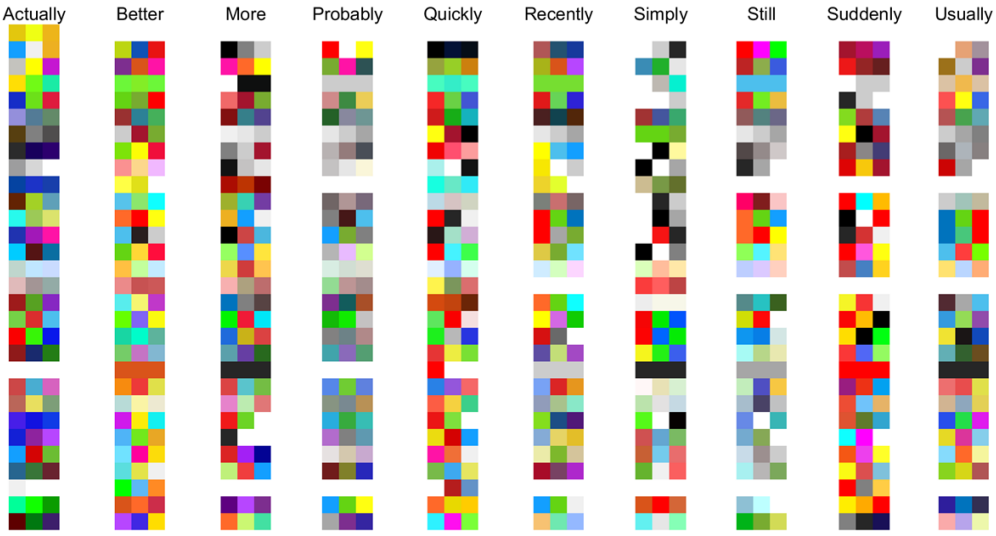
Proper Noun



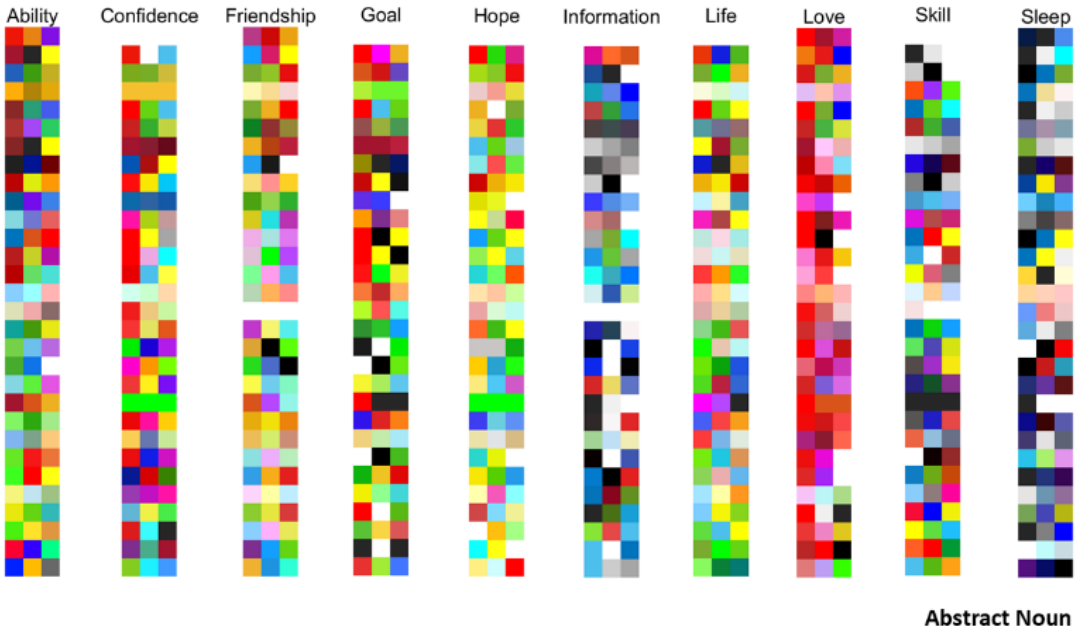
Function Words



Verb



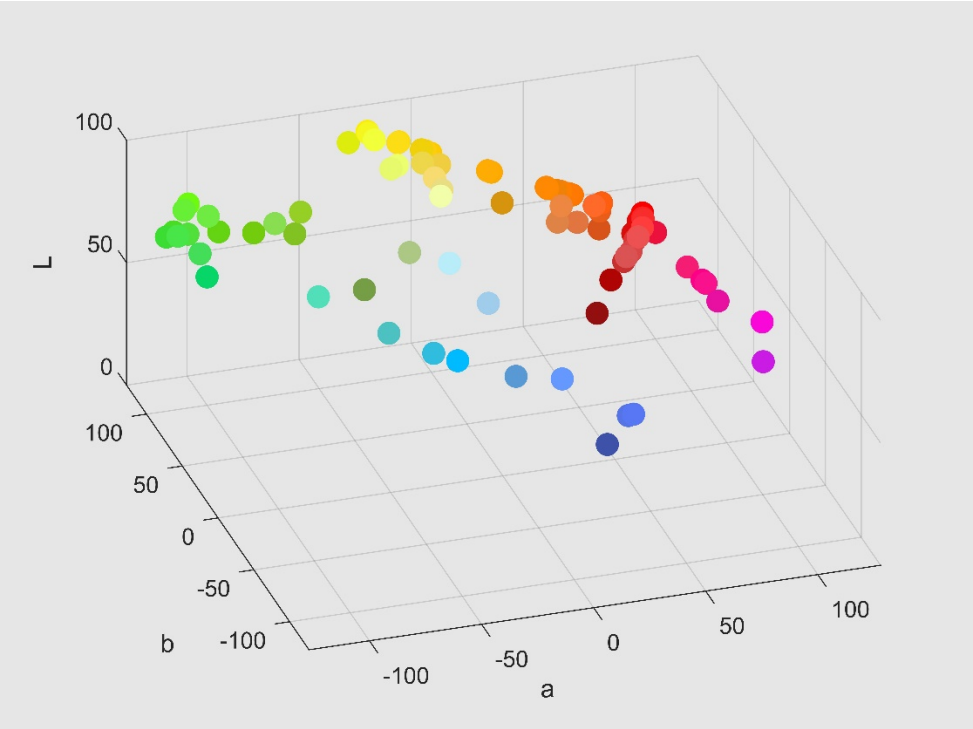
Adverb

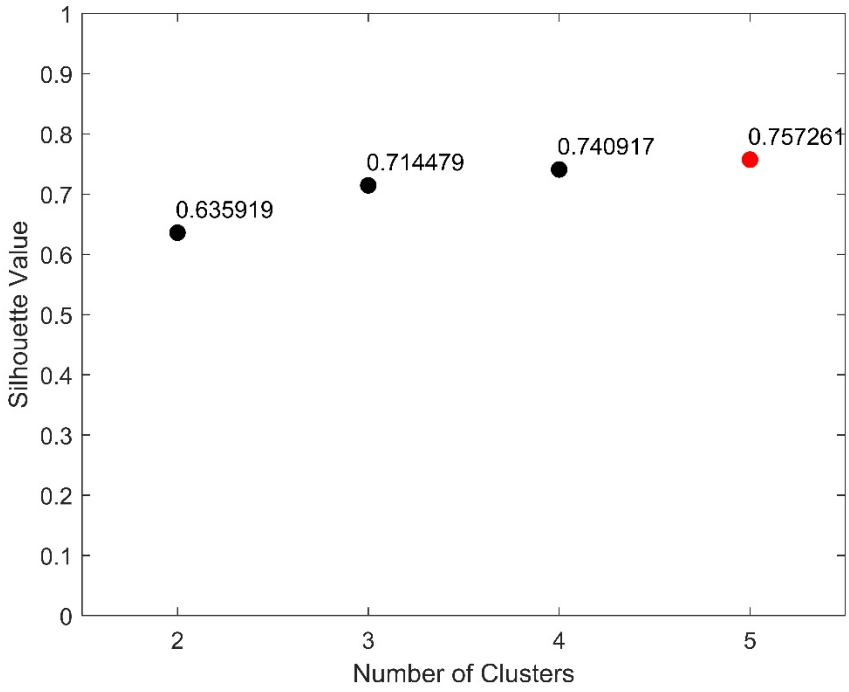

Ability
Confidence
Friendship
Goal
Hope
Information
Life
Love
Skill
Sleep
Abstract Noun

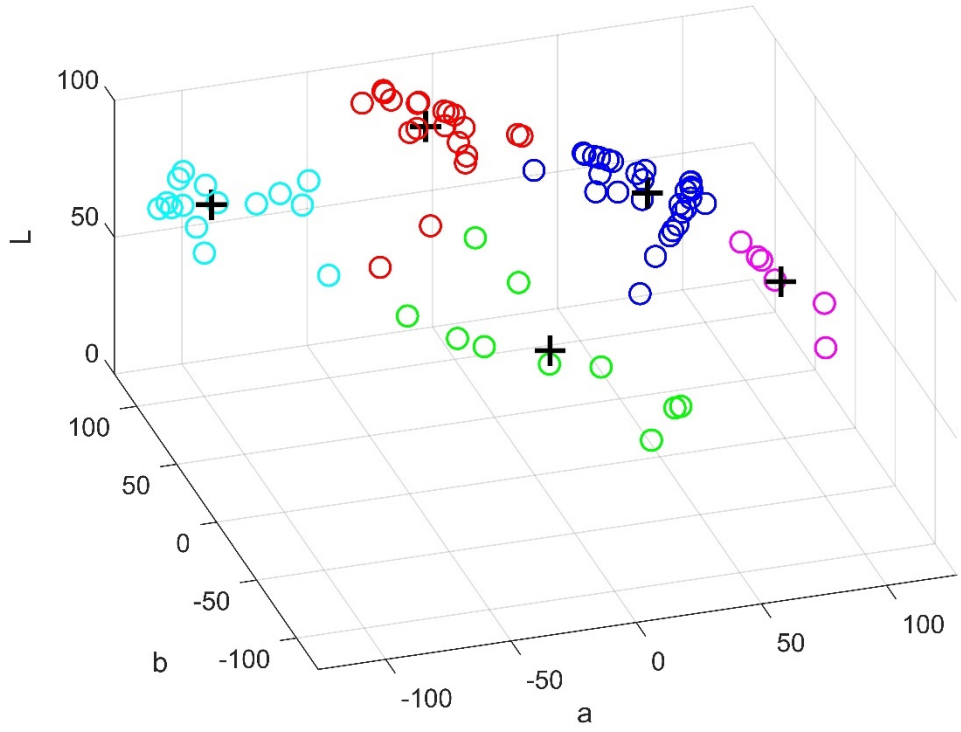
Appendix D2: Experiment 2 (Chapter 6)

Clustering analysis of each sample (the colour points distribution in space; the number of clusters determine):

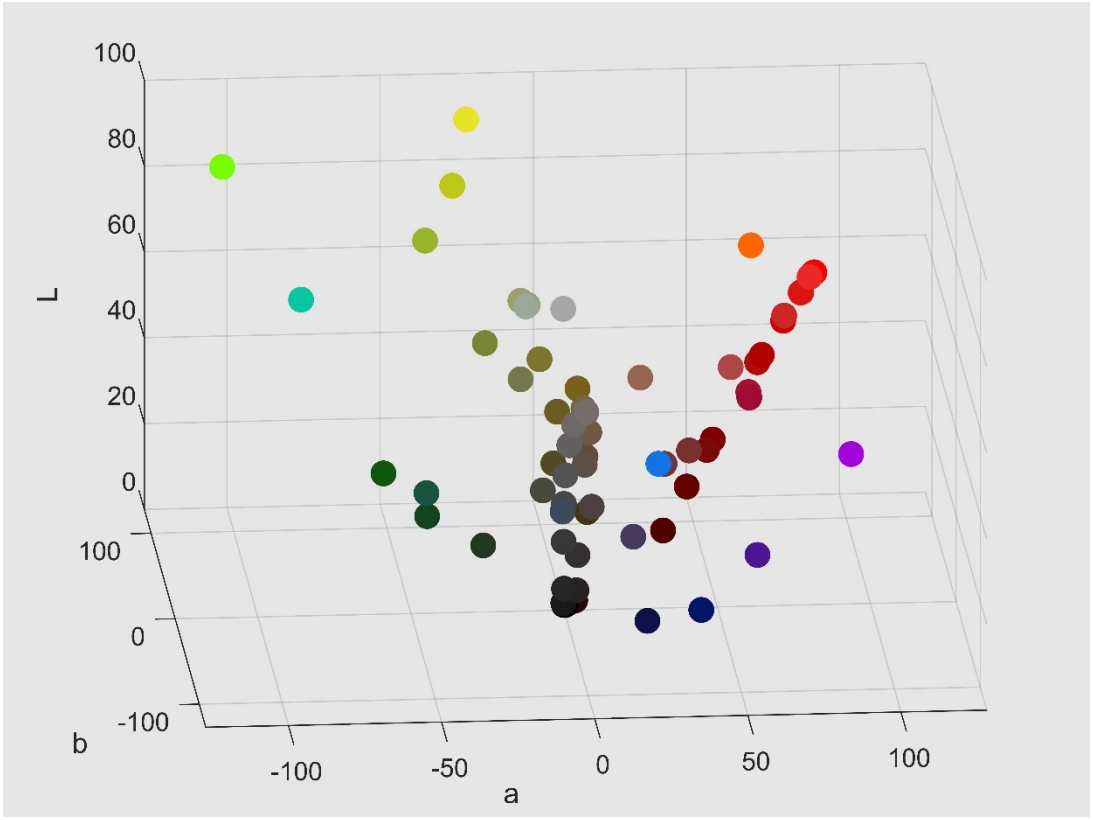
1. Active

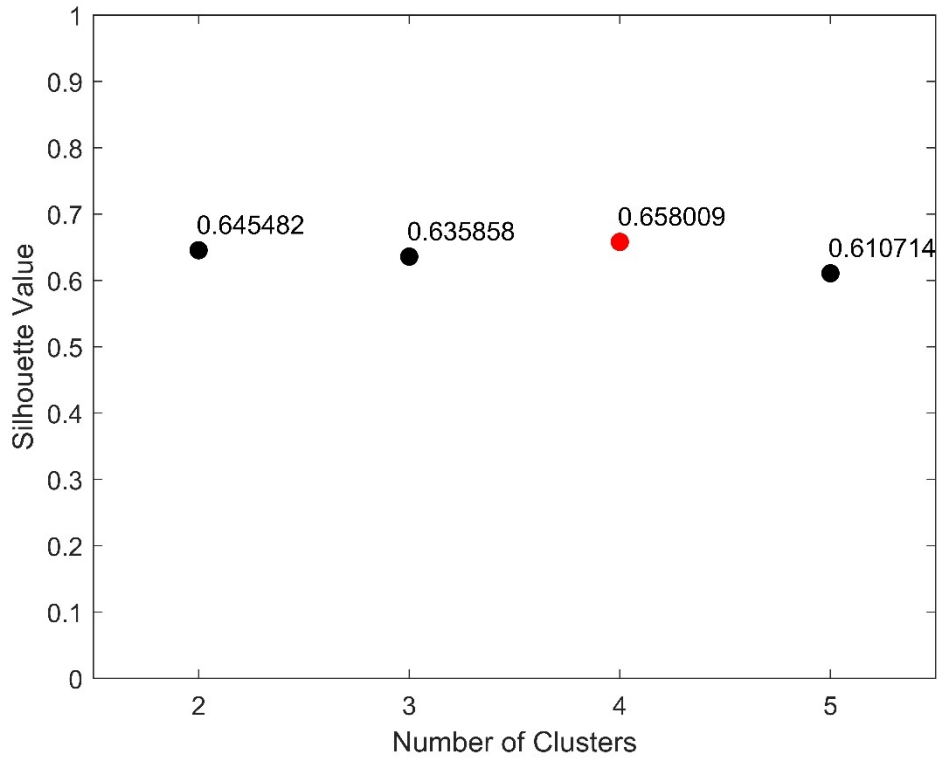


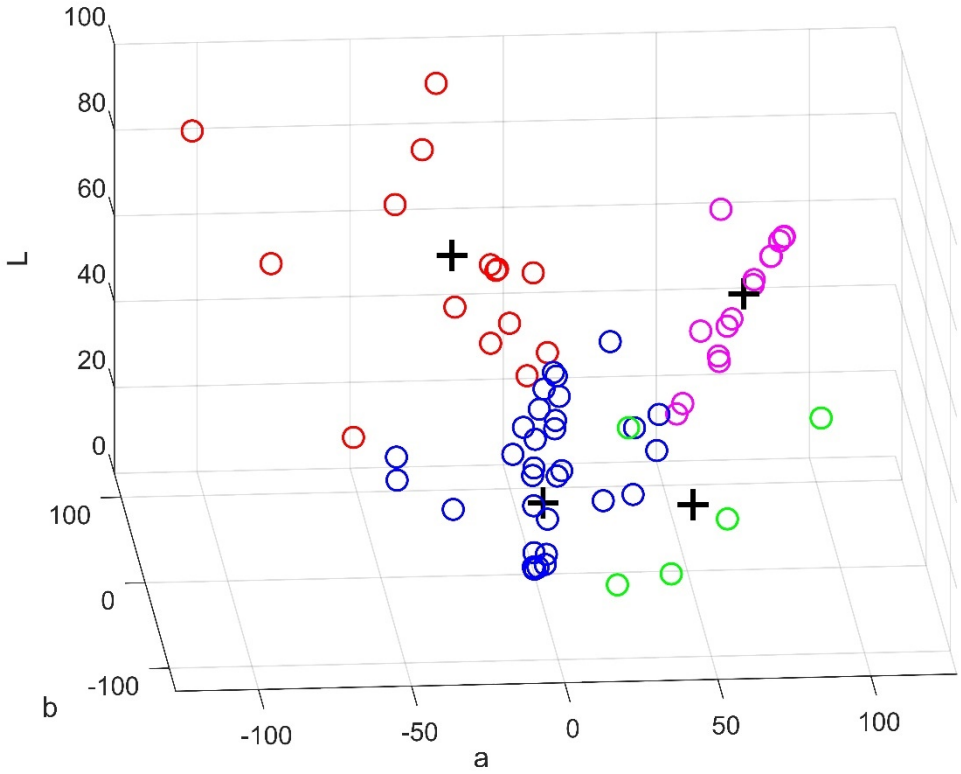



100
50
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

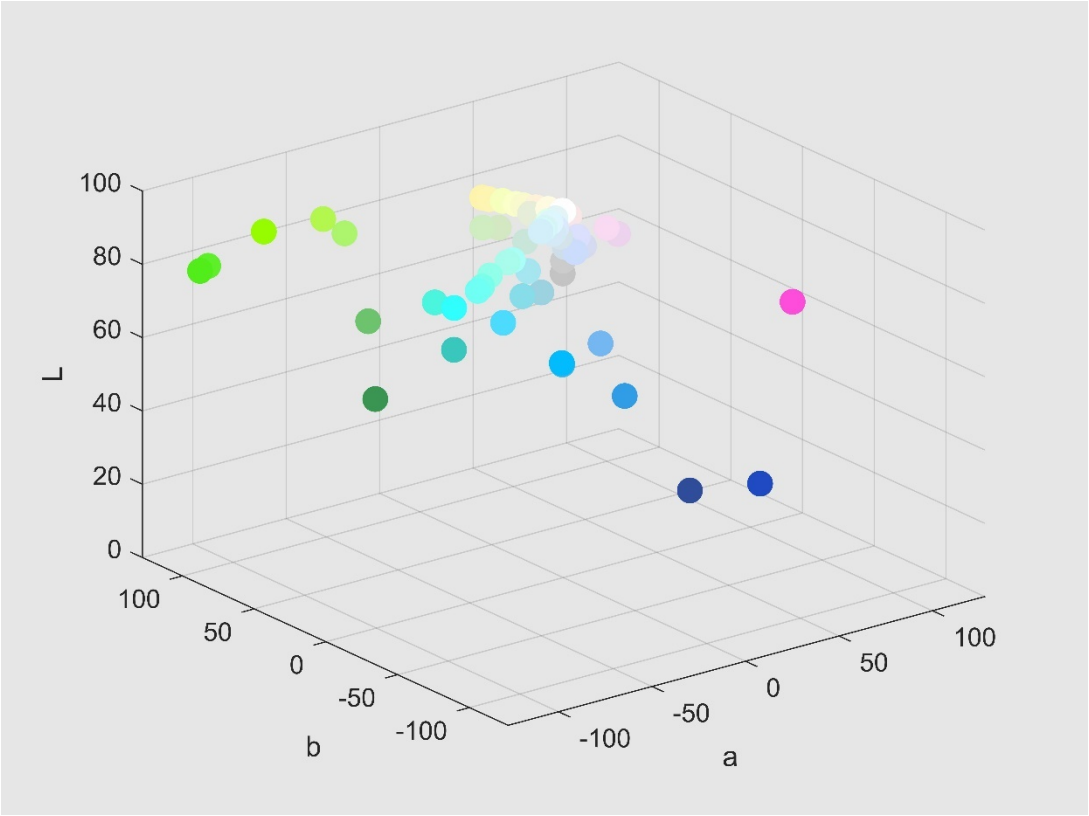
2. Bad

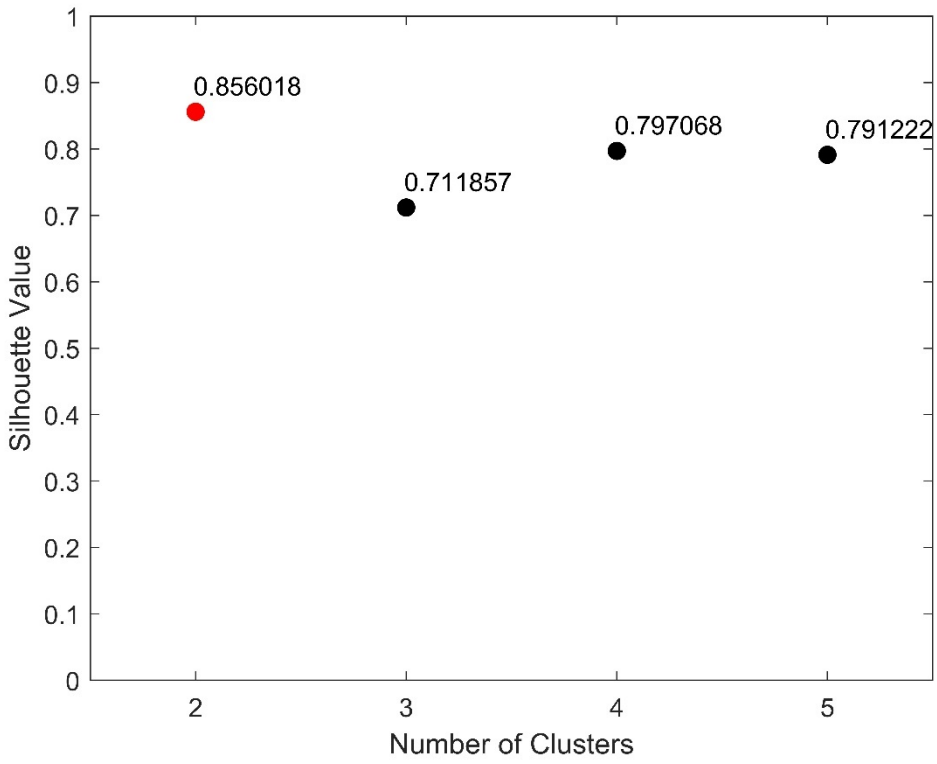

100
80
60
40
20
0
L
100
0
-100
b
-100
-50
0
50
100
a

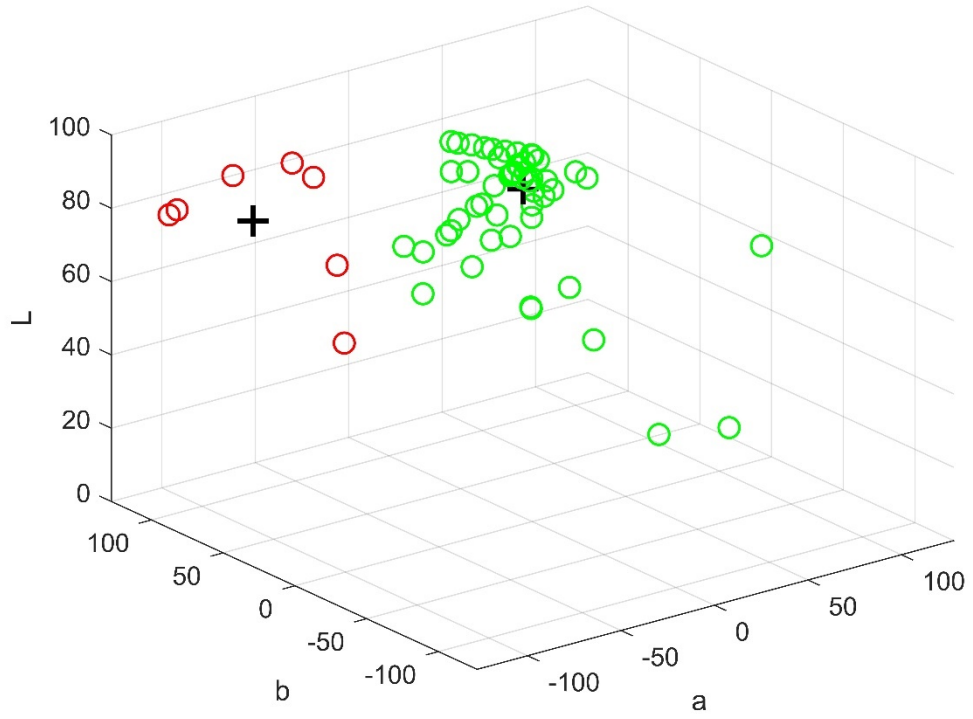

Silhouette Value
Number of Clusters
0.645482
0.635858
0.658009
0.610714
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
80
60
40
20
0
100
0
-100
-100
-50
0
50
100

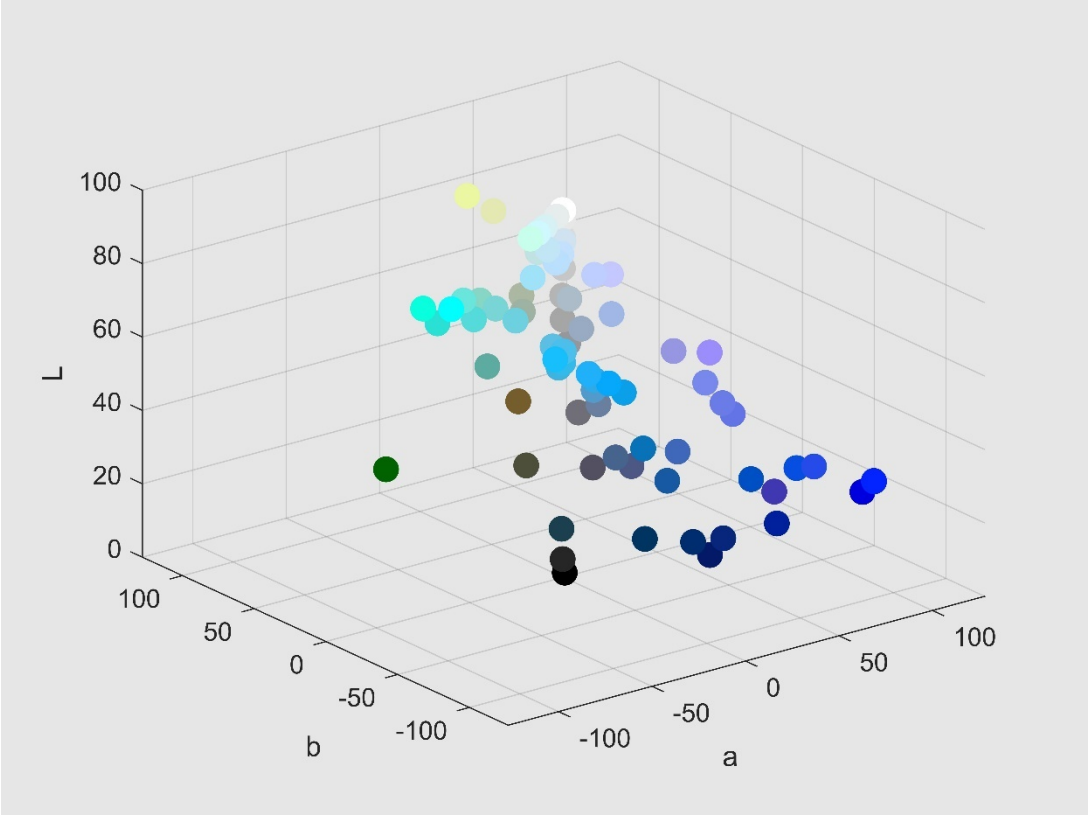
3. Clean

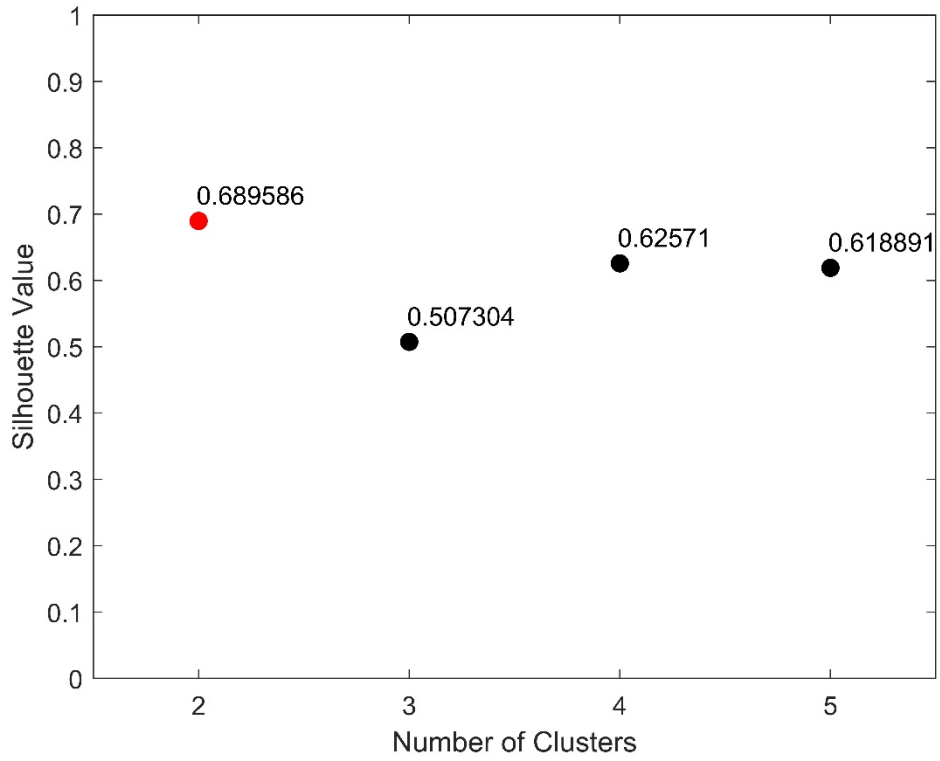

L
100
80
60
40
20
0
b
100
50
0
-50
-100
a
-100
-50
0
50
100

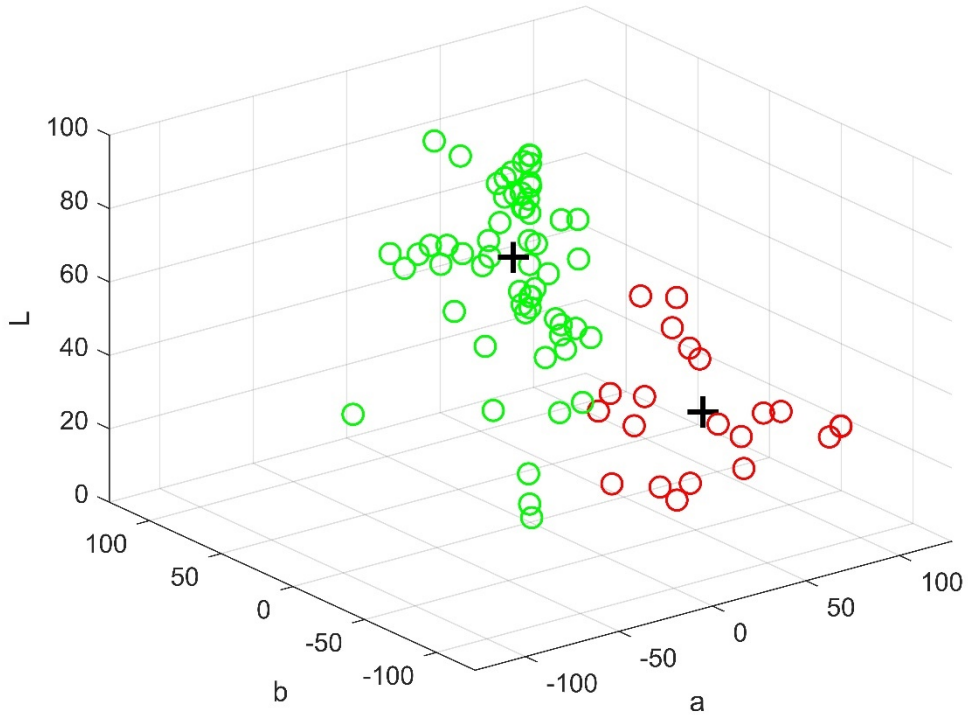

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.856018
0.711857
0.797068
0.791222
2
3
4
5
Number of Clusters


100
80
60
40
20
0
L
100
50
0
-50
-100
b
100
50
0
-50
-100
a

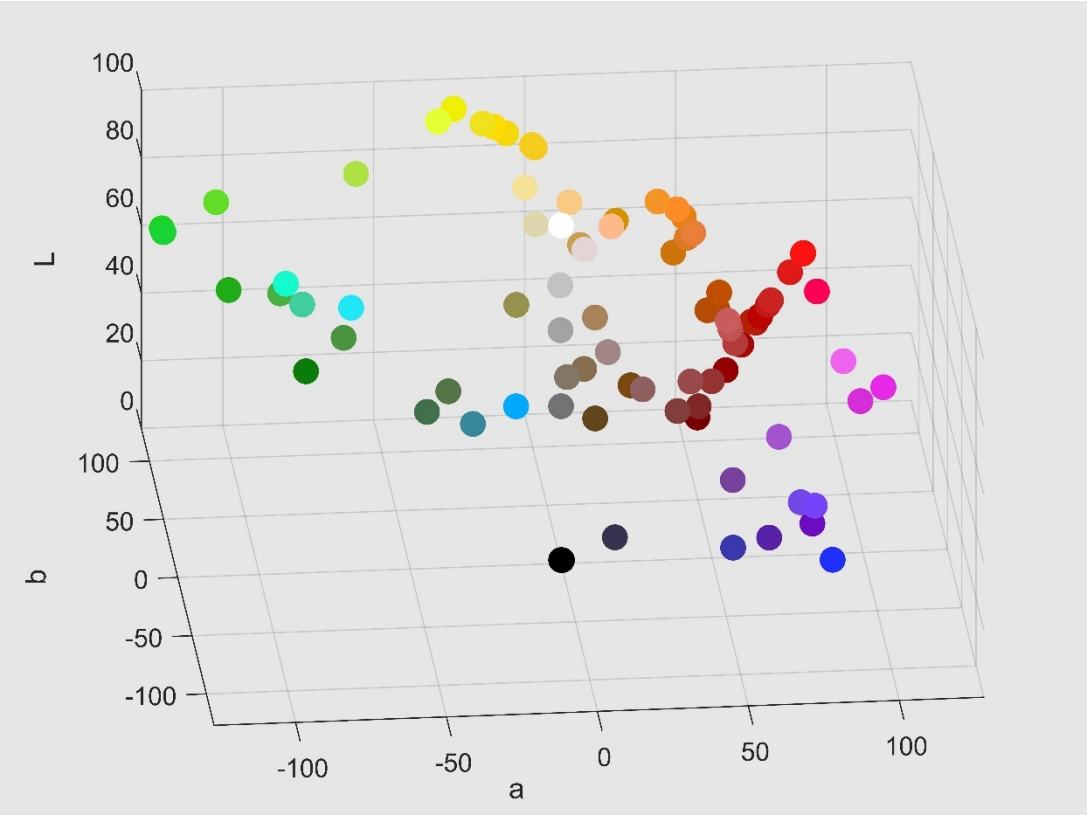
4. Cold

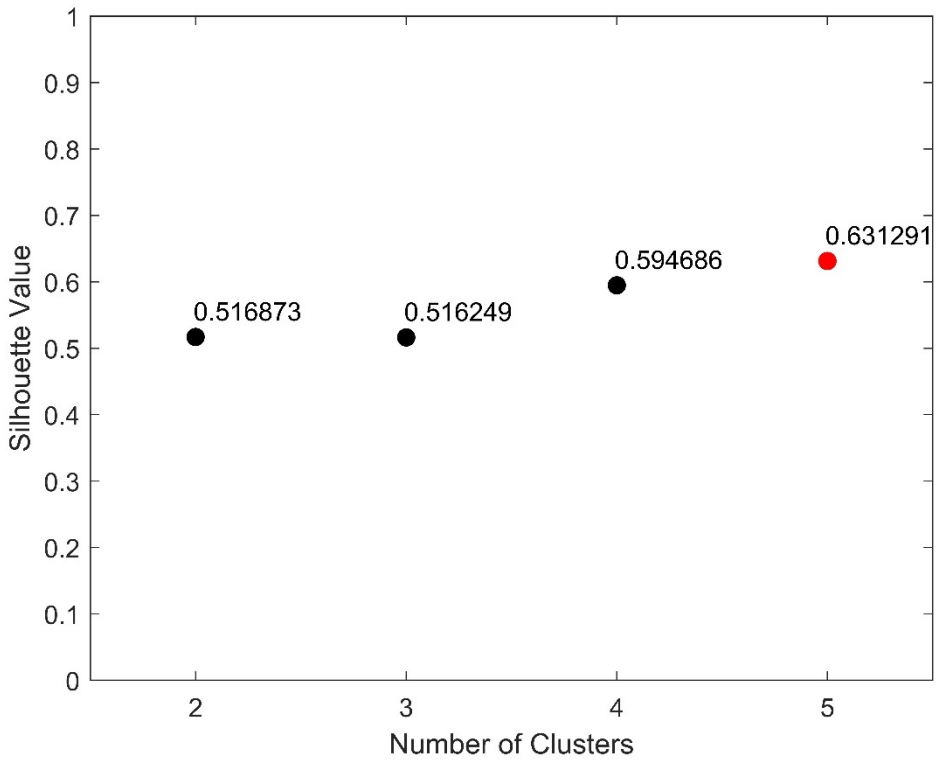

100
80
60
40
20
0
L
100
50
0
-50
-100
b
100
50
0
-50
-100
a

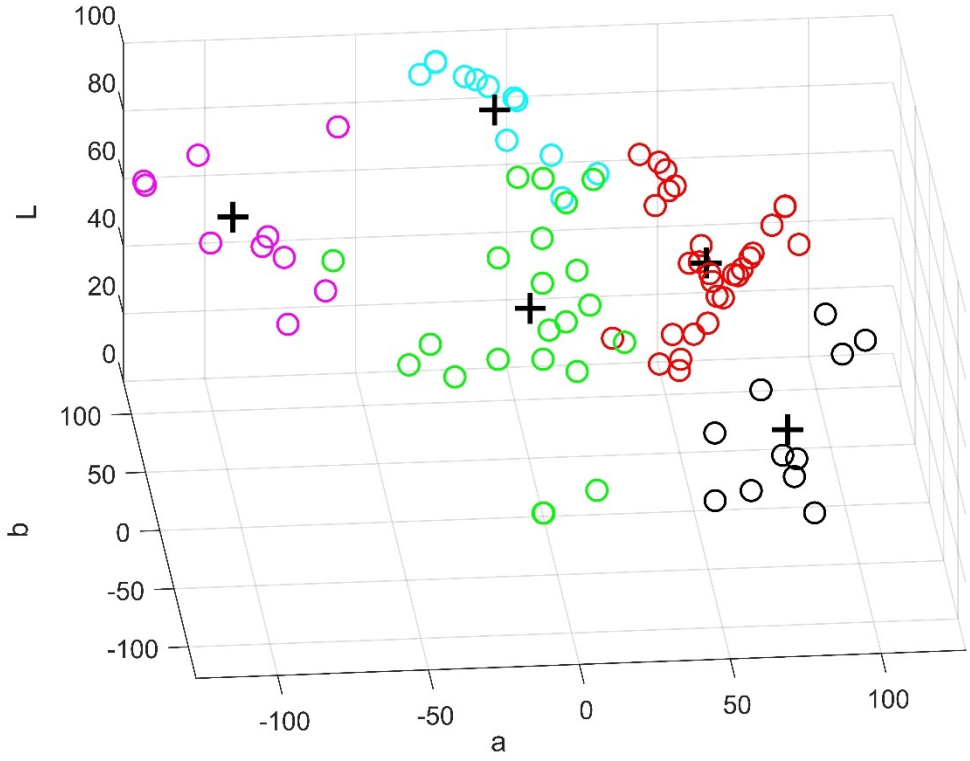

Silhouette Value
Number of Clusters
0.689586
0.507304
0.62571
0.618891
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
80
60
40
20
0
100
50
0
-50
-100
100
50
0
-50
-100

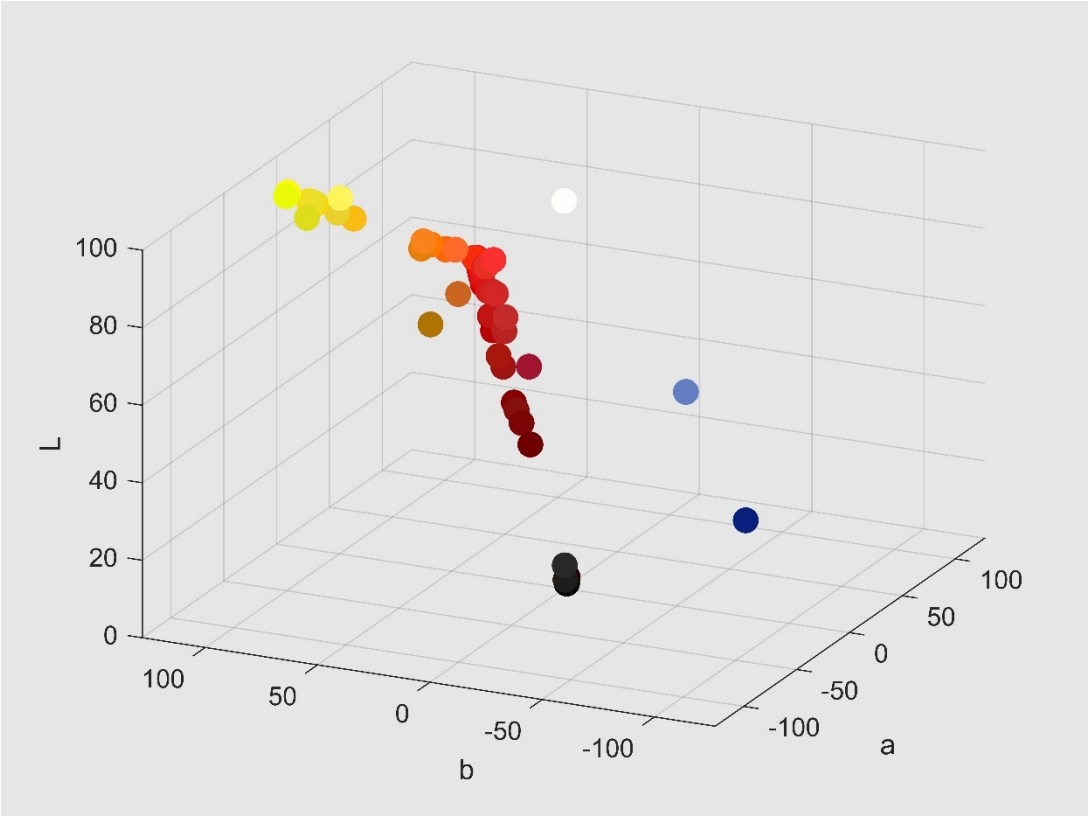
5. Cultural

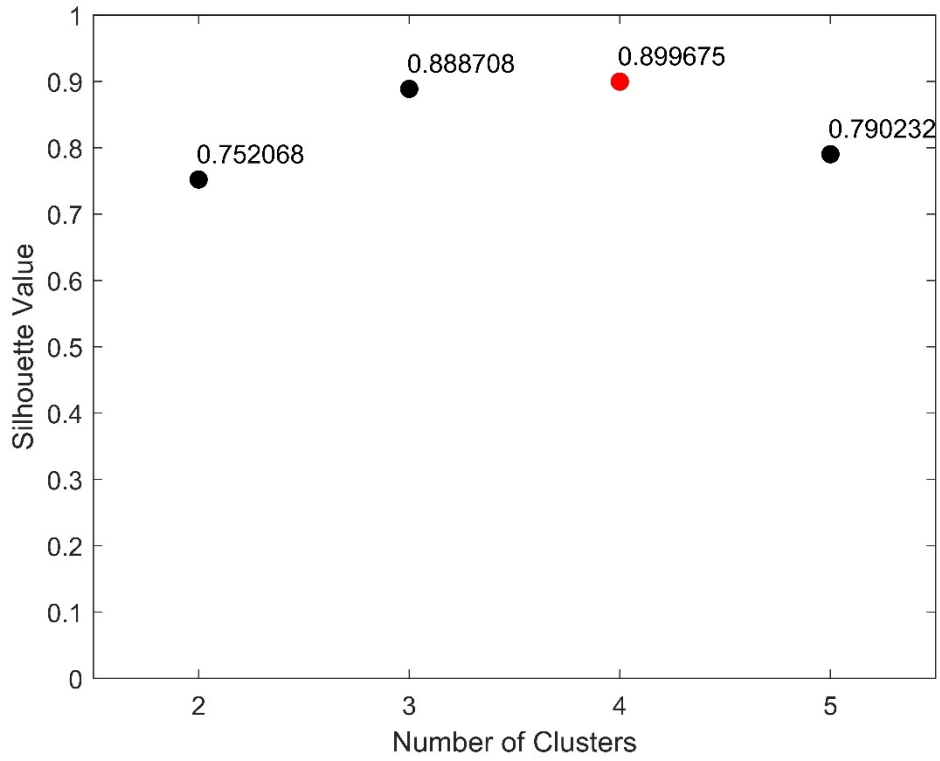

100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

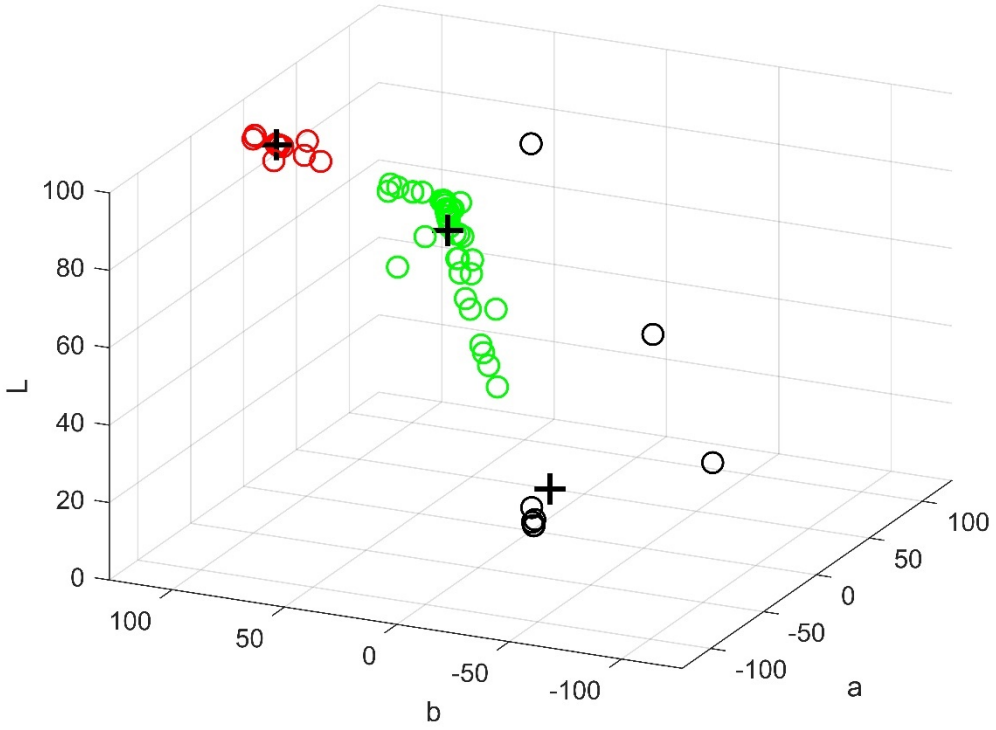

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Silhouette Value
0.516873
0.516249
0.594686
0.631291
2
3
4
5
Number of Clusters


L
b
a
100
80
60
40
20
0
100
50
0
-50
-100
-100
-50
0
50
100

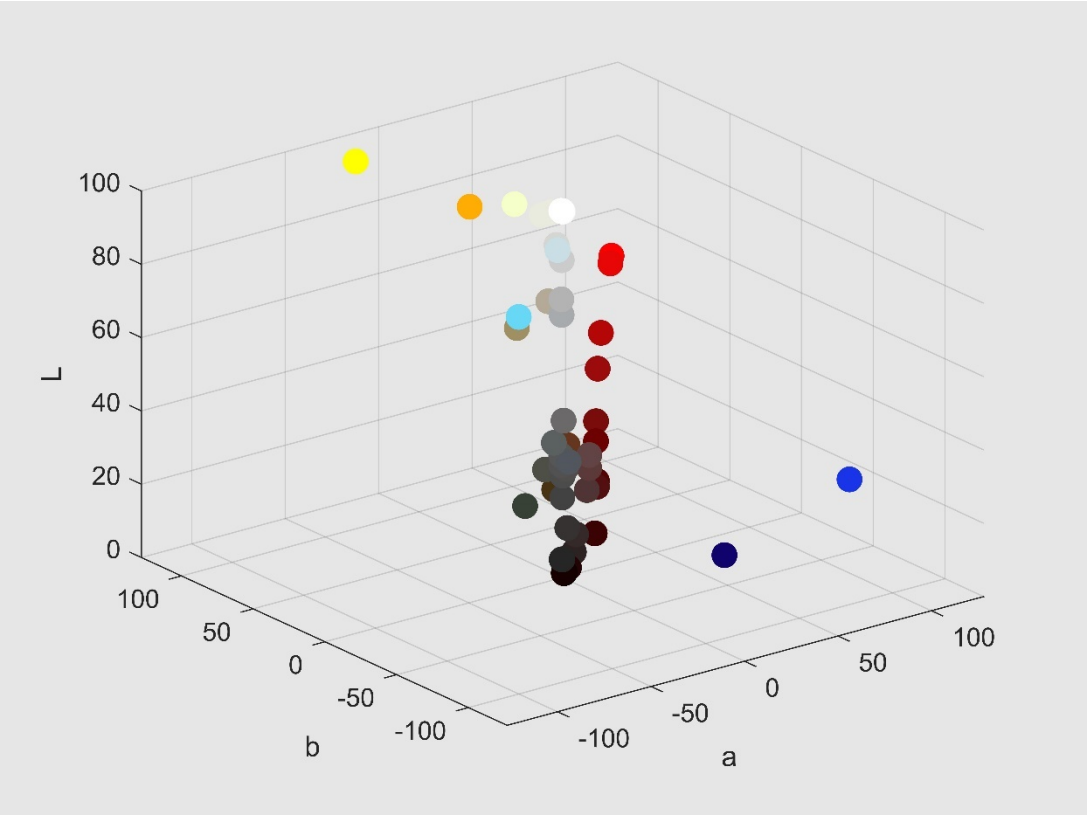
6. Dangerous

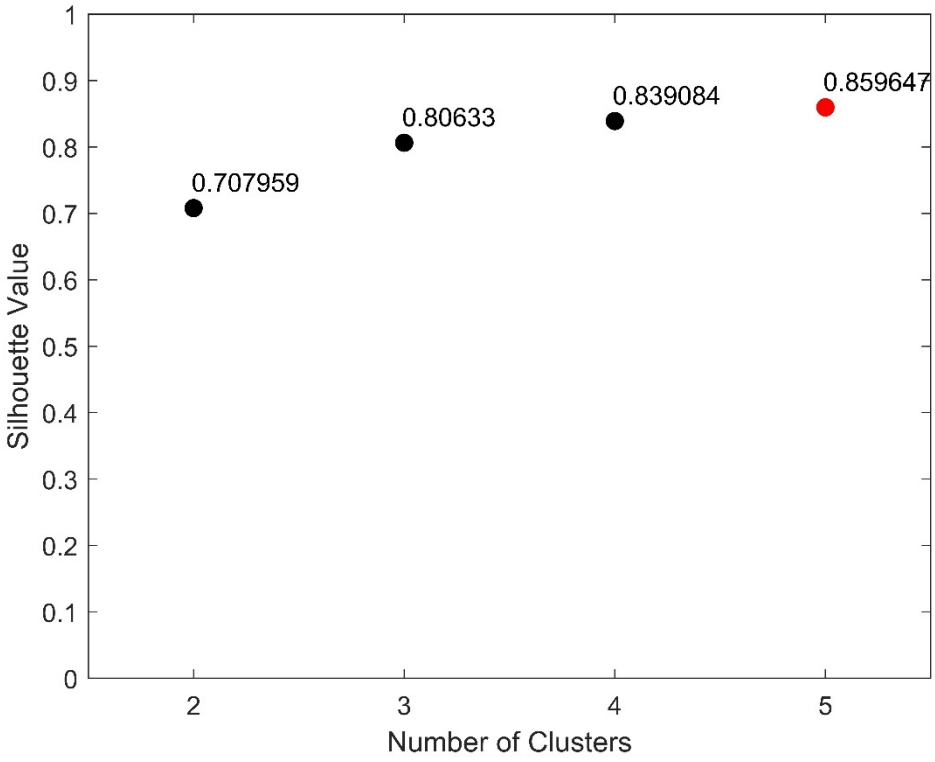

L
b
a
100
80
60
40
20
0
100
50
0
-50
-100
100
50
0
-50
-100

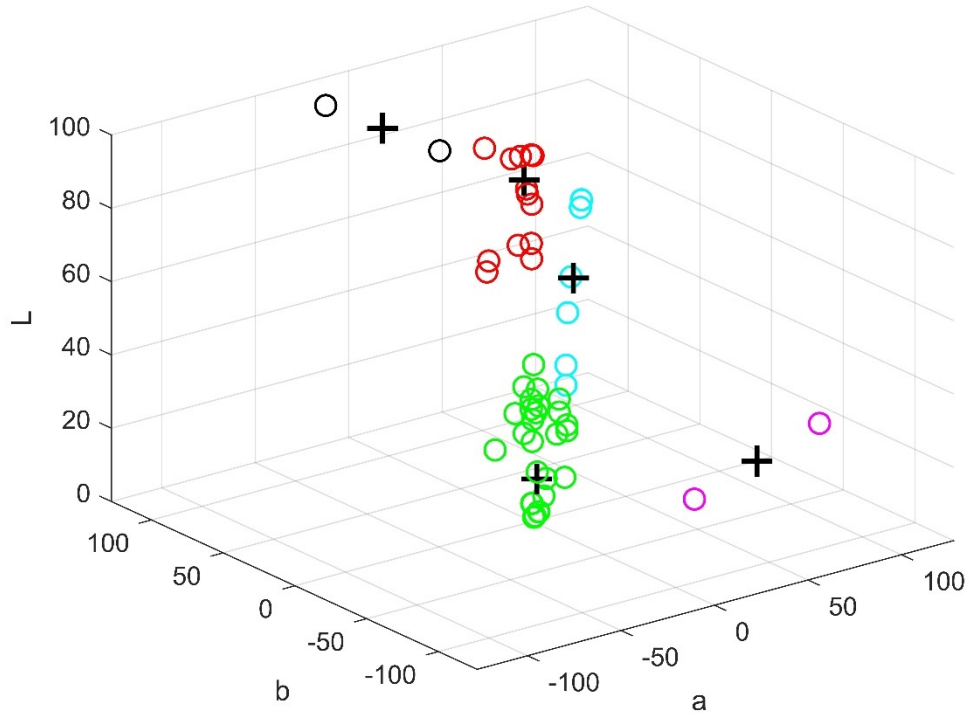

0.888708
0.899675
0.790232
0.752068
Silhouette Value
Number of Clusters


L
b
a

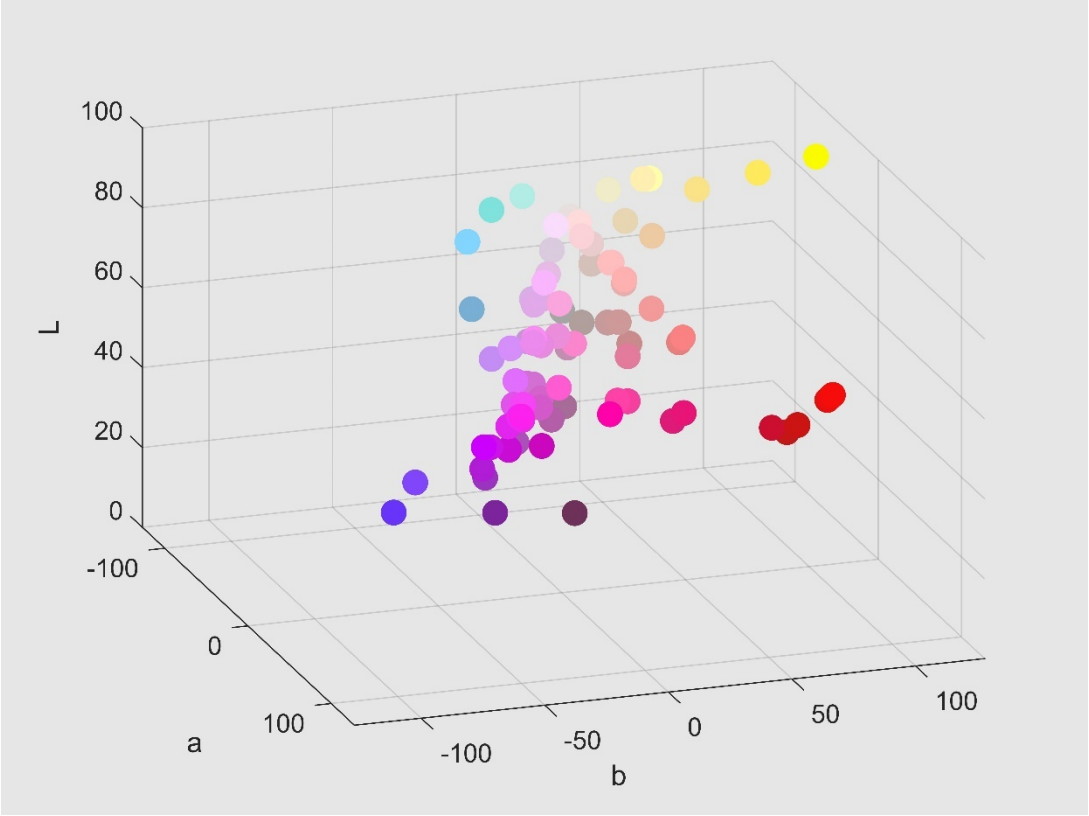
7. Dead

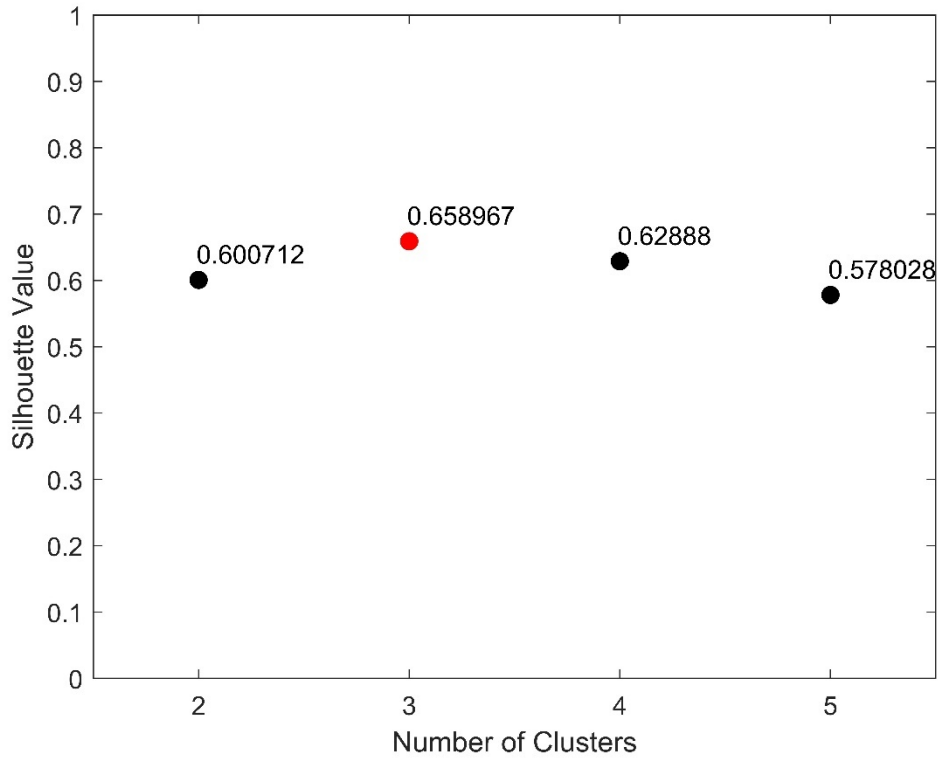

L
100
80
60
40
20
0
b
100
50
0
-50
-100
a
-100
-50
0
50
100

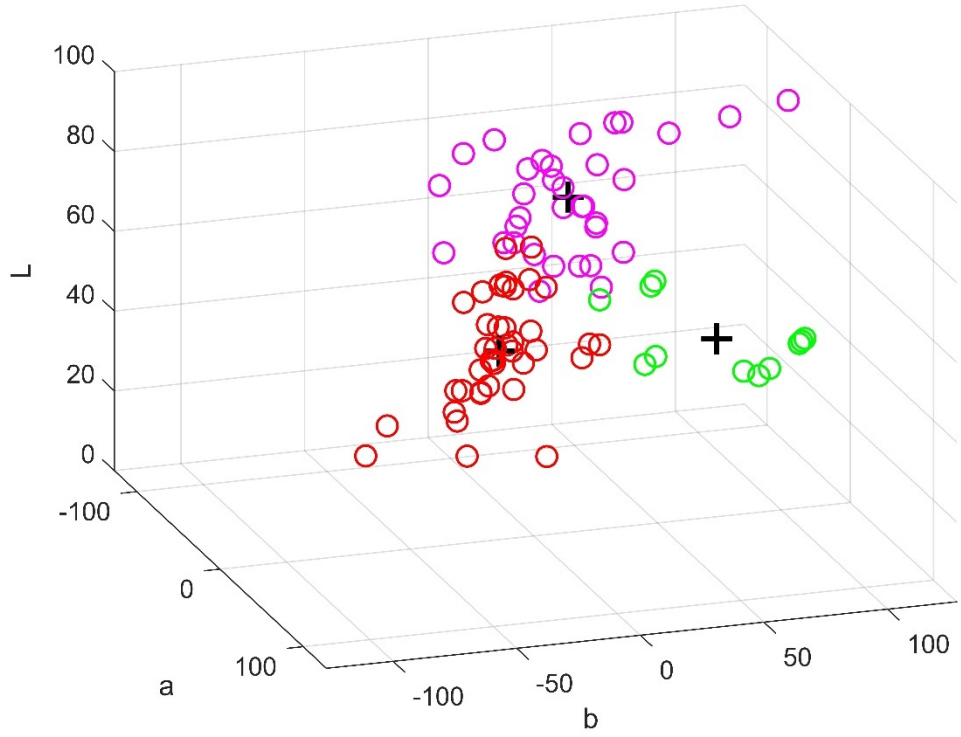

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.707959
0.80633
0.839084
0.859647
2
3
4
5
Number of Clusters


L
100
80
60
40
20
0
100
50
0
-50
-100
b
100
50
0
-50
-100
a

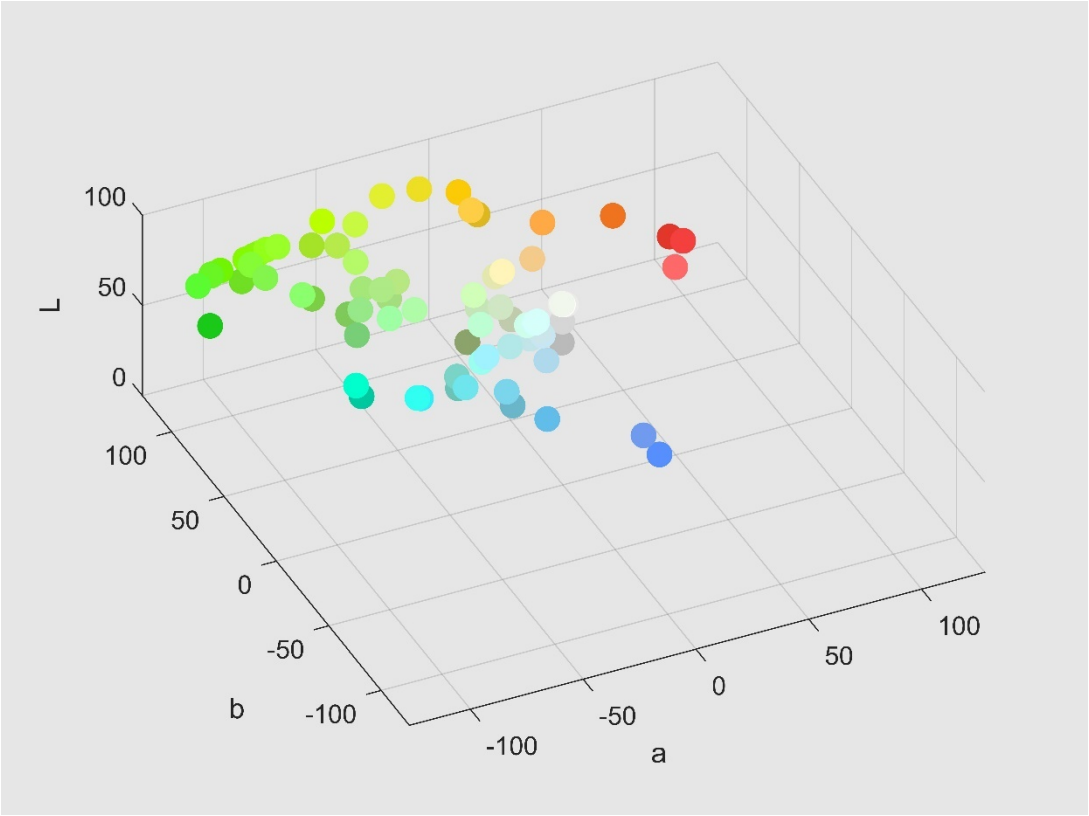
8. Female

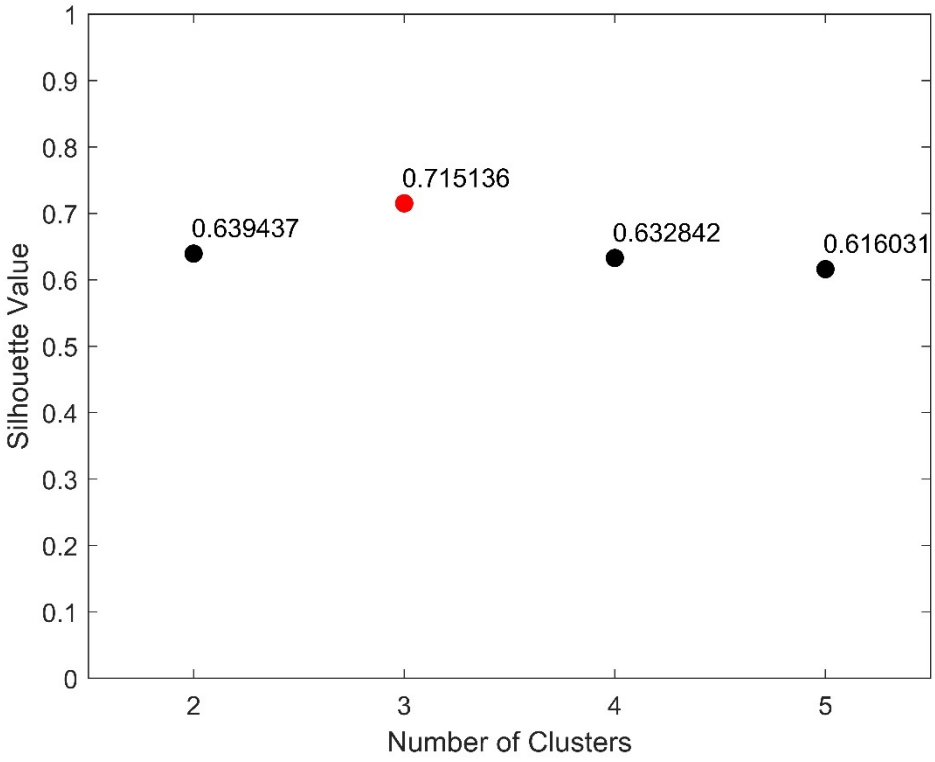

L
100
80
60
40
20
0
-100
0
100
a
100
50
0
-50
-100
b

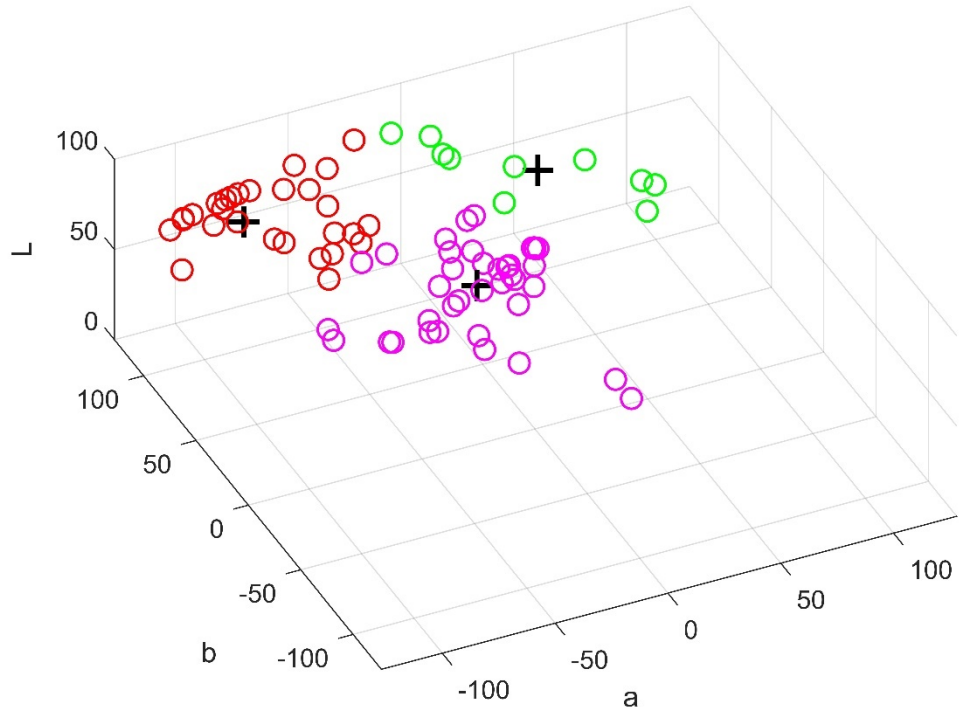

Silhouette Value
Number of Clusters
0.600712
0.658967
0.62888
0.578028
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
80
60
40
20
0
-100
0
100
-100
-50
0
50
100

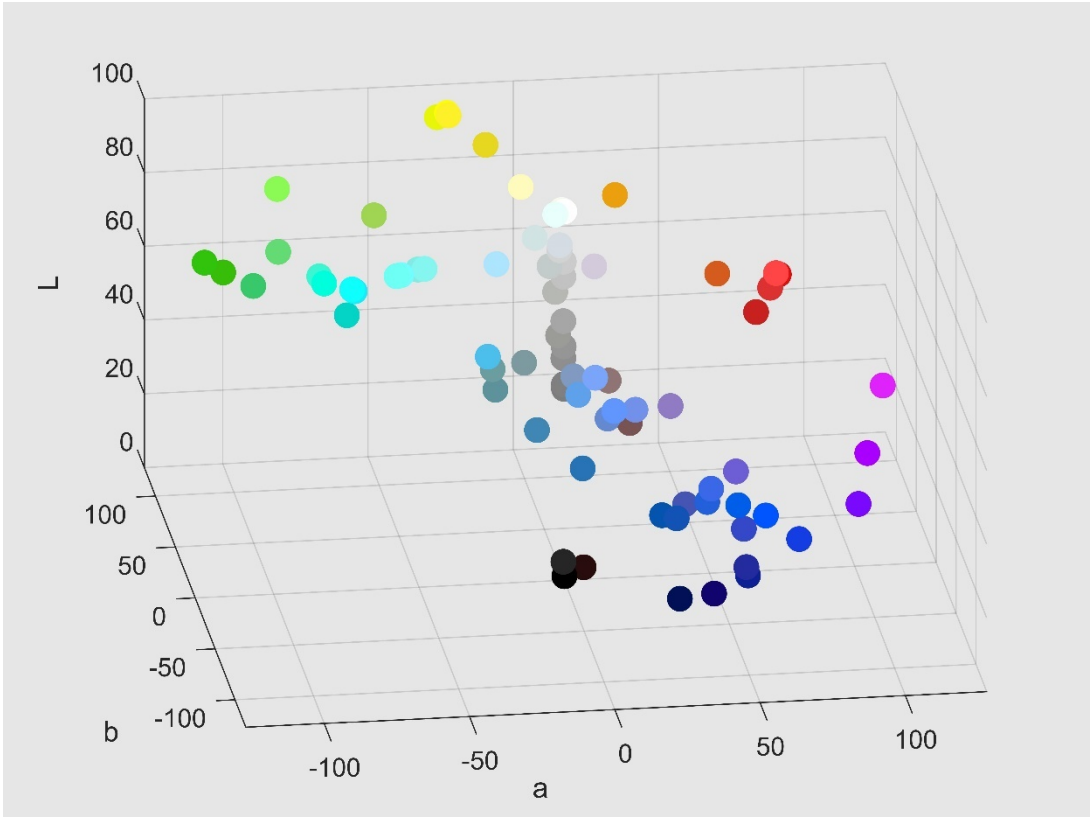
9. Fresh

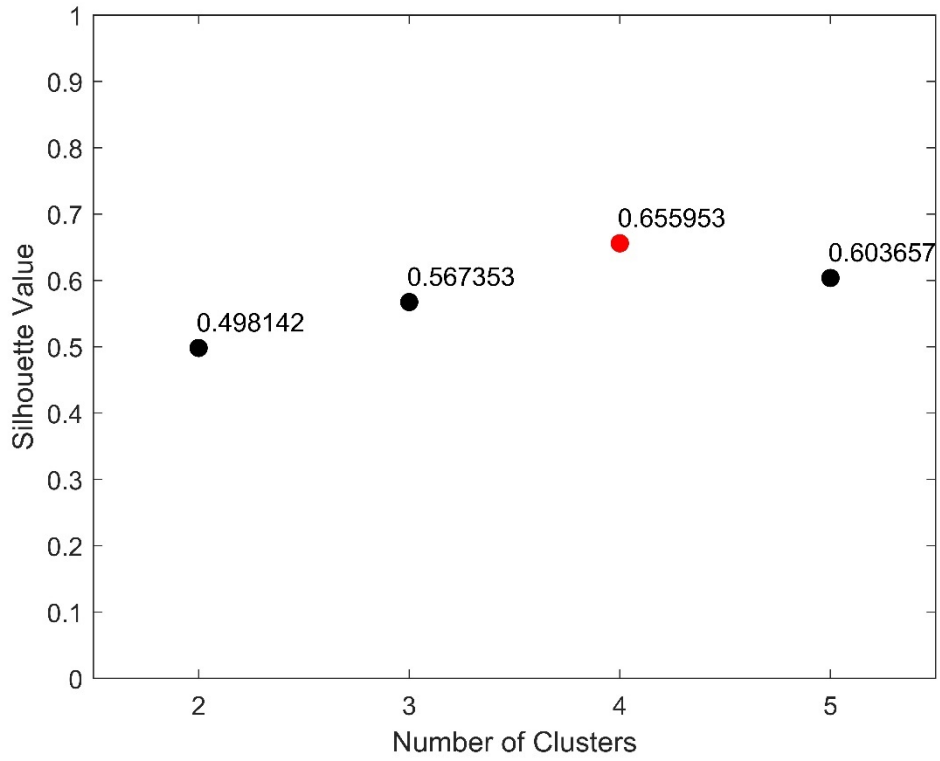

L
100
50
0
b
100
50
0
-50
-100
a
-100
-50
0
50
100

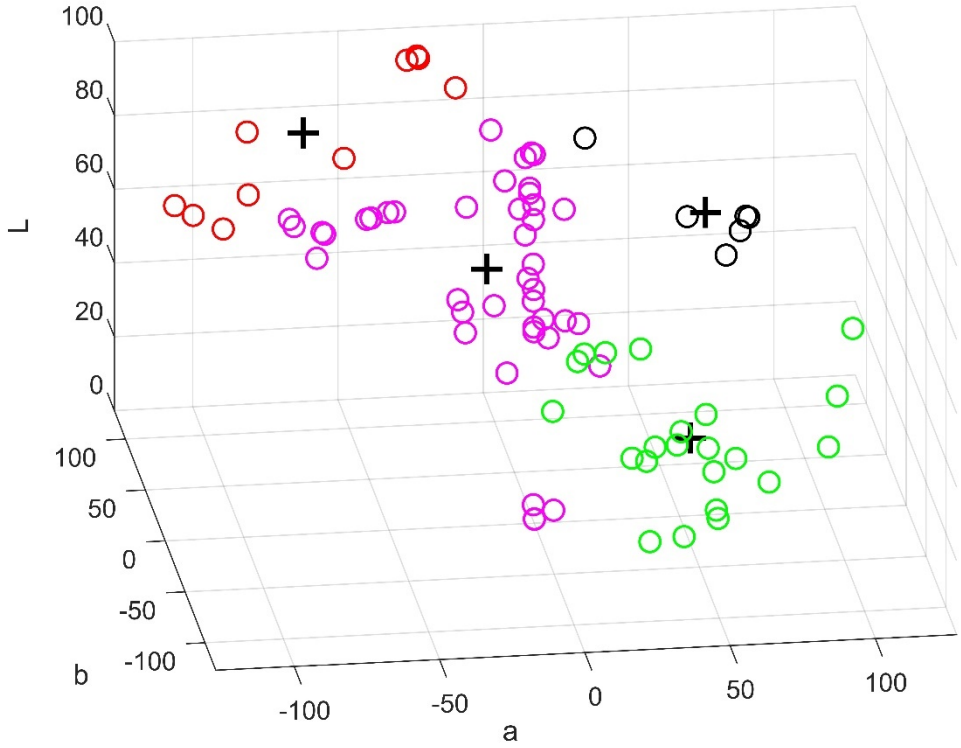

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.639437
0.715136
0.632842
0.616031
2
3
4
5
Number of Clusters


L
100
50
0
100
50
0
-50
-100
b
-100
-50
0
50
100
a

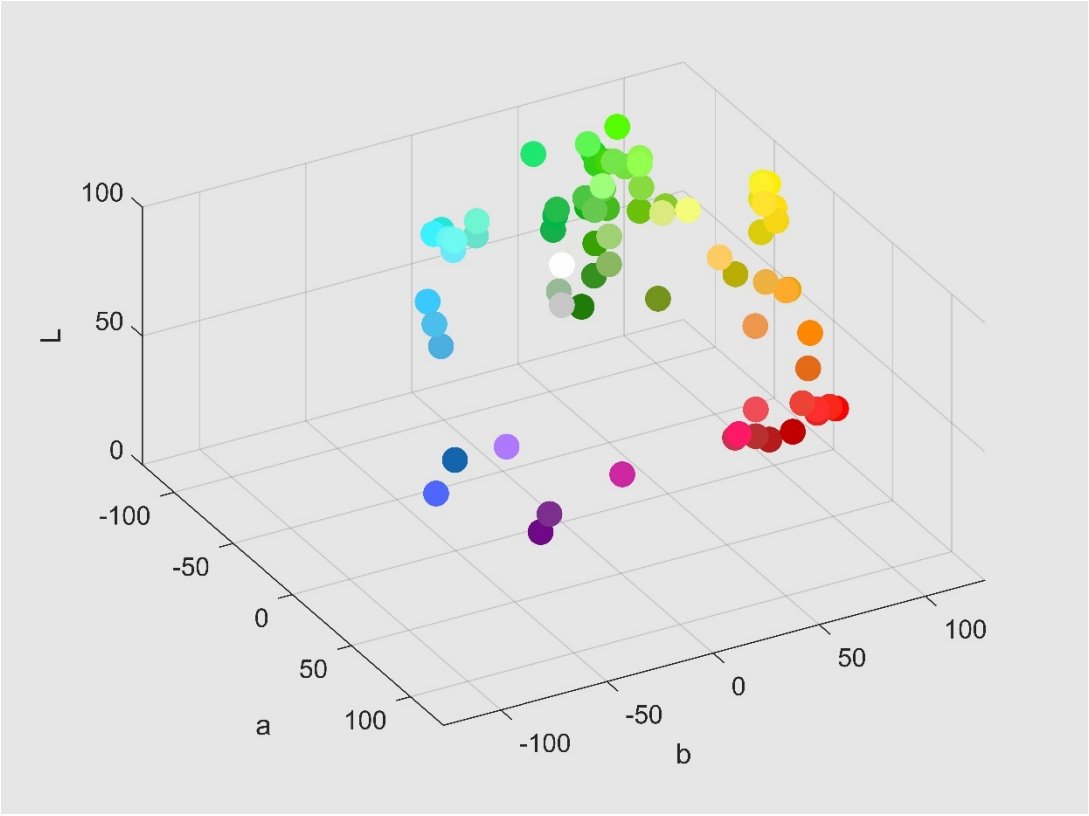
10. Future

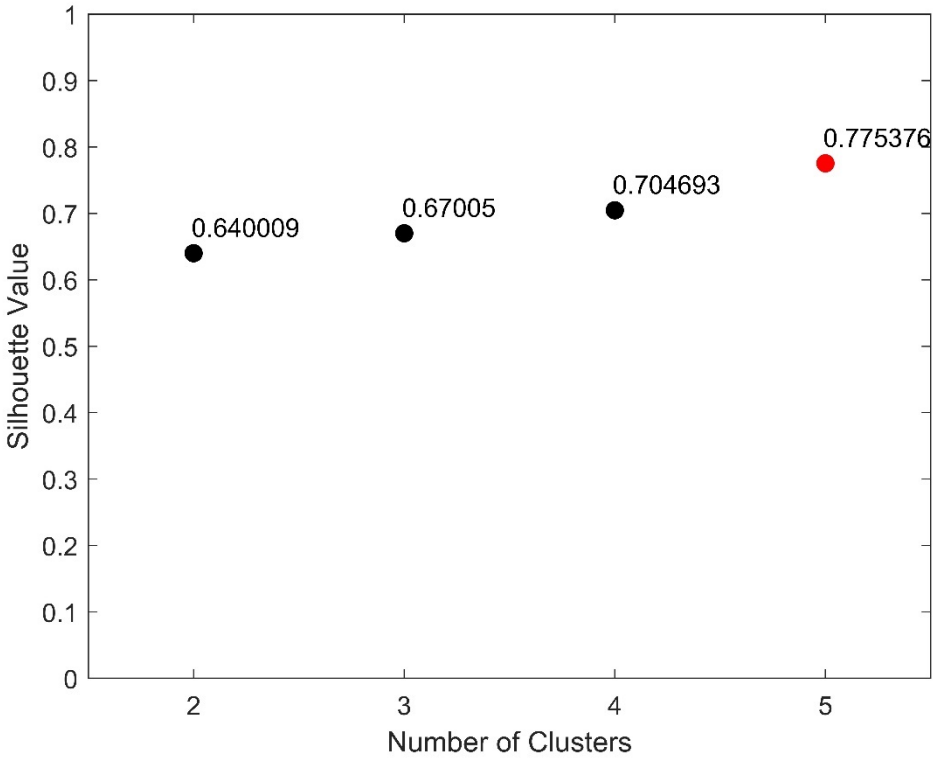

L
100
80
60
40
20
0
100
50
0
-50
-100
b
-100
-50
0
50
100
a

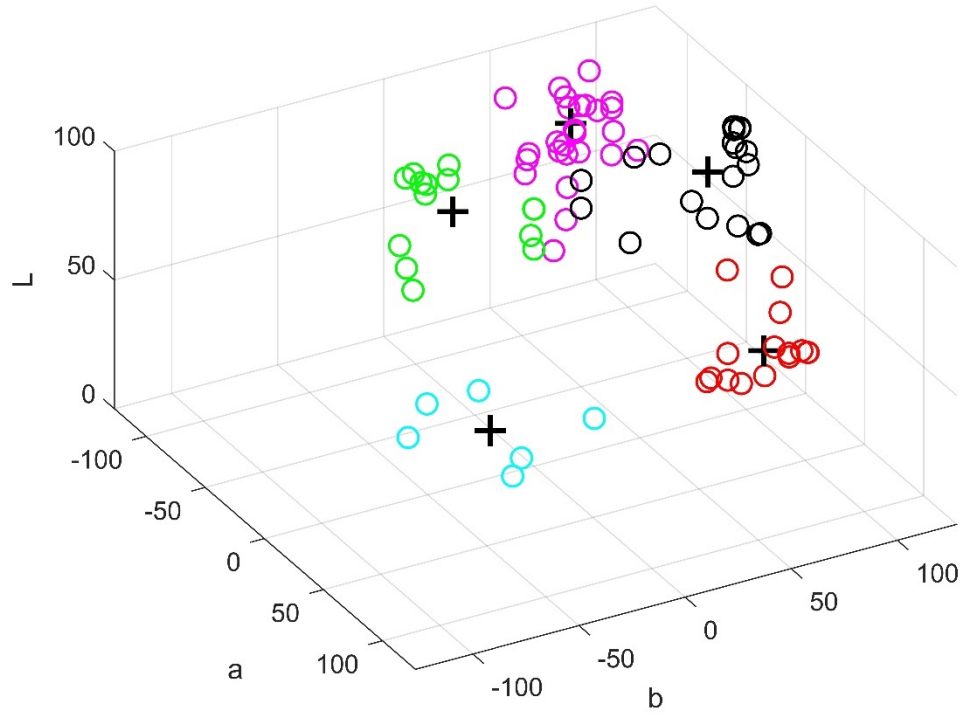

Silhouette Value
Number of Clusters
0.498142
0.567353
0.655953
0.603657


L
a
b

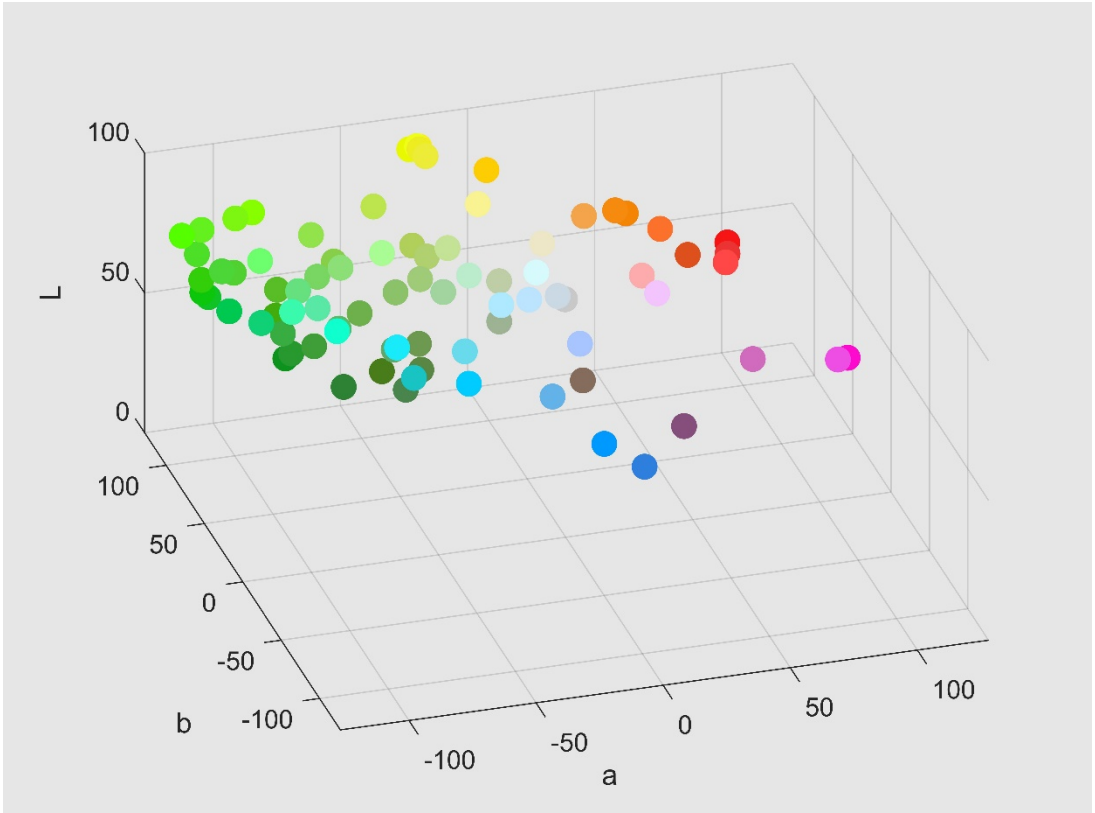
11. Good

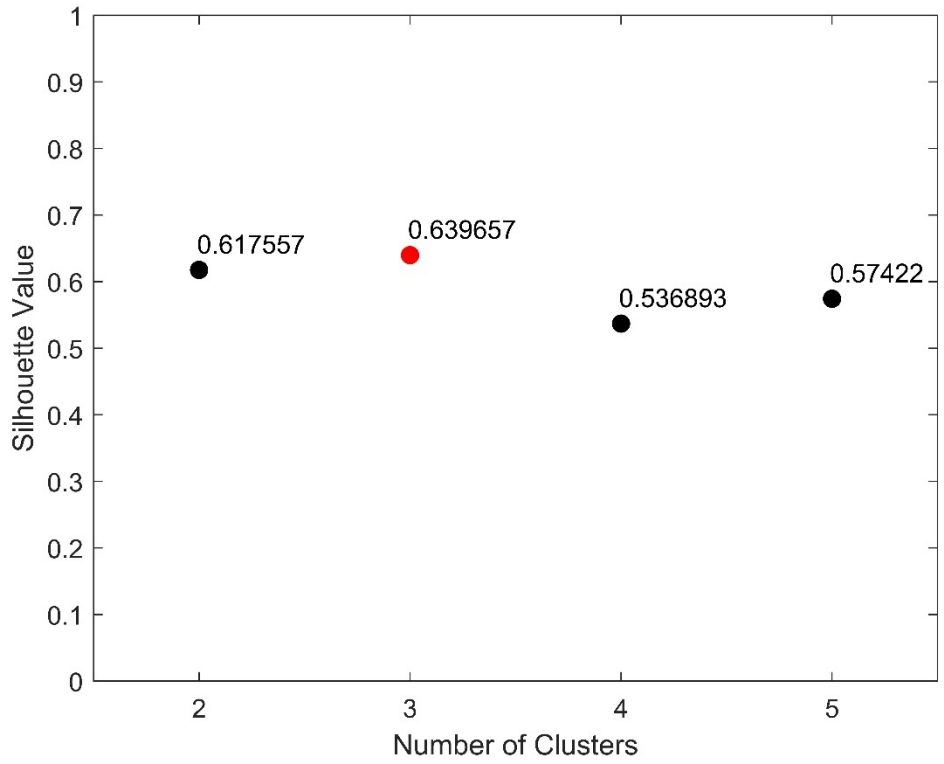

L
100
50
0
-100
-50
0
50
100
a
100
50
0
-50
-100
b

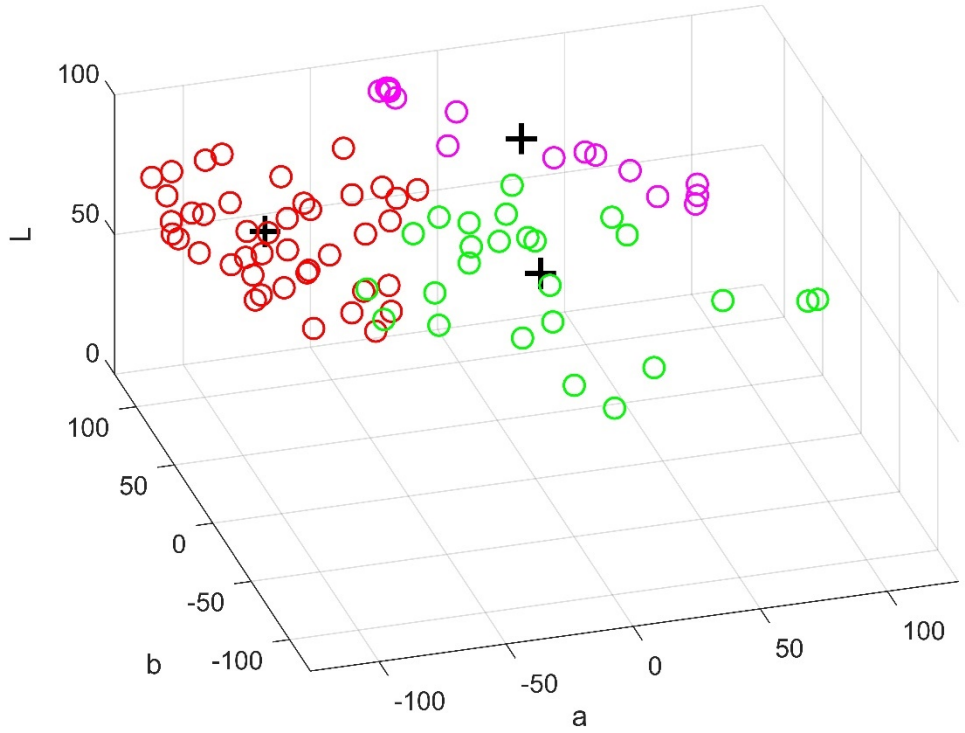

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.640009
0.67005
0.704693
0.775376
2
3
4
5
Number of Clusters


100
50
0
L
-100
-50
0
50
100
a
-100
-50
0
50
100
b

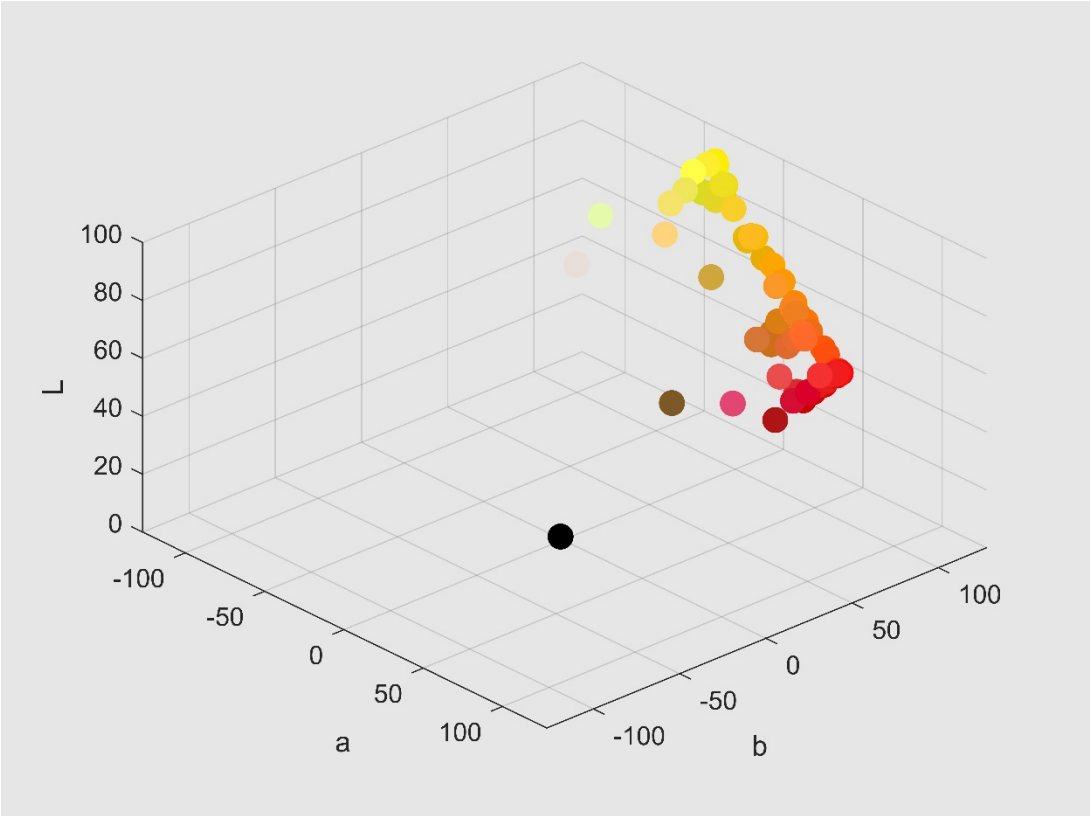
12. Healthy

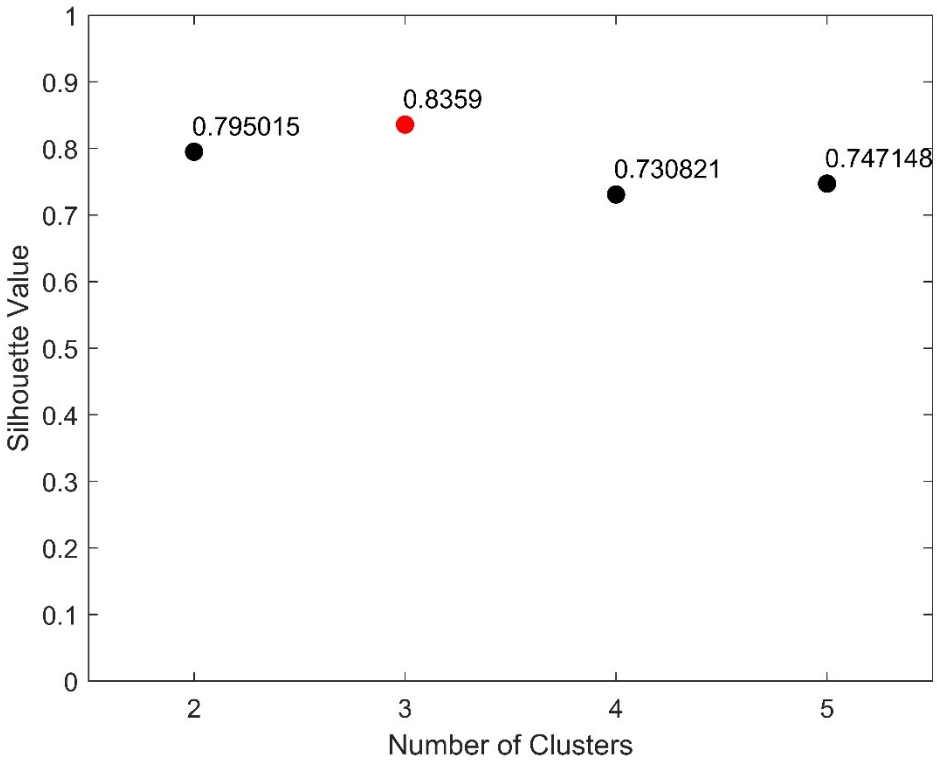

100
50
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

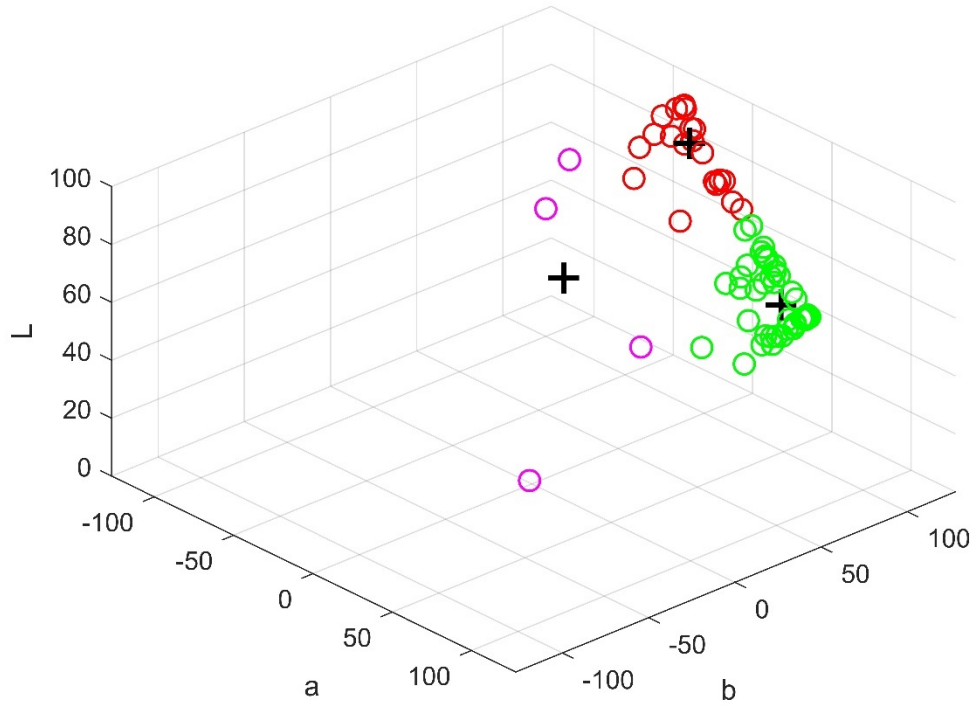

Silhouette Value
Number of Clusters
0.617557
0.639657
0.536893
0.57422
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
50
0
-100
-50
0
50
100

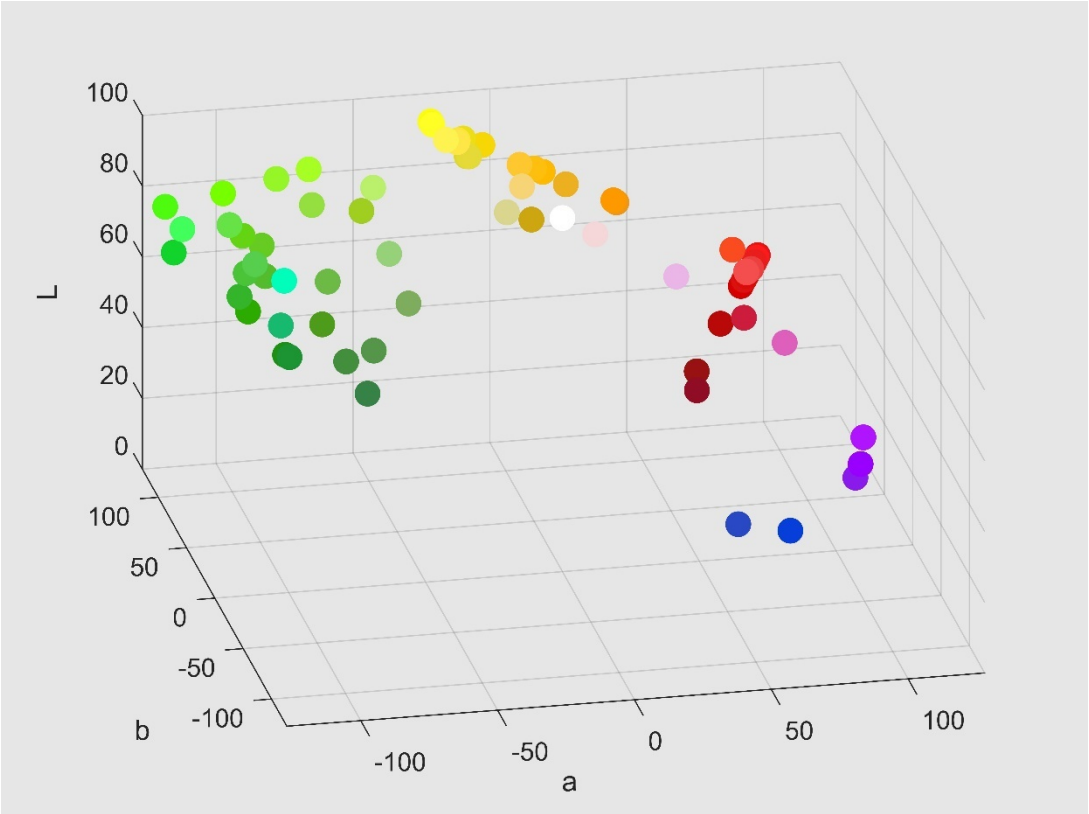
13. Hot

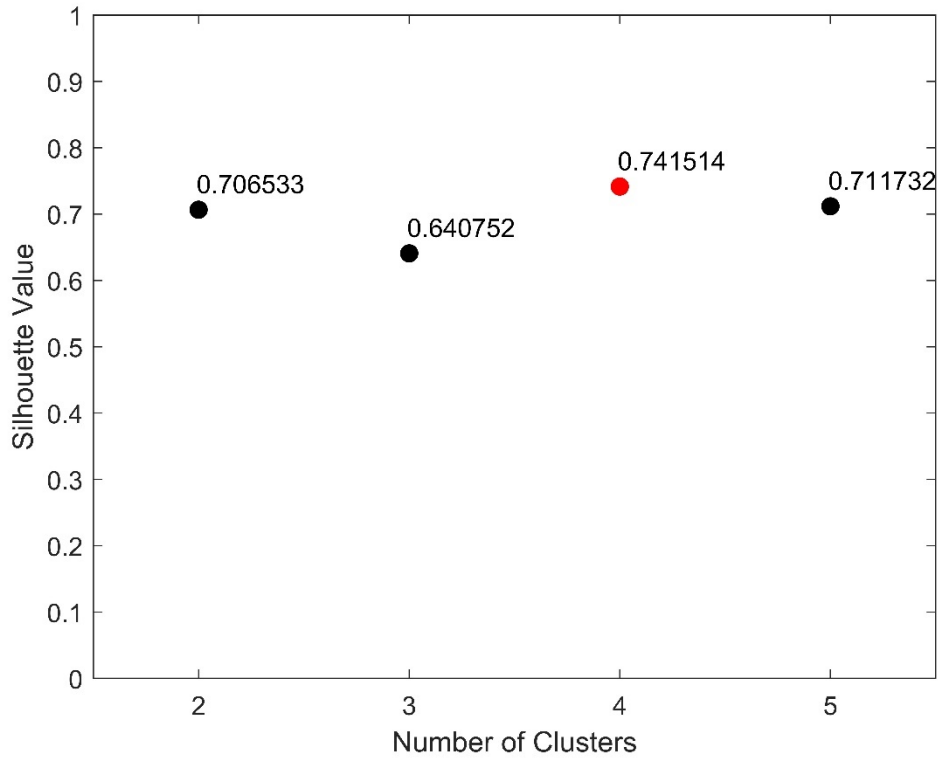

L
100
80
60
40
20
0
-100
-50
0
50
100
a
-100
-50
0
50
100
b

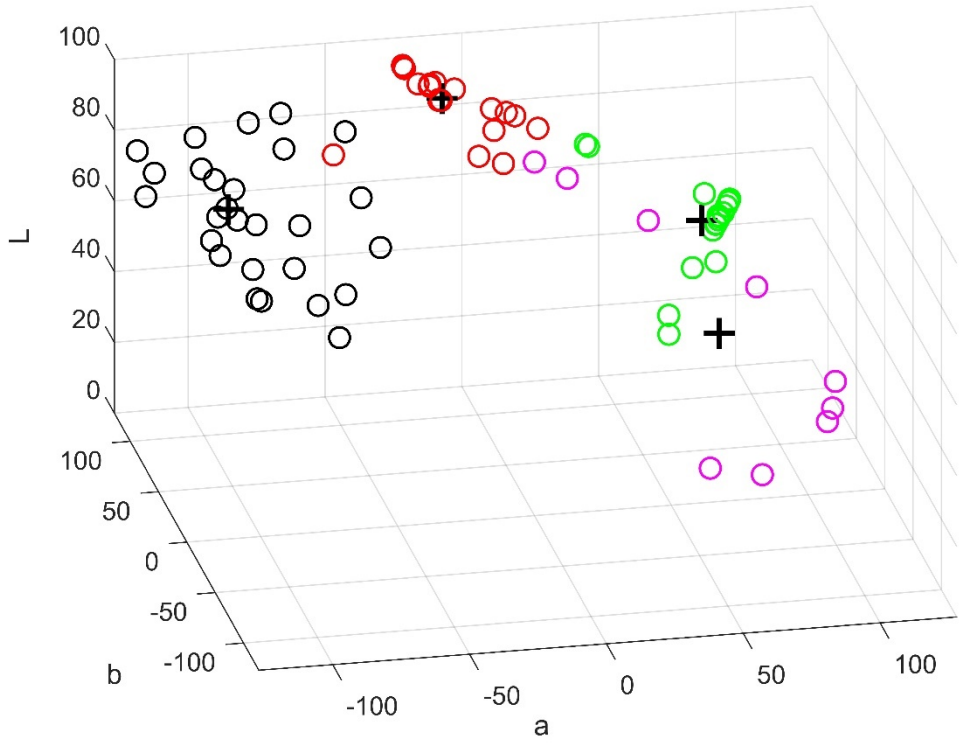

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.795015
0.8359
0.730821
0.747148
2
3
4
5
Number of Clusters


L
100
80
60
40
20
0
-100
-50
0
50
100
a
-100
-50
0
50
100
b

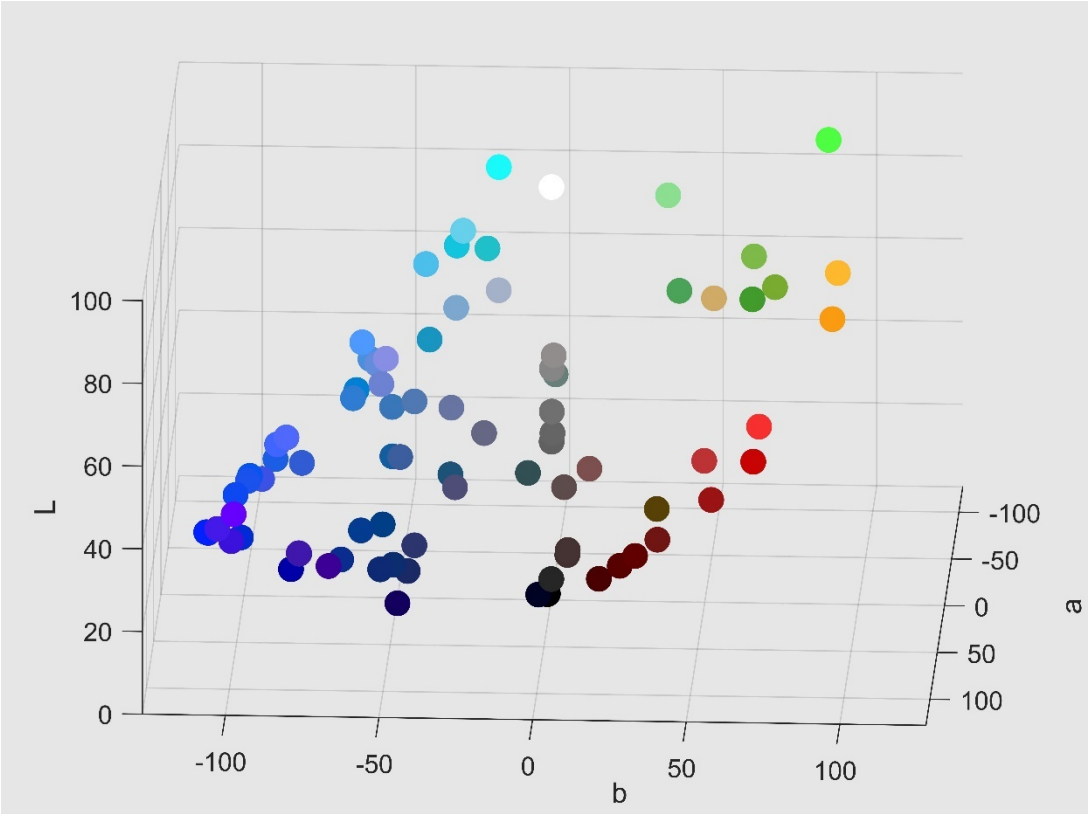
14. Lucky

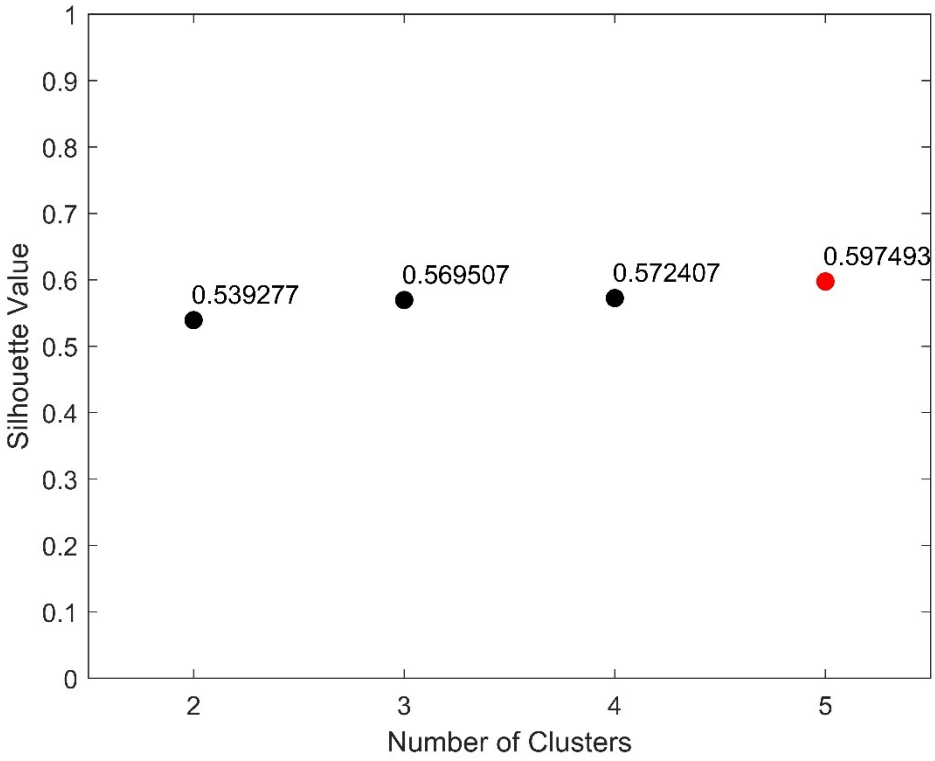

L
100
80
60
40
20
0
100
50
0
-50
-100
b
-100
-50
0
50
100
a

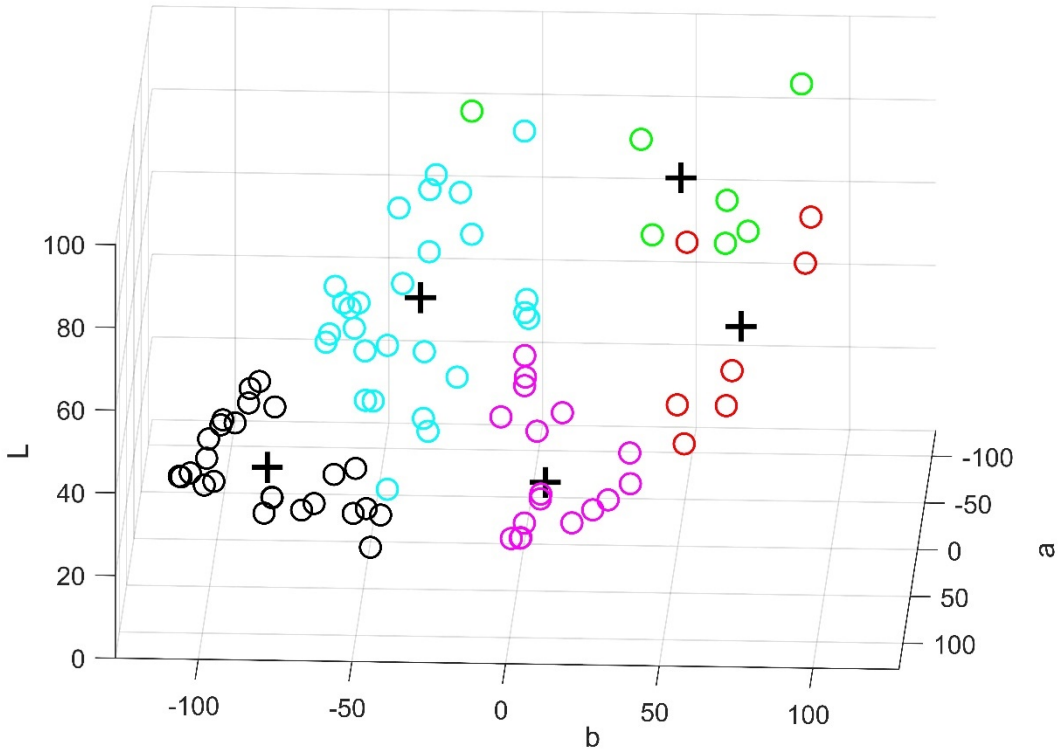

Silhouette Value
Number of Clusters
0.706533
0.640752
0.741514
0.711732
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
80
60
40
20
0
100
50
0
-50
-100
-100
-50
0
50
100

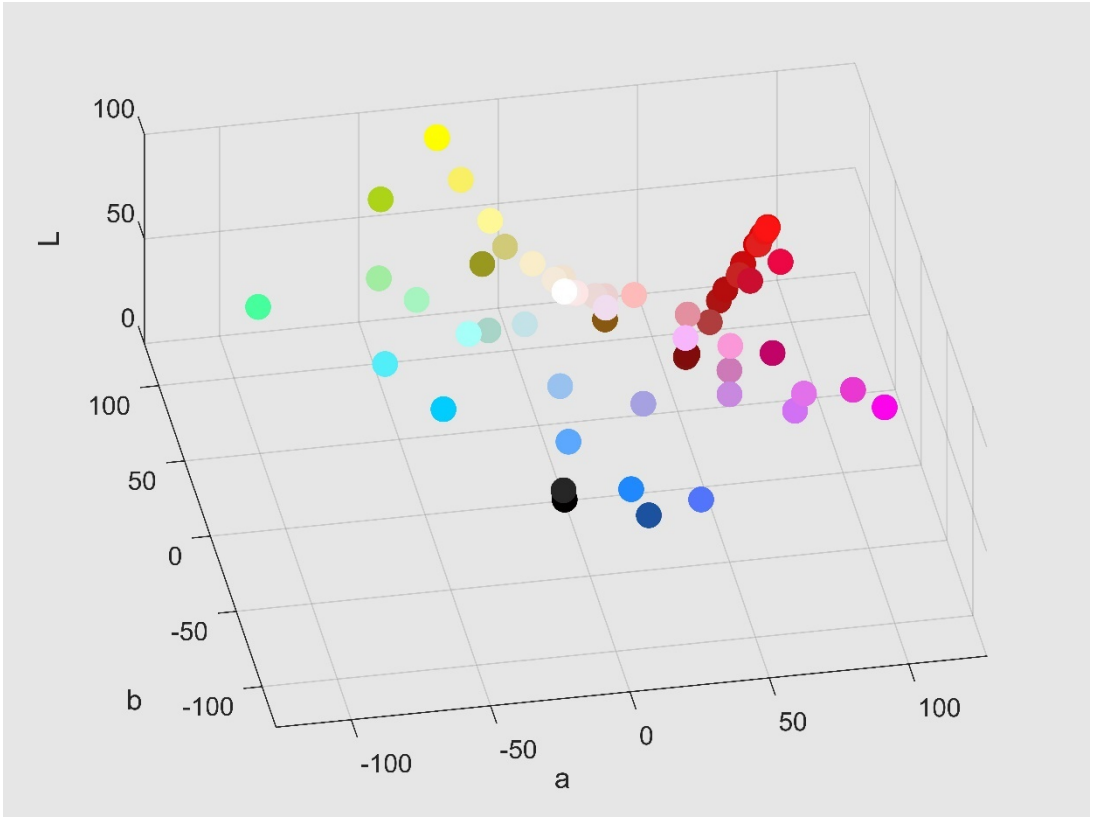
15. Male

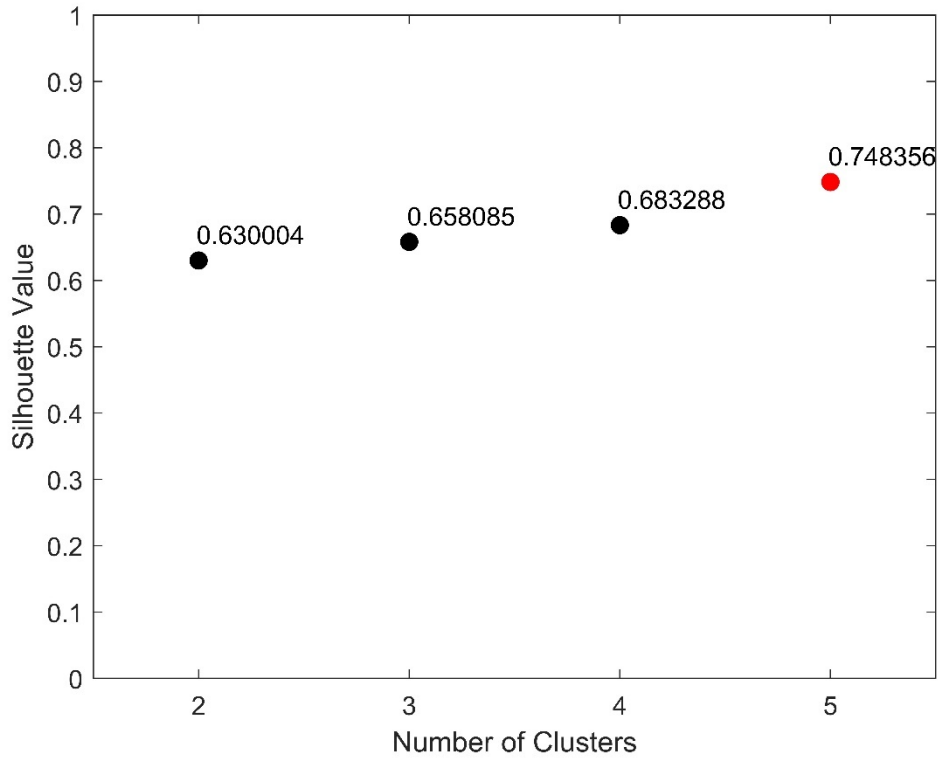

L
100
80
60
40
20
0
-100
-50
0
50
100
b
-100
-50
0
50
100
a

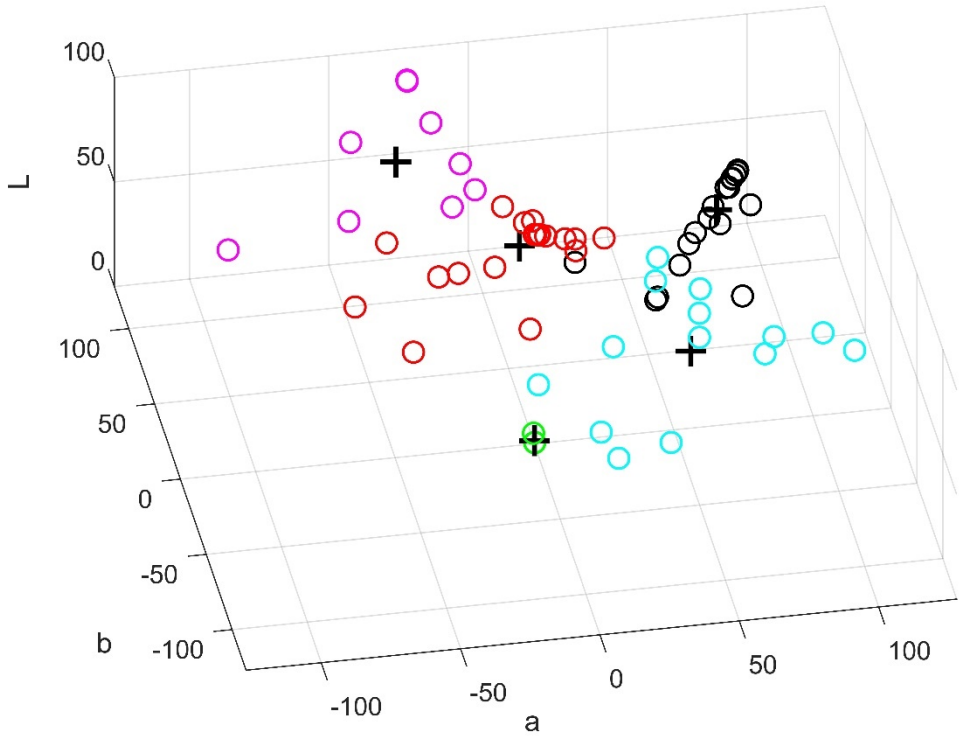

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.539277
0.569507
0.572407
0.597493
2
3
4
5
Number of Clusters


100
80
60
40
20
0
L
-100
-50
0
50
100
b
-100
-50
0
50
100
a

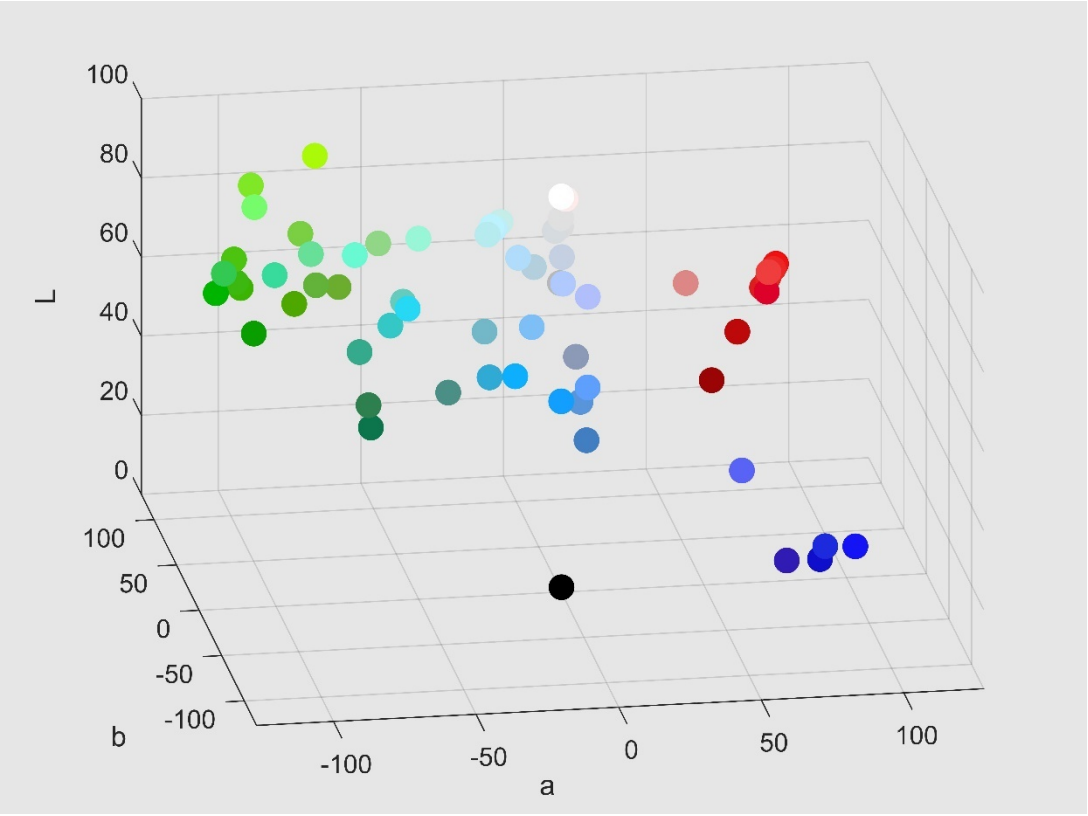
16. married

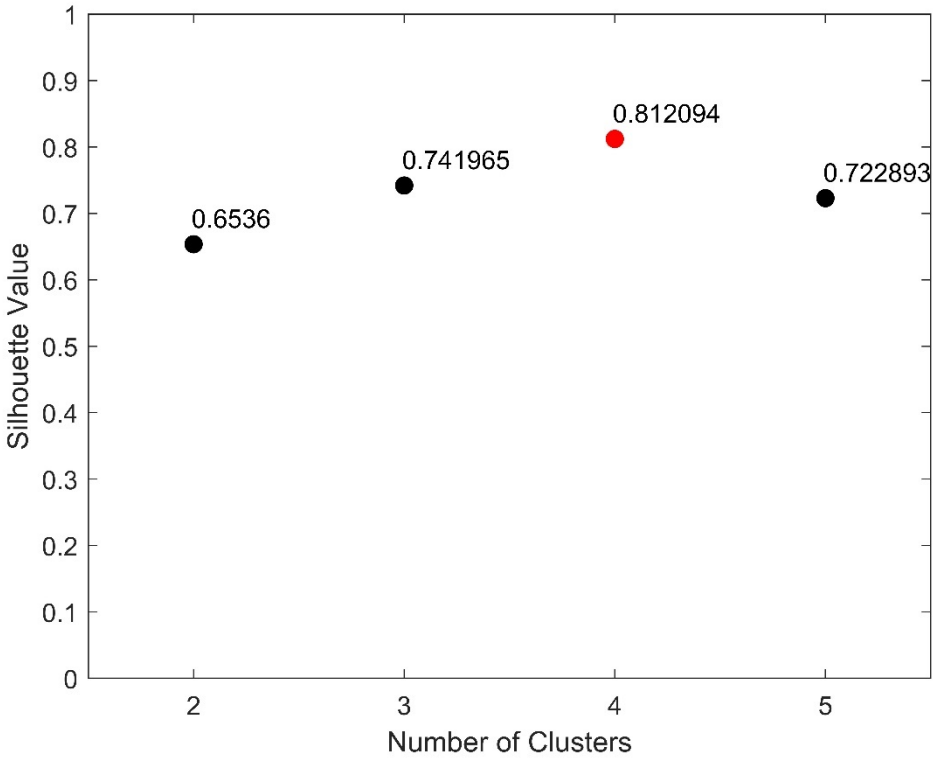

100
50
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

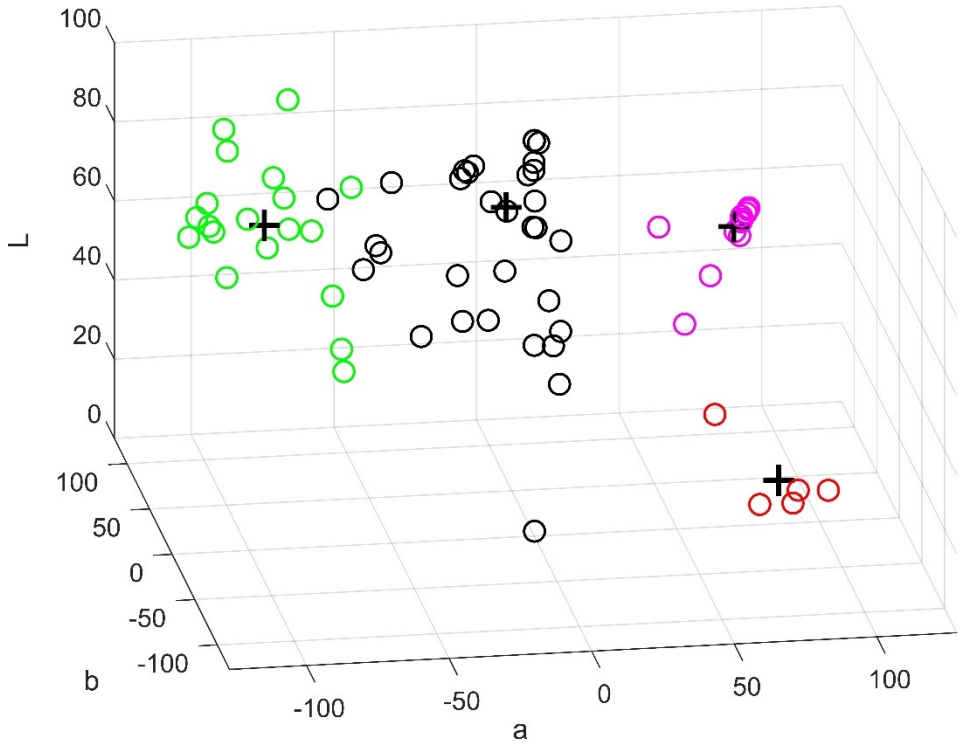

Silhouette Value
Number of Clusters
0.630004
0.658085
0.683288
0.748356
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
50
0
-50
-100

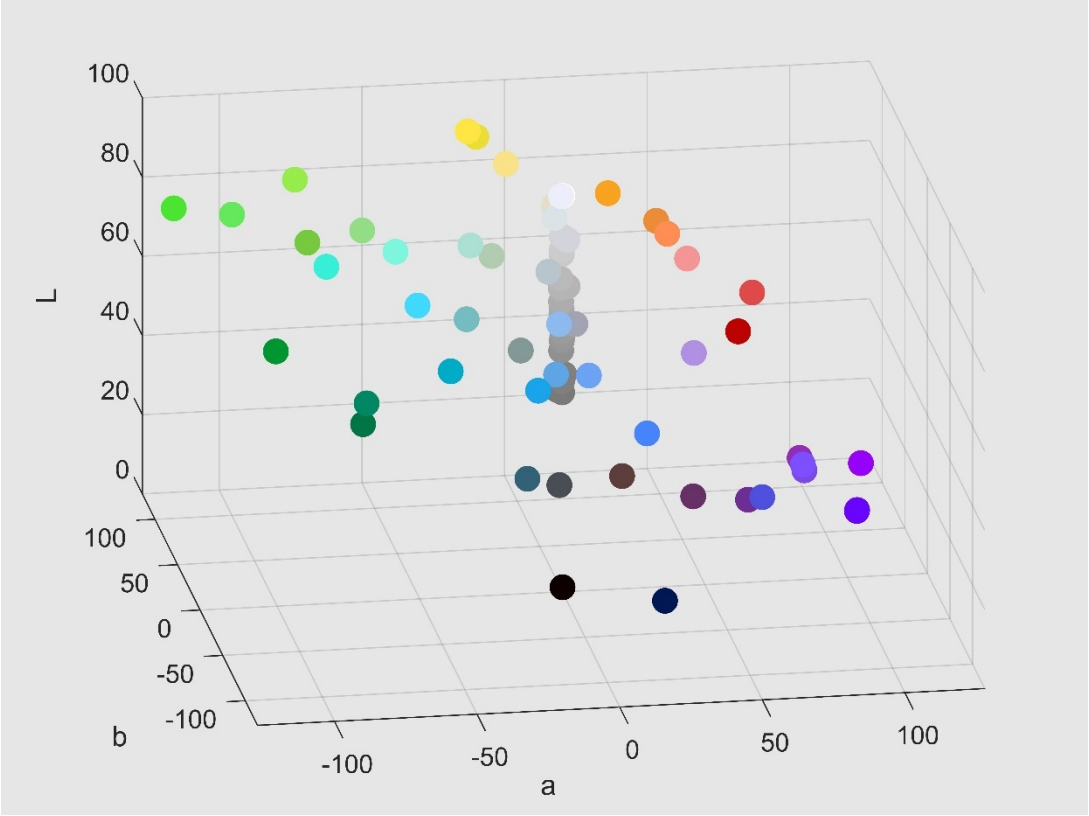
17. medical

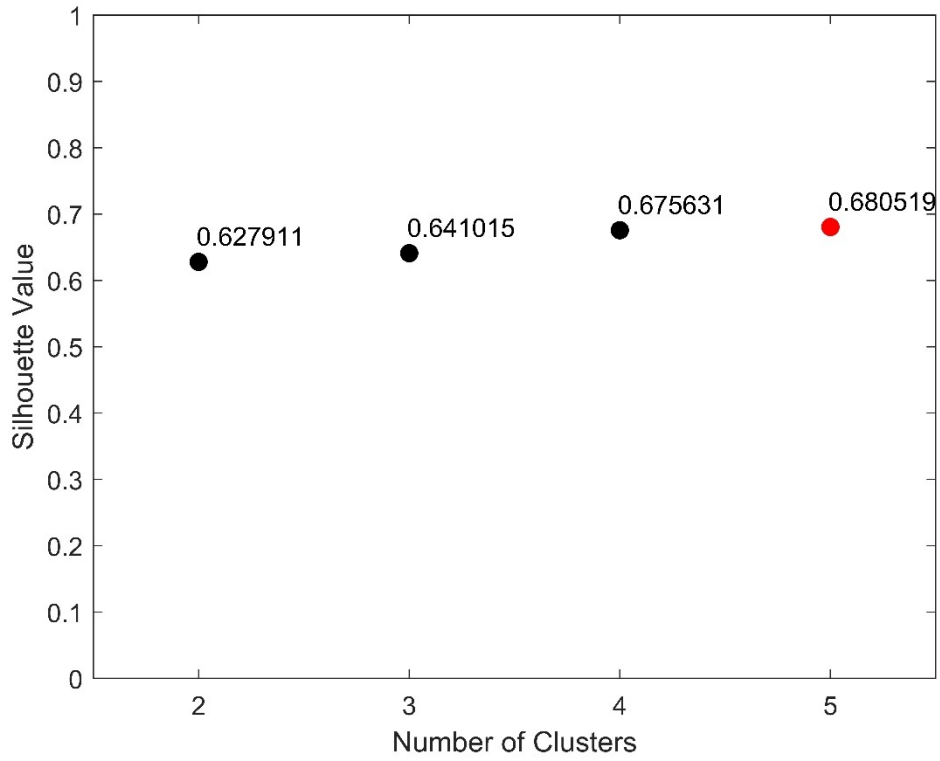

L
100
80
60
40
20
0
b
100
50
0
-50
-100
a
-100
-50
0
50
100

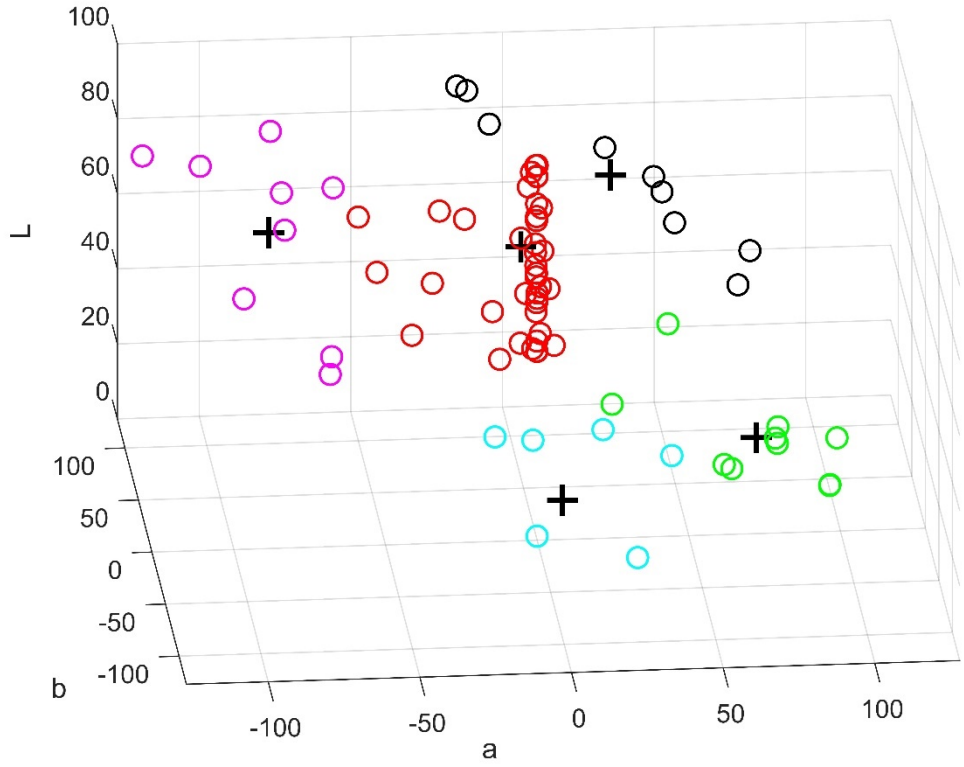

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.6536
0.741965
0.812094
0.722893
2
3
4
5
Number of Clusters


100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

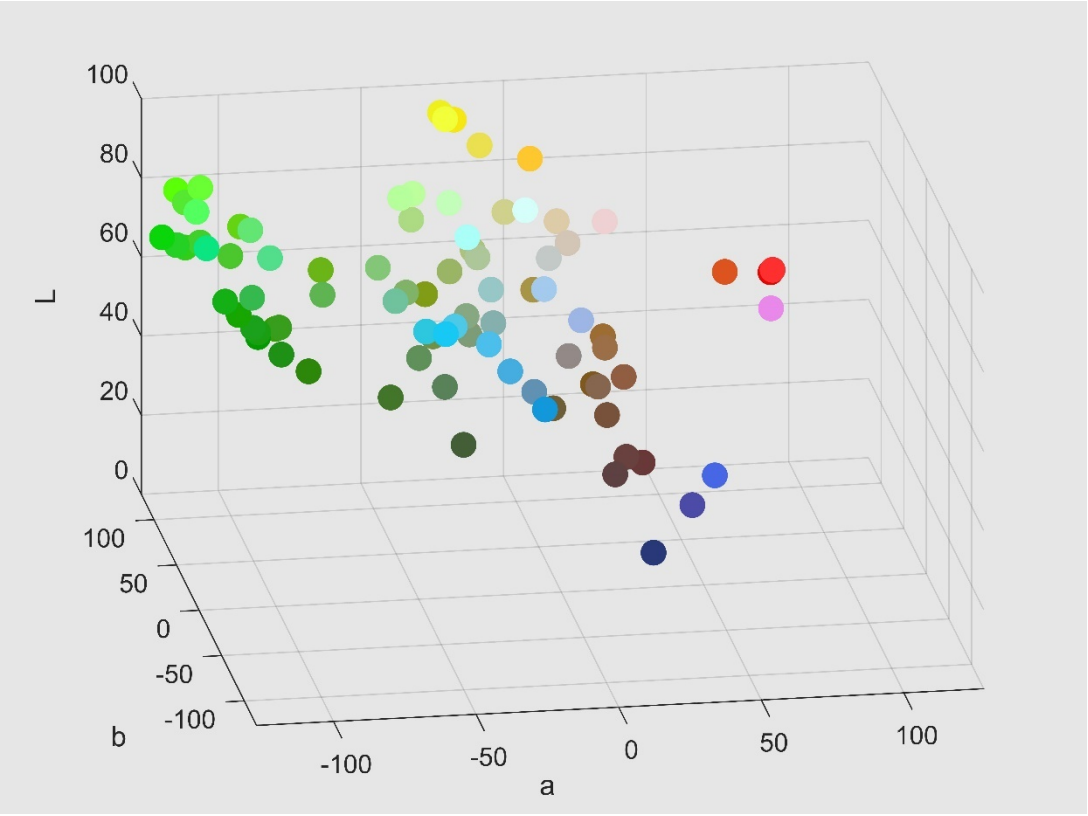
18. modern

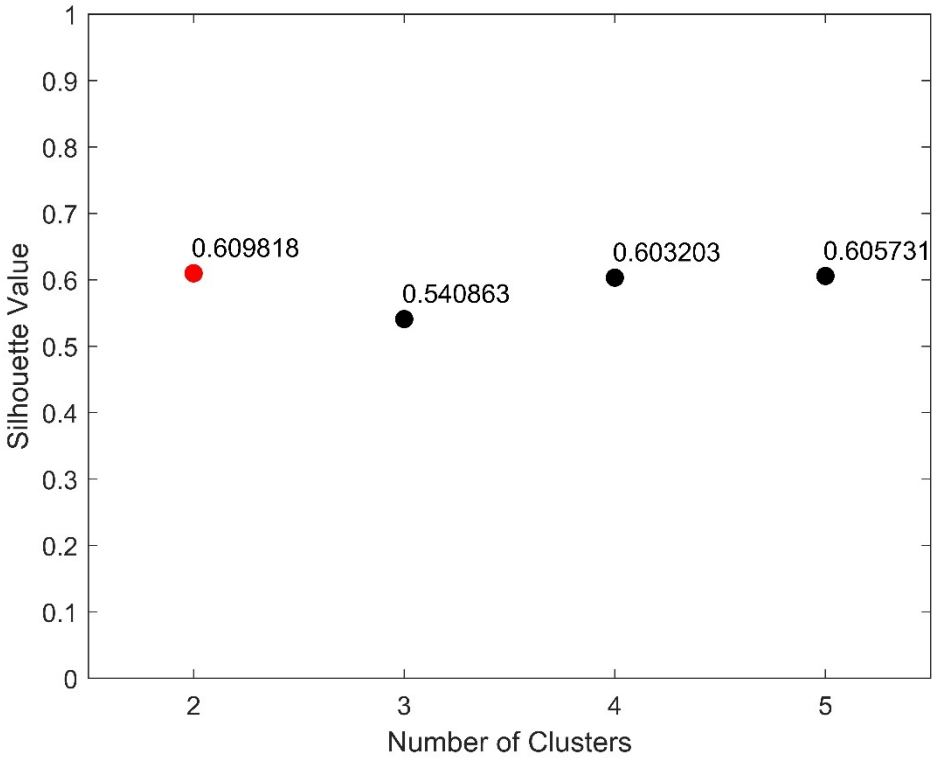

100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

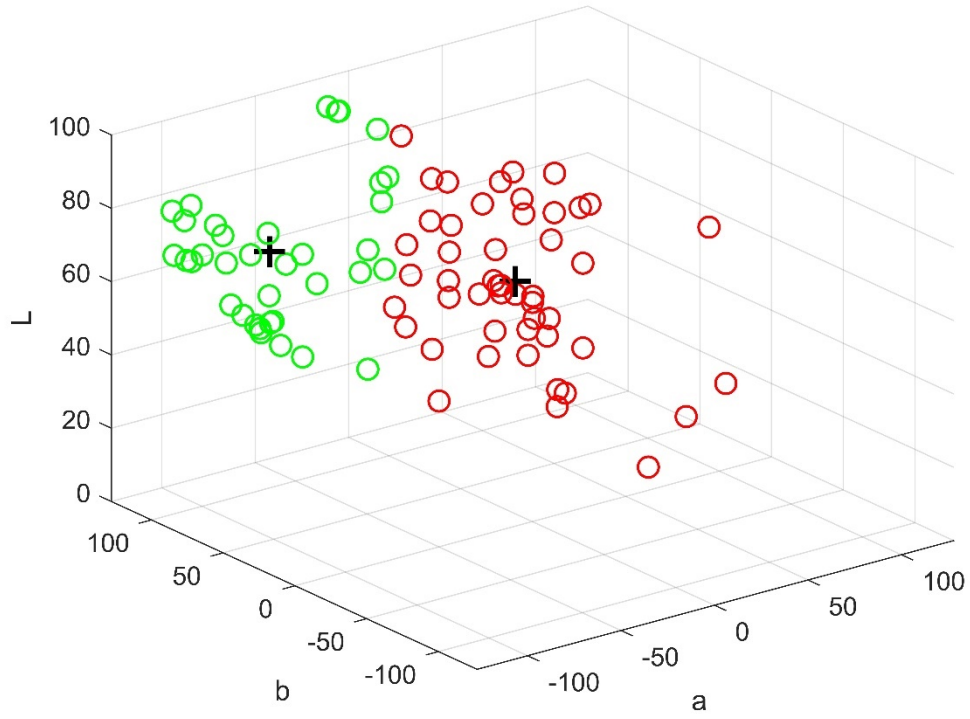

Silhouette Value
Number of Clusters
0.627911
0.641015
0.675631
0.680519
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
80
60
40
20
0
-100
-50
0
50
100

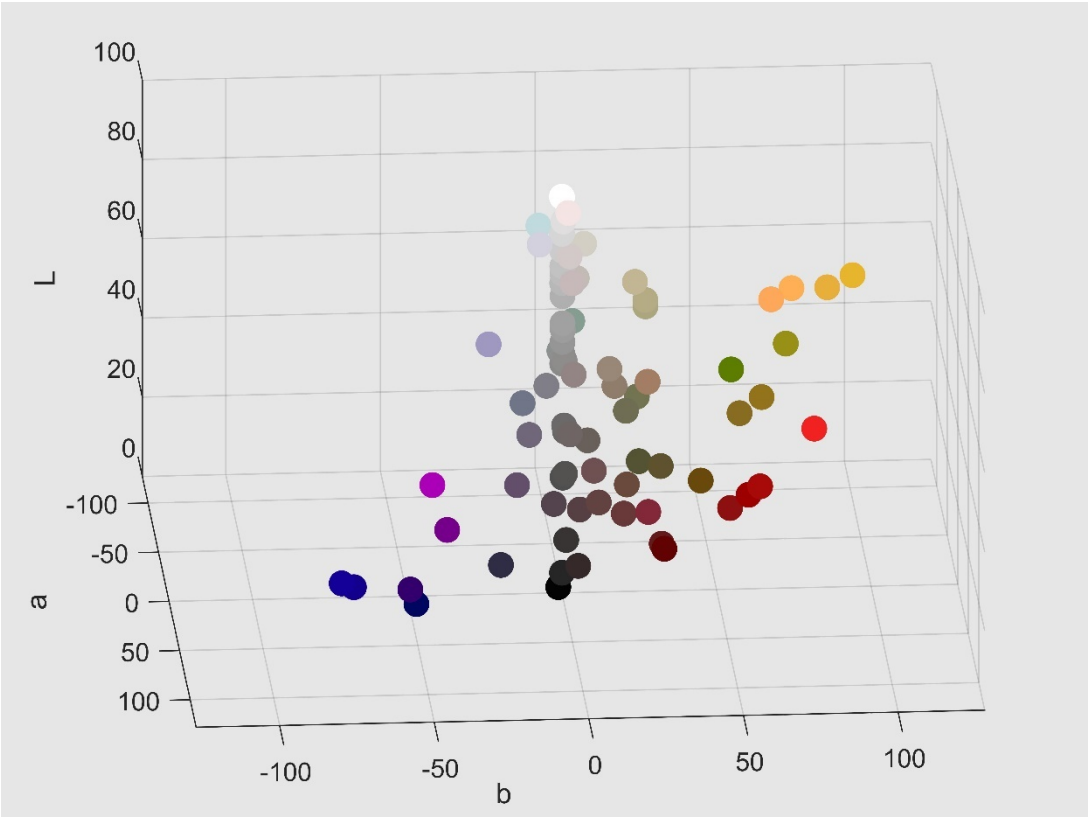
19. natural

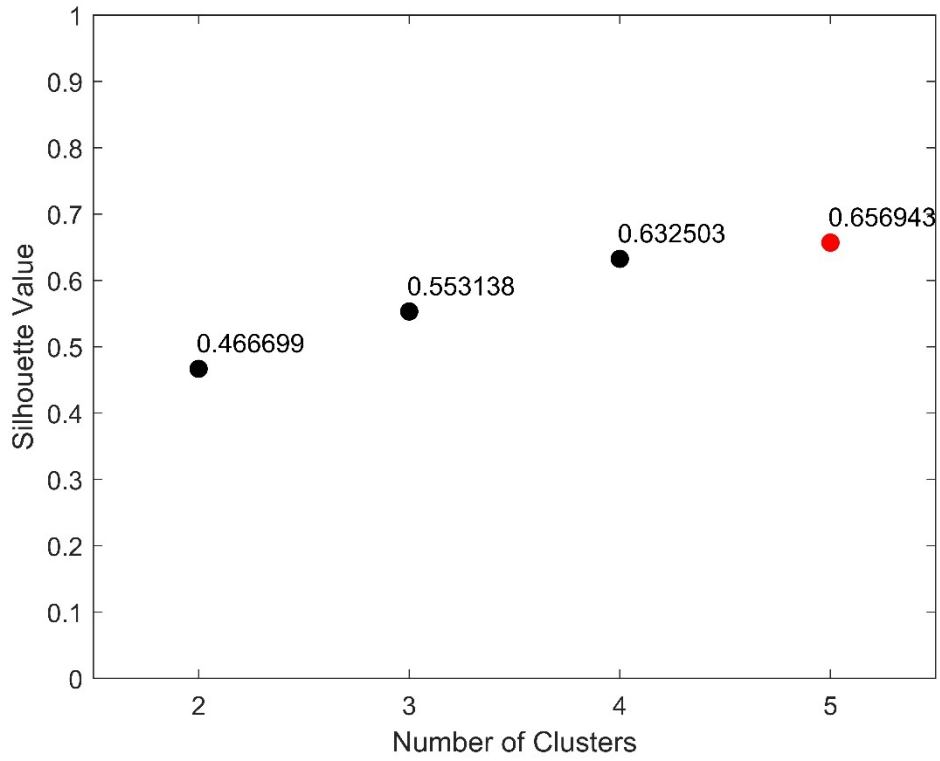

L
100
80
60
40
20
0
b
100
50
0
-50
-100
a
-100
-50
0
50
100

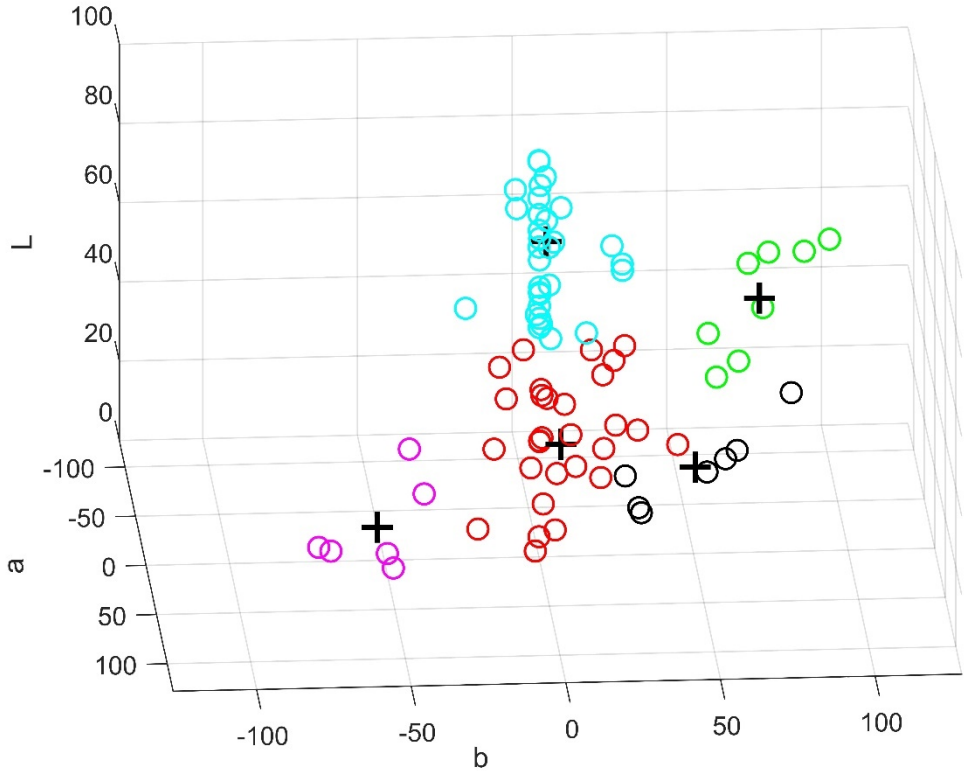

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.609818
0.540863
0.603203
0.605731
2
3
4
5
Number of Clusters


100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

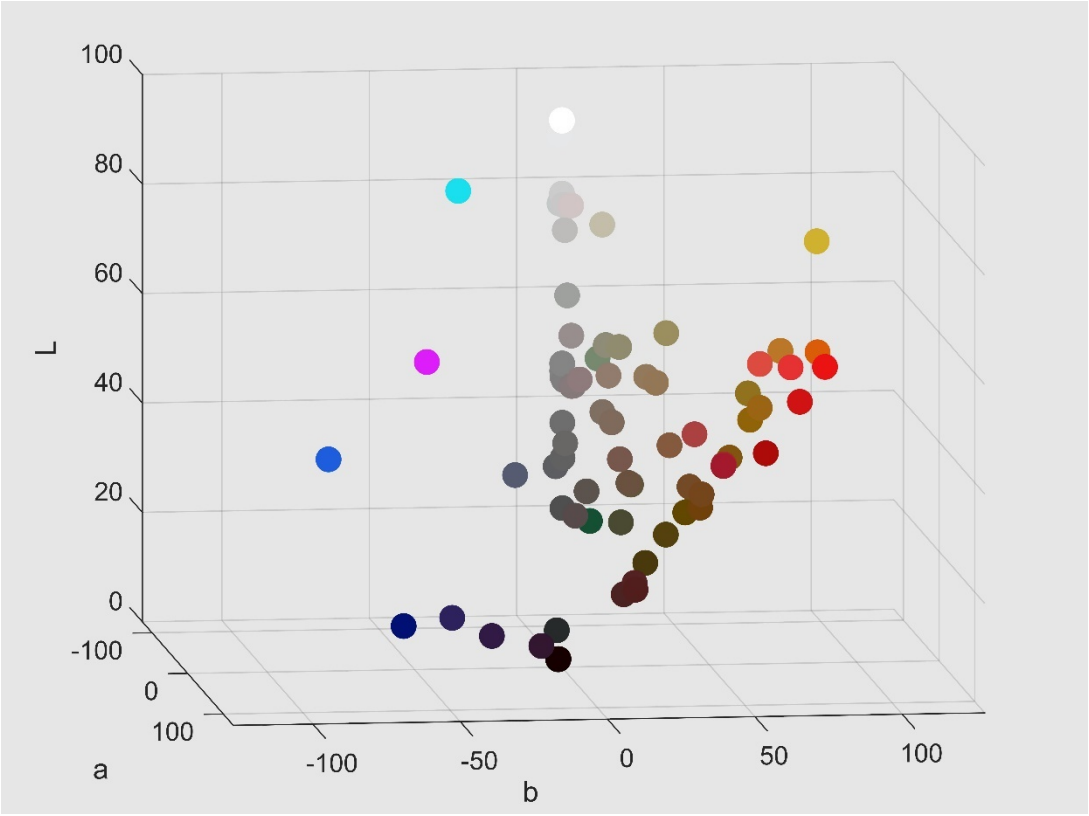
20. old

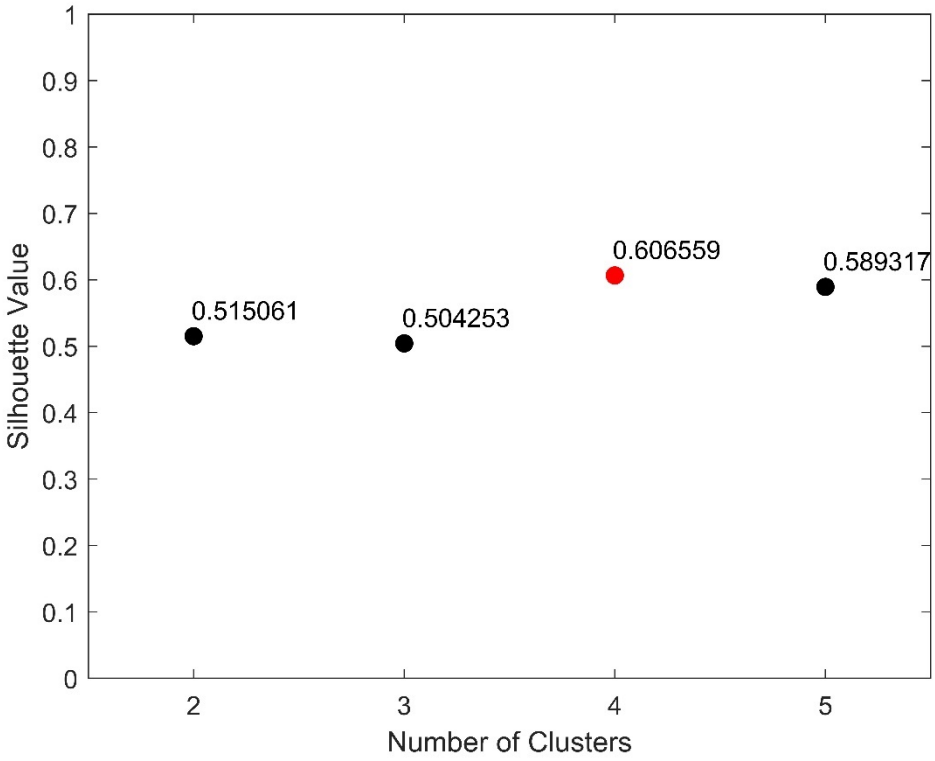

100
80
60
40
20
0
L
-100
-50
0
50
100
a
-100
-50
0
50
100
b

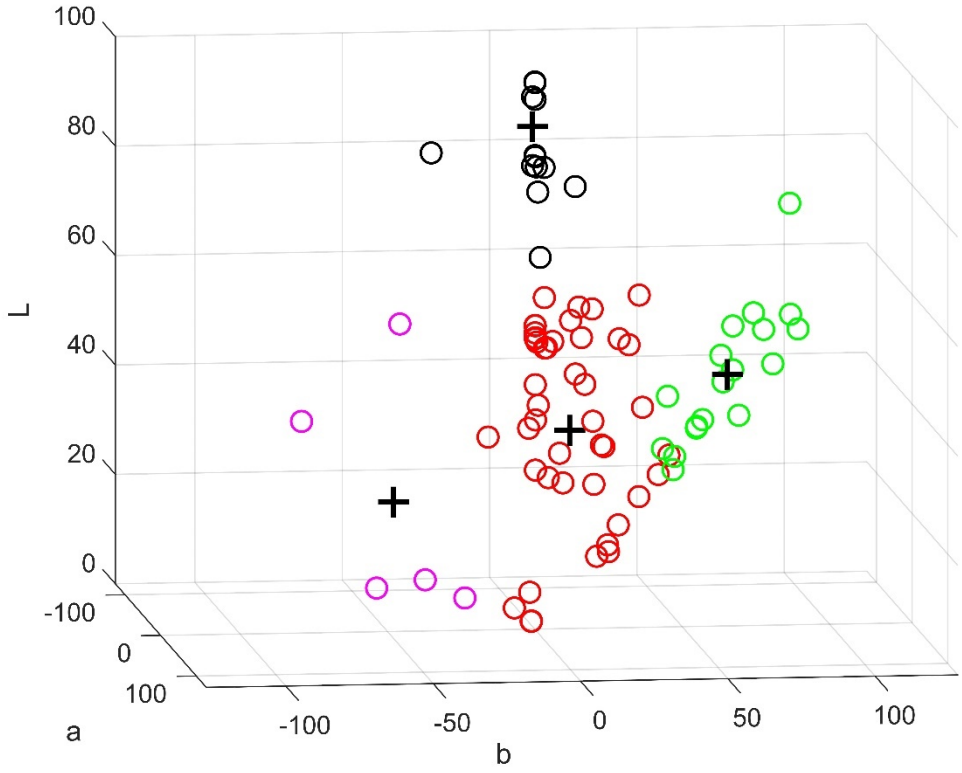

Silhouette Value
Number of Clusters
0.466699
0.553138
0.632503
0.656943


L
a
b

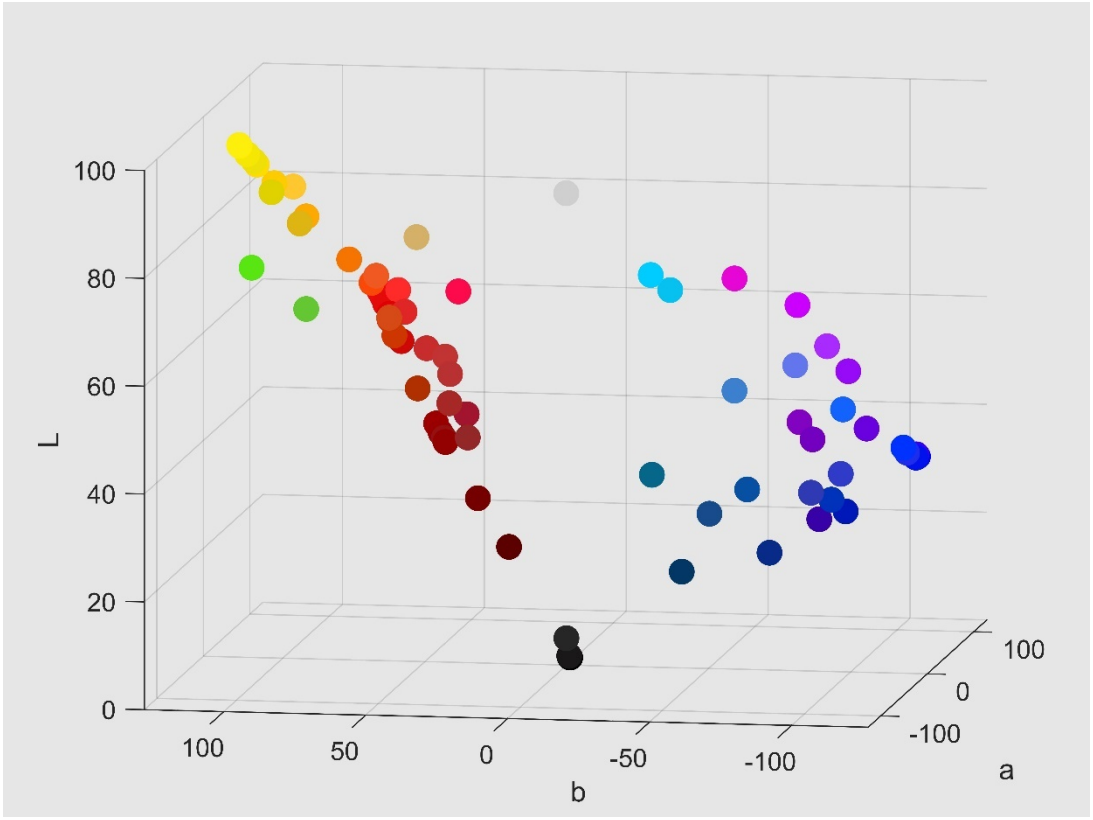
21. poor

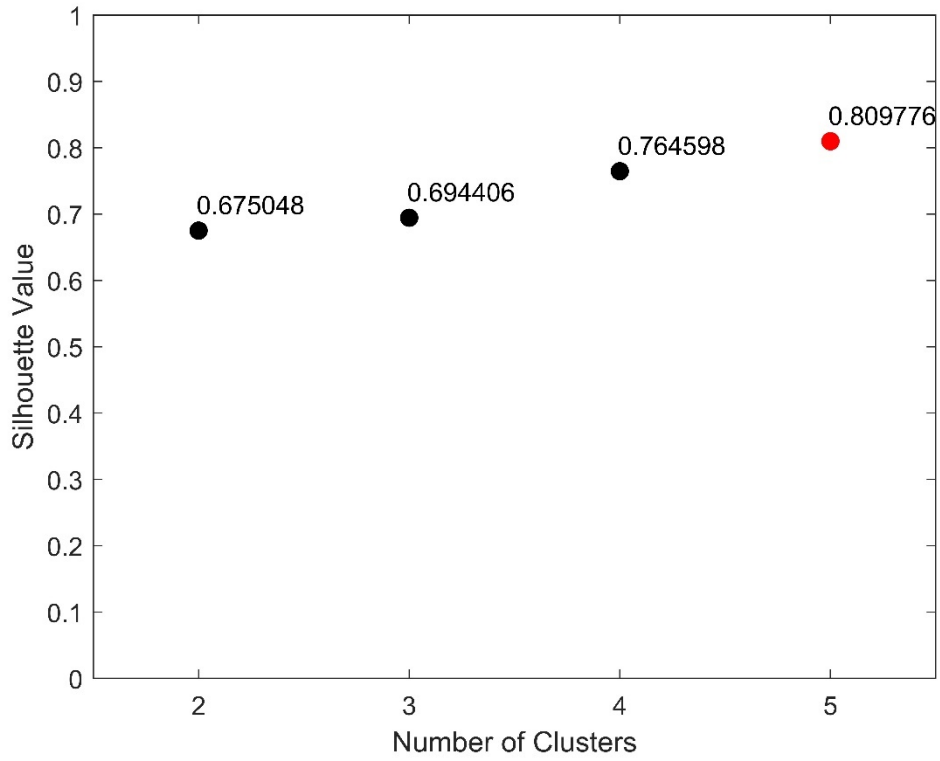

100
80
60
40
20
0
L
-100
0
100
a
-100
-50
0
50
100
b

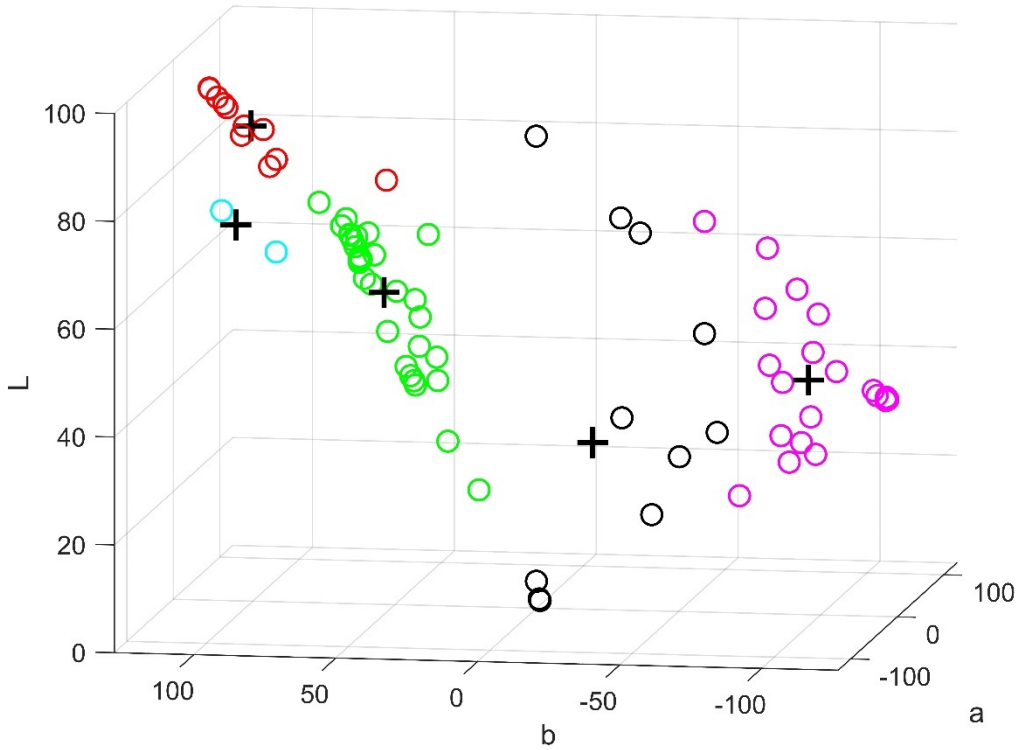

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Silhouette Value
0.515061
0.504253
0.606559
0.589317
2
3
4
5
Number of Clusters


100
80
60
40
20
0
L
-100
0
100
a
-100
-50
0
50
100
b

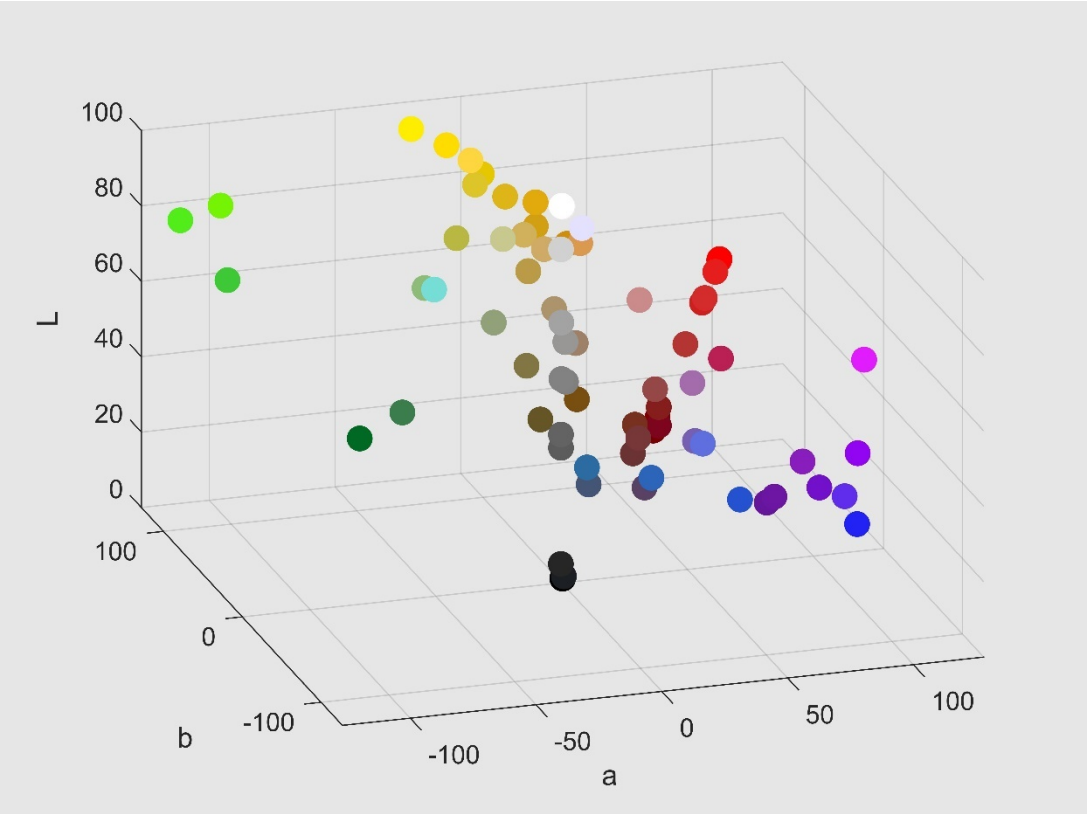
22. powerful

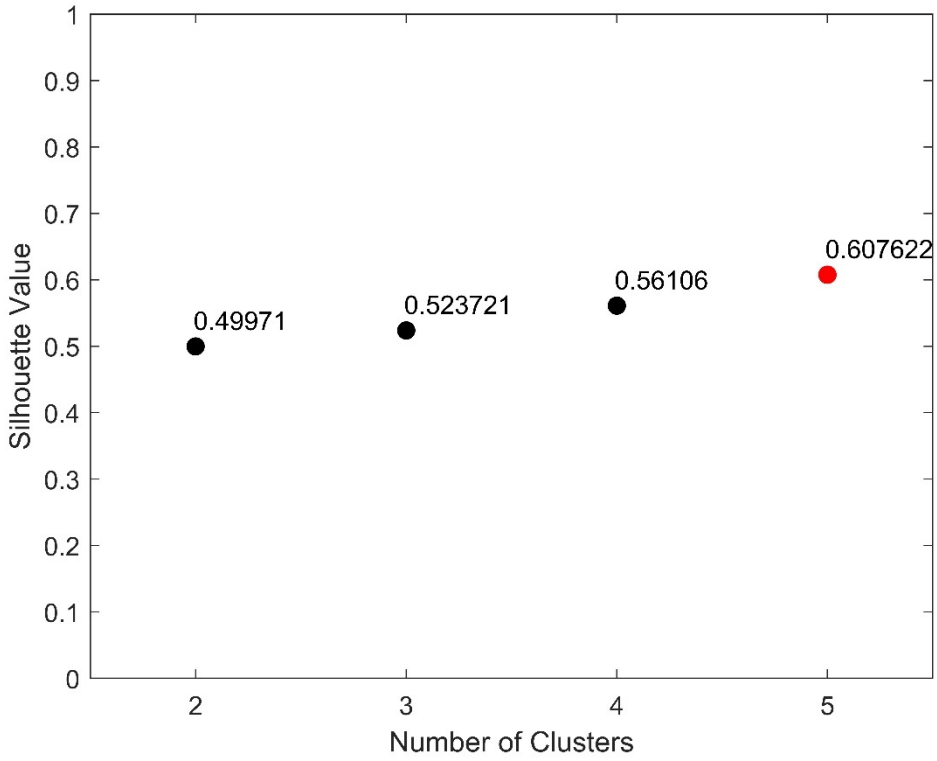

100
80
60
40
20
0
L
100
50
0
-50
-100
b
100
0
-100
a

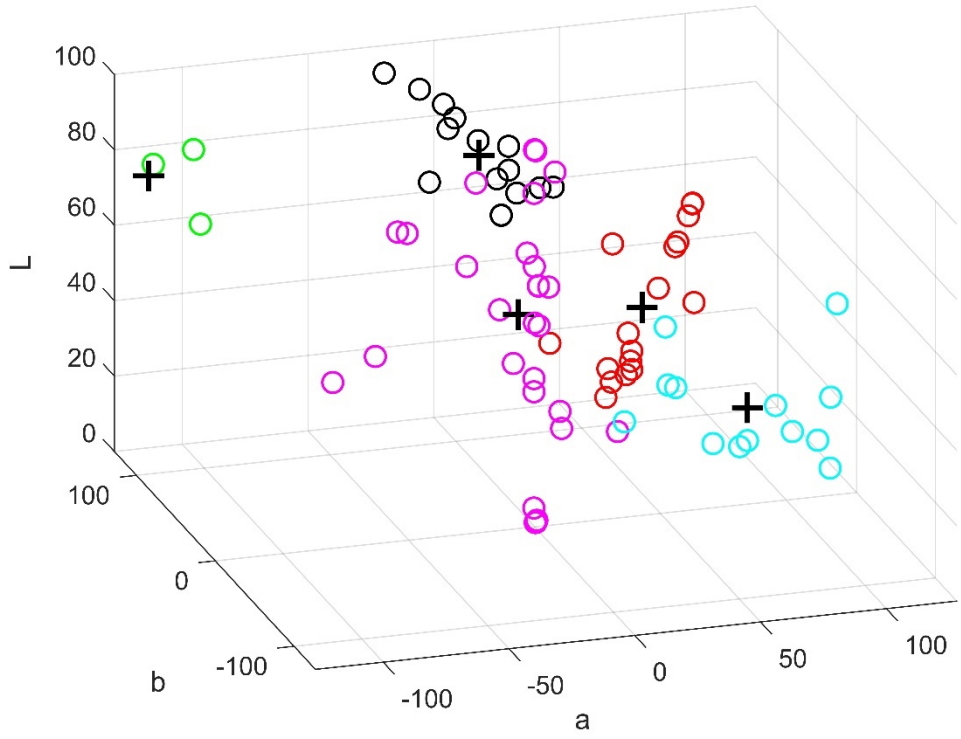

Silhouette Value
Number of Clusters
0.675048
0.694406
0.764598
0.809776


L
b
a

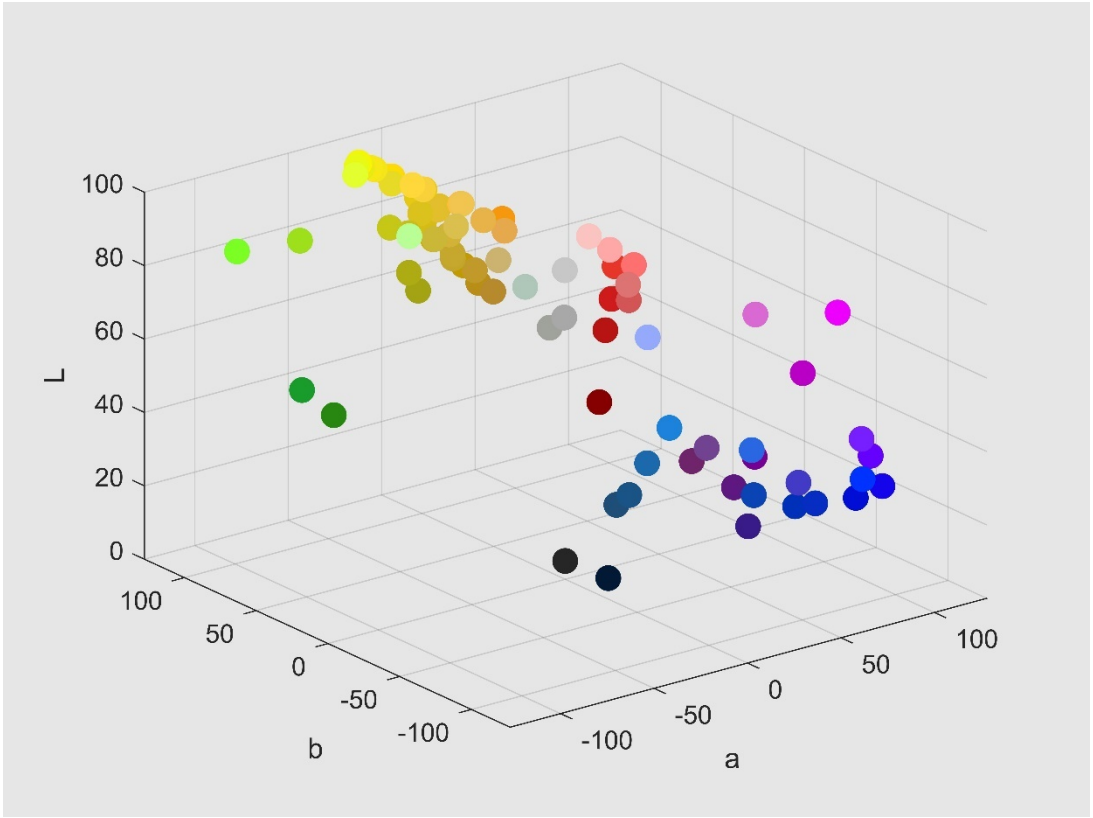
23. religious

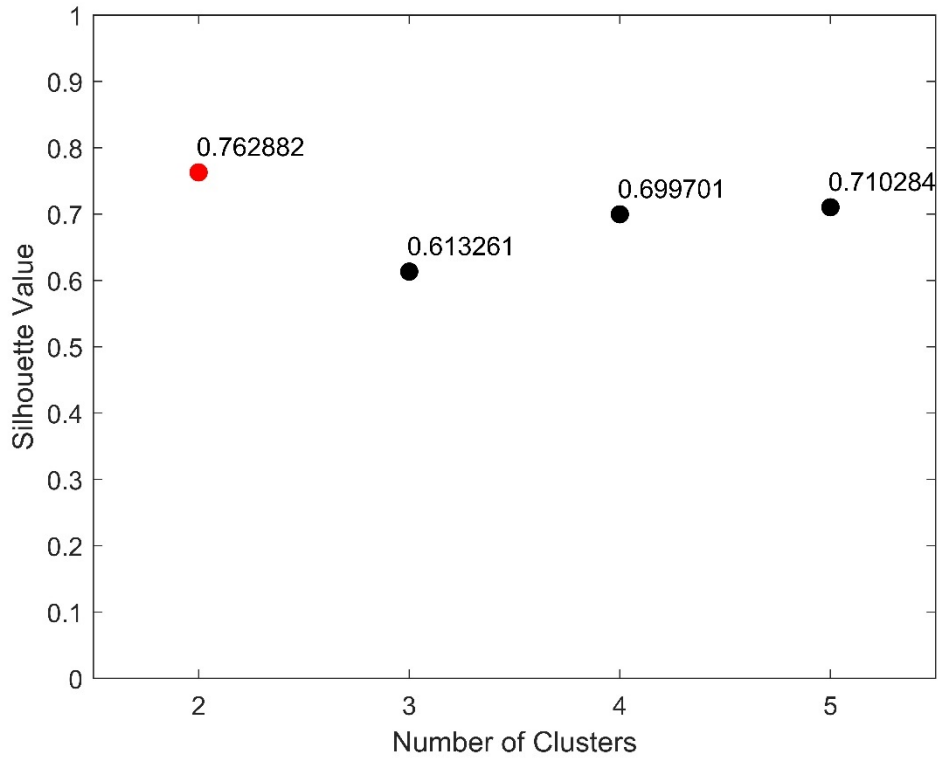


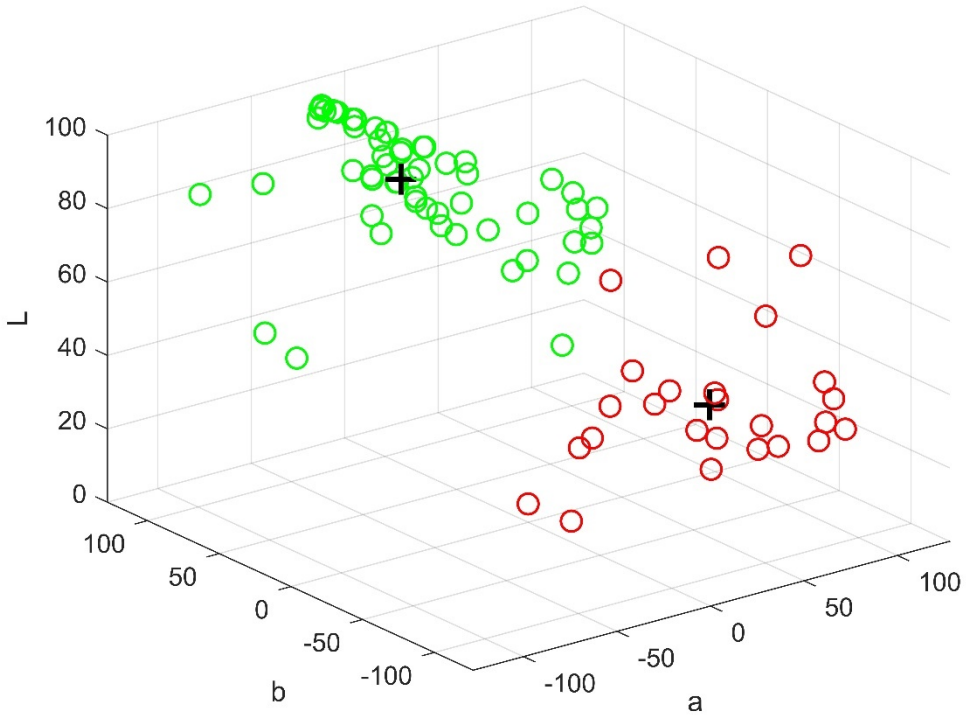



100
80
60
40
20
0
L
100
0
-100
b
-100
-50
0
50
100
a

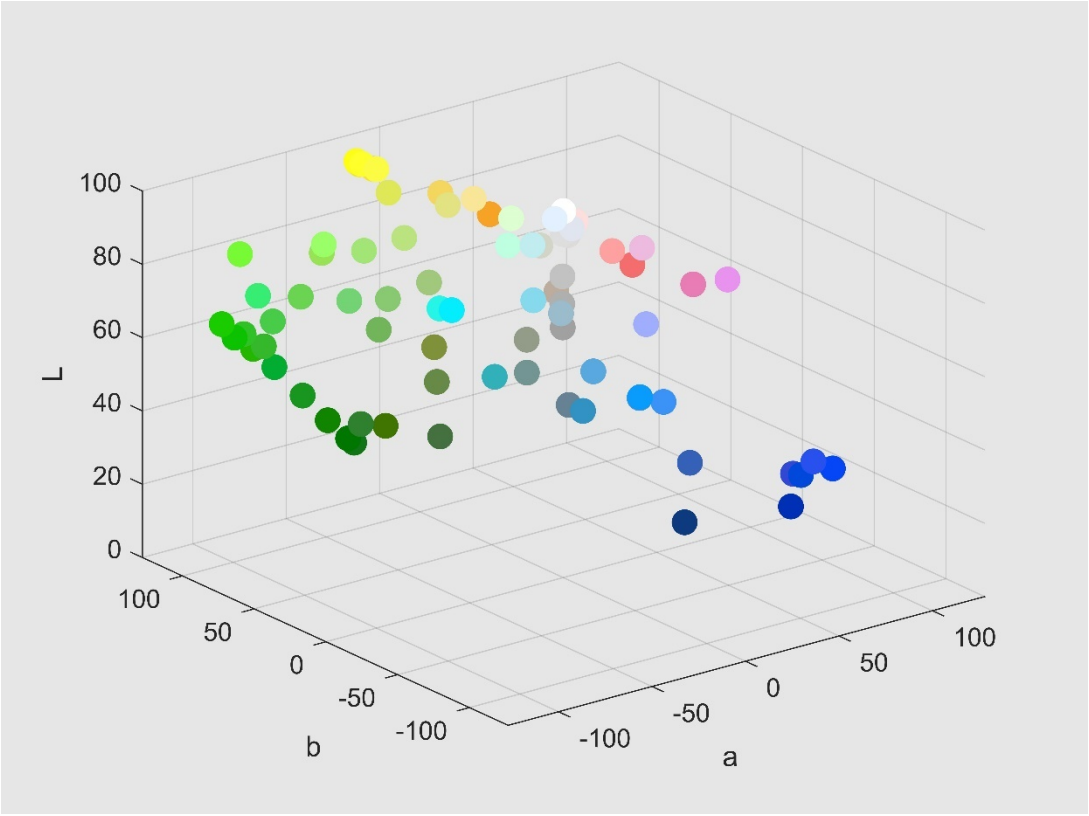
24. rich

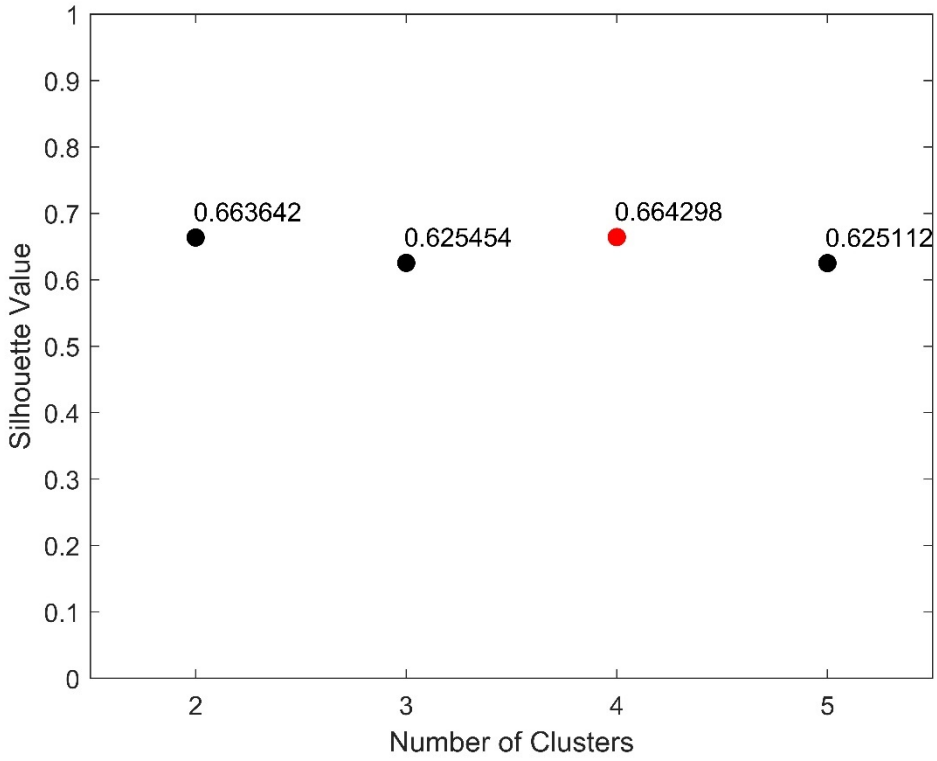

100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

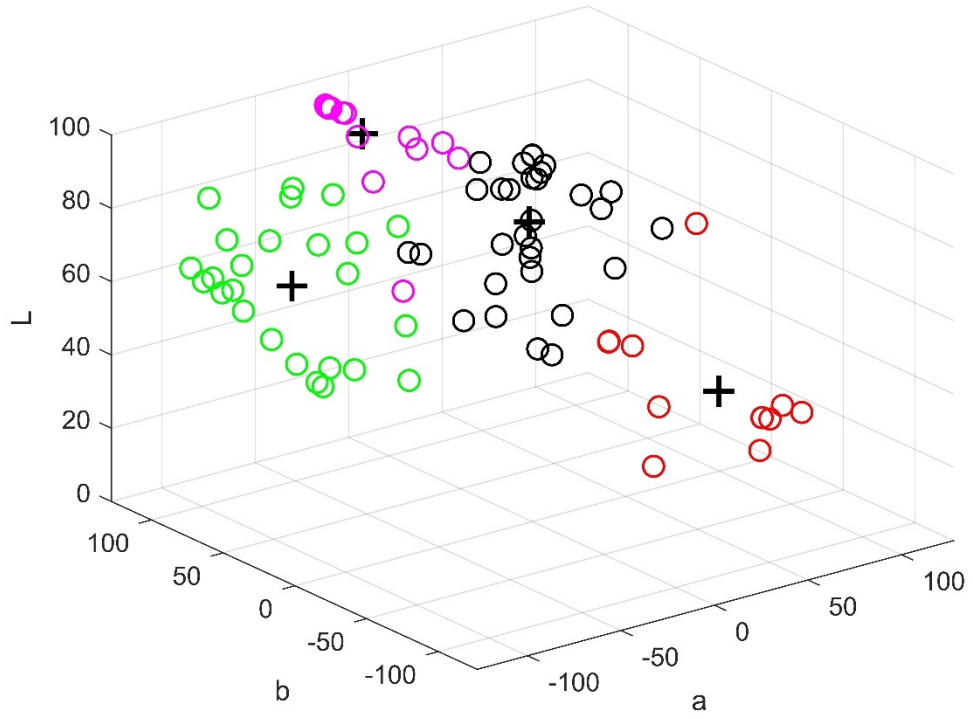

Silhouette Value
Number of Clusters
0.762882
0.613261
0.699701
0.710284


L
a
b

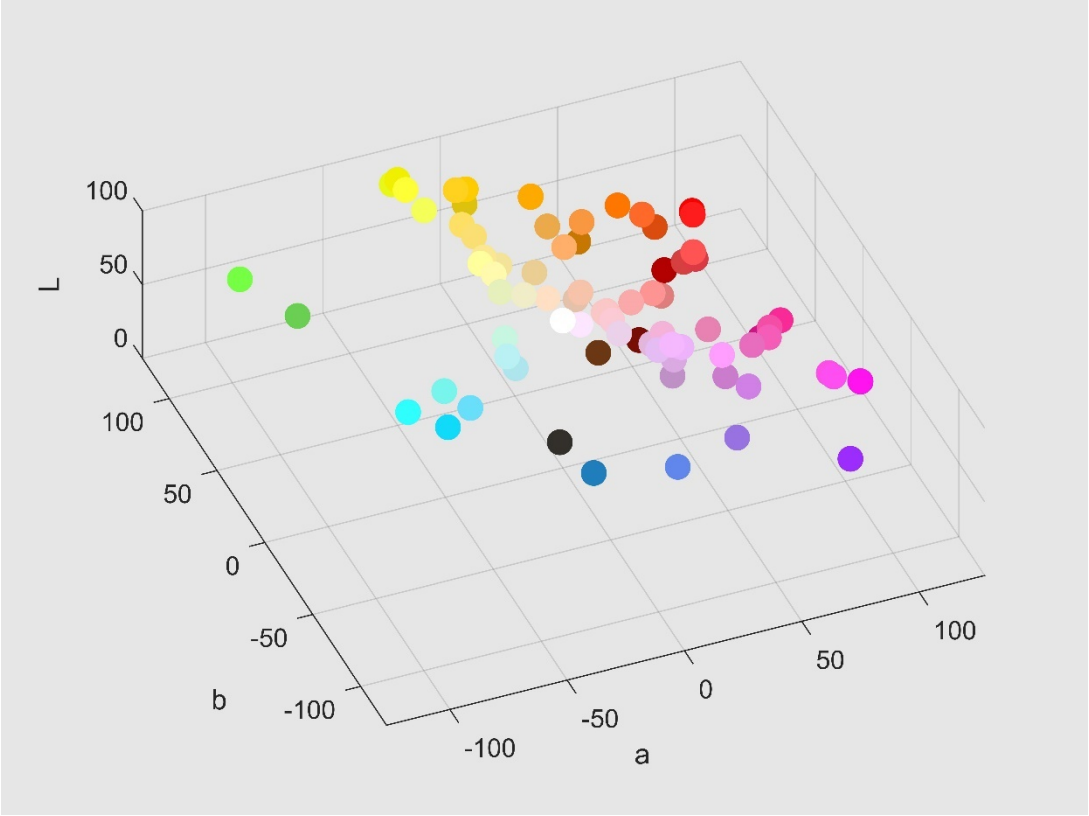
25. safe

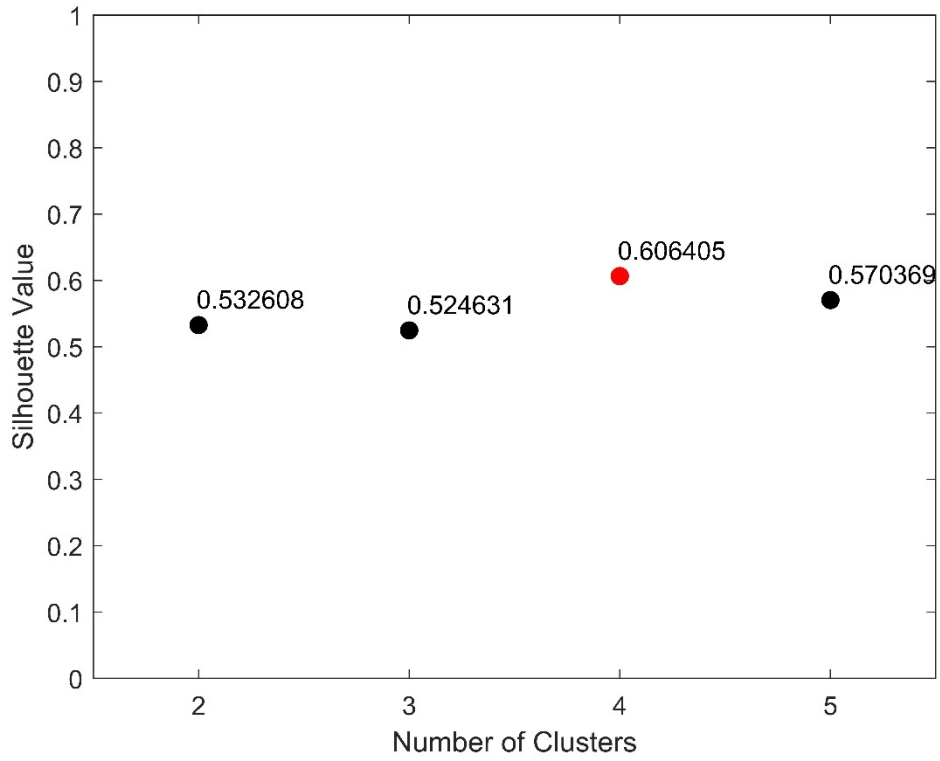

L
100
80
60
40
20
0
100
50
0
-50
-100
b
-100
-50
0
50
100
a

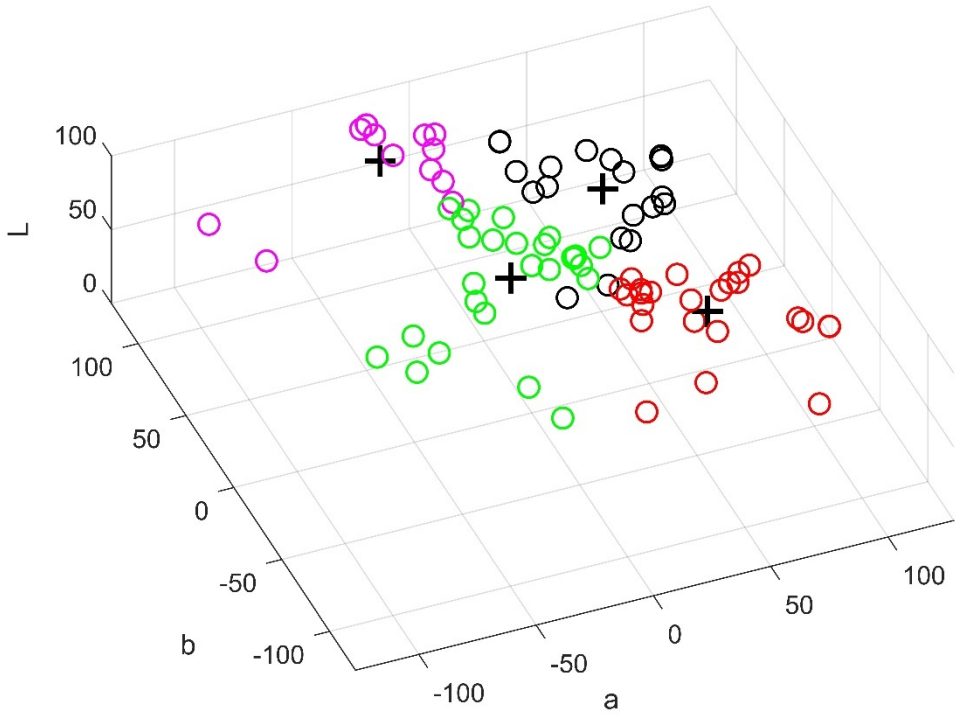

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.663642
0.625454
0.664298
0.625112
2
3
4
5
Number of Clusters


100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

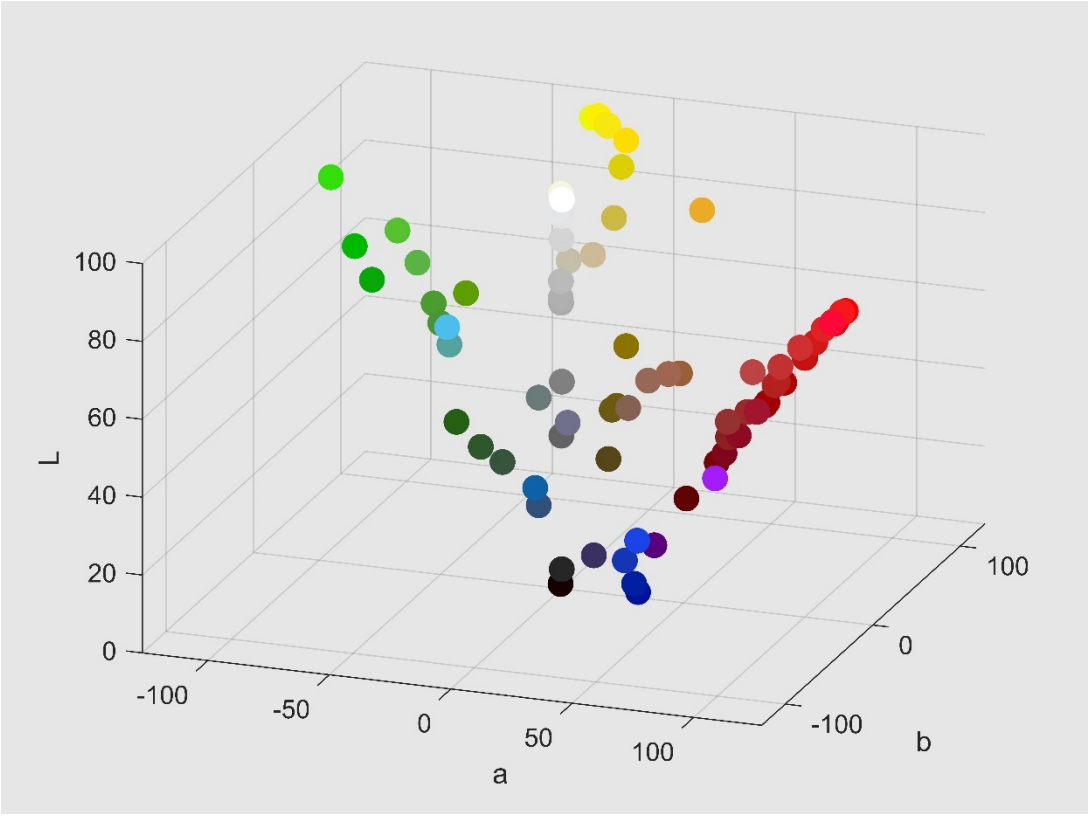
26. sweet

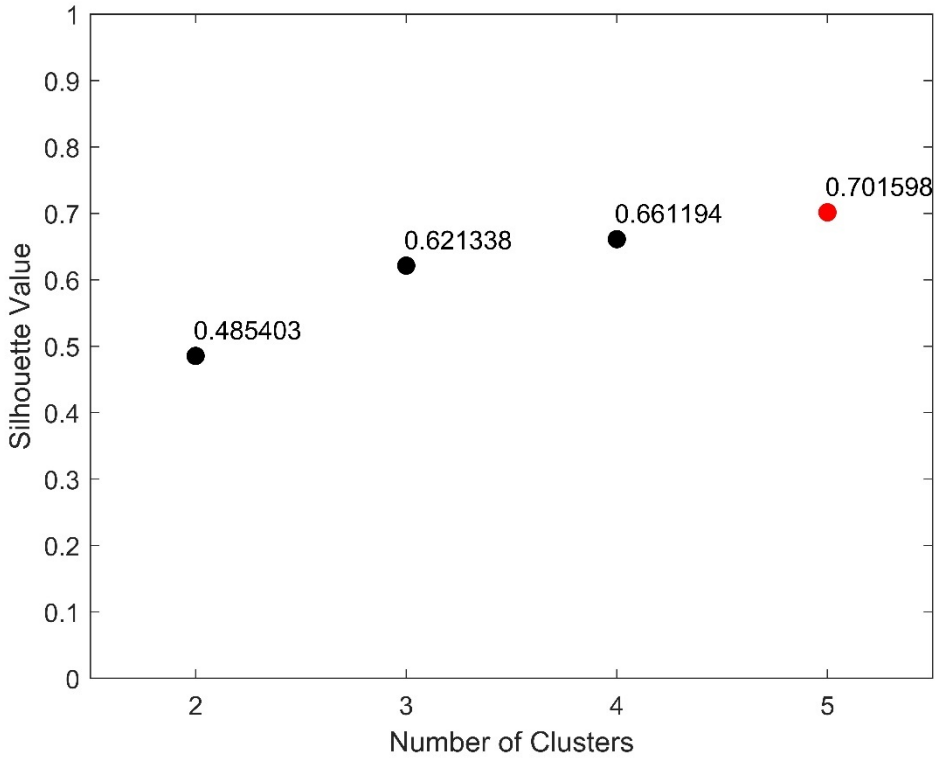

100
50
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

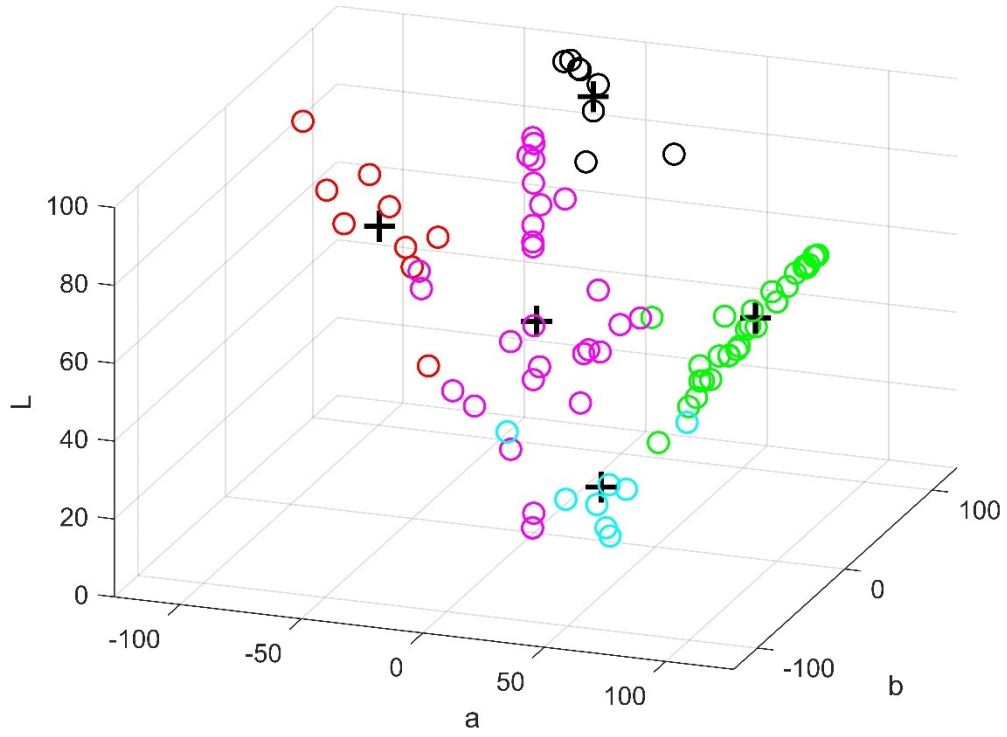

Silhouette Value
Number of Clusters
0.532608
0.524631
0.606405
0.570369
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5


L
a
b
100
50
0
-50
-100

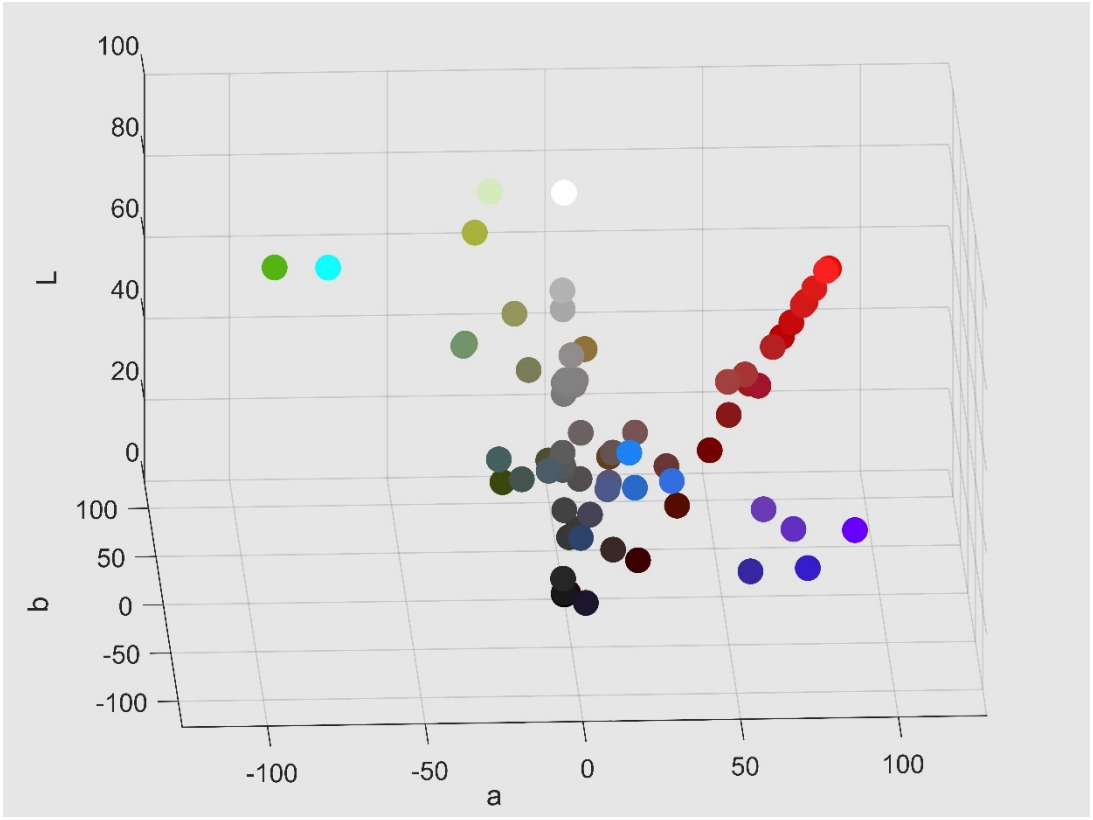
27. traditional

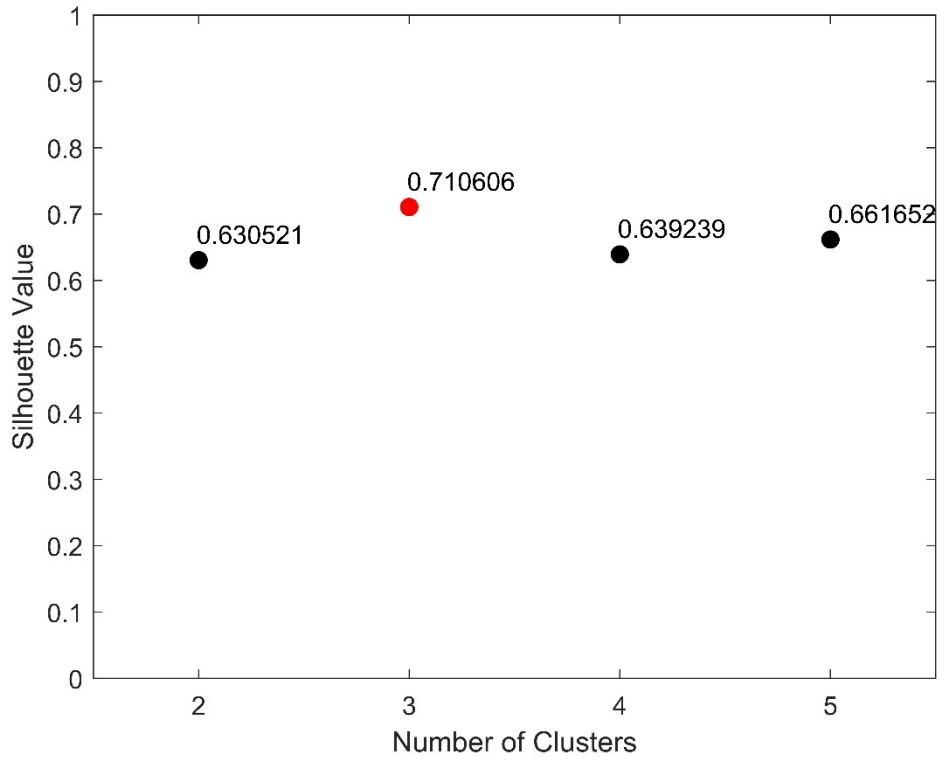


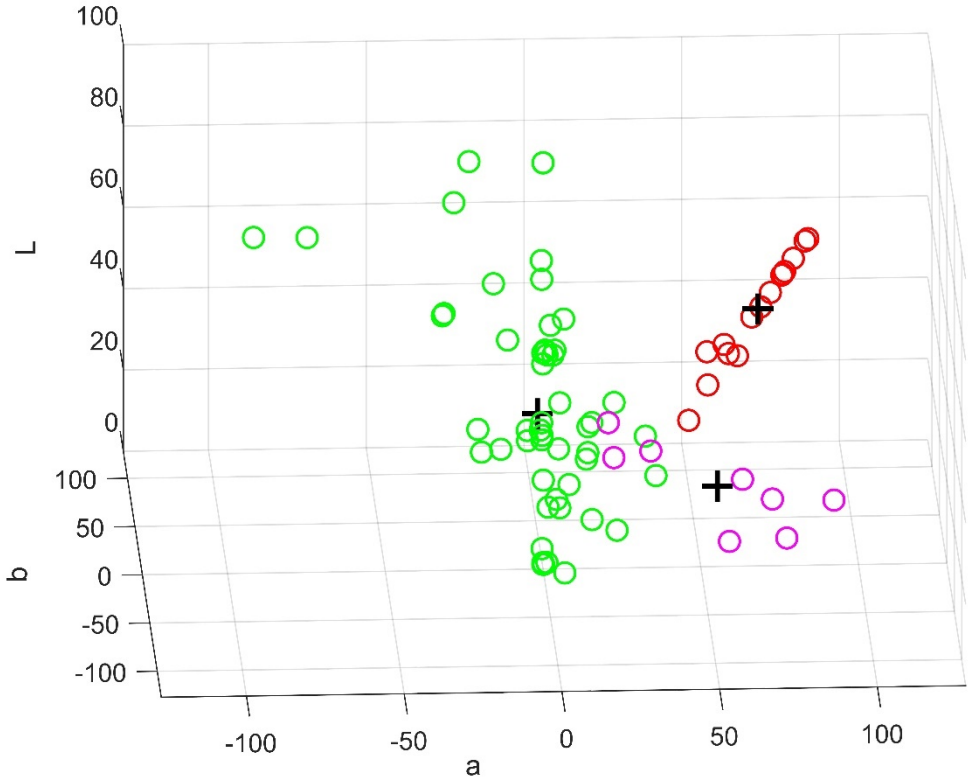



100
80
60
40
20
0
L
-100
-50
0
50
100
a
100
0
-100
b

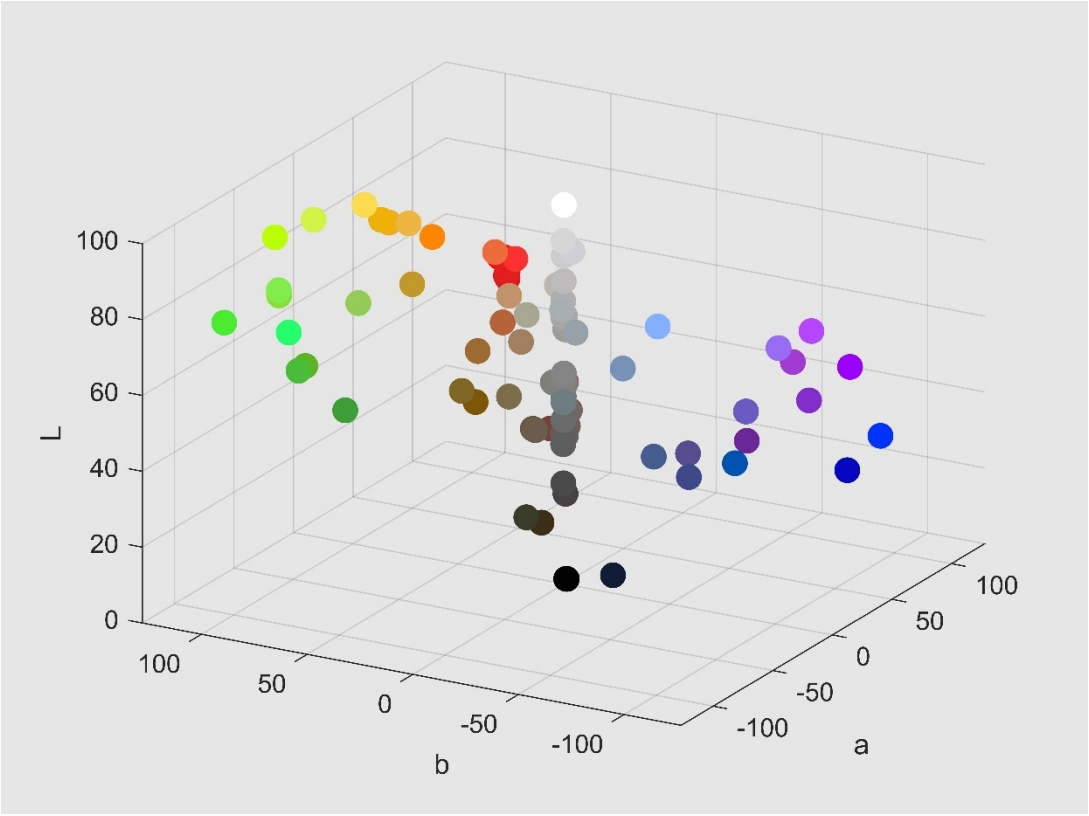
28. unlucky

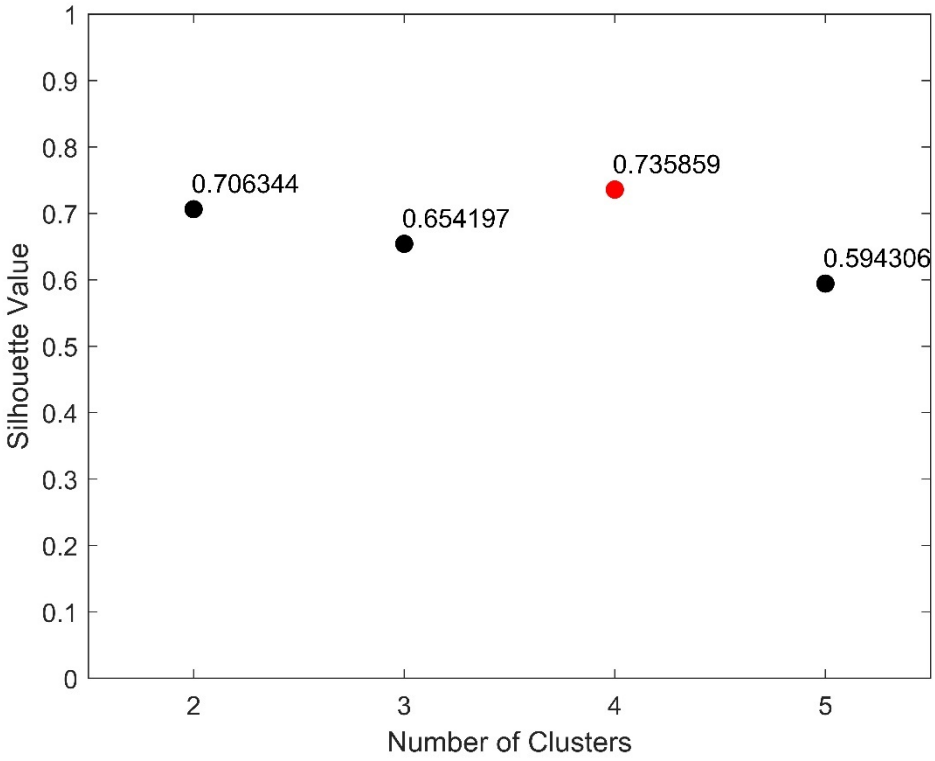

100
80
60
40
20
0
L
100
50
0
-50
-100
b
-100
-50
0
50
100
a

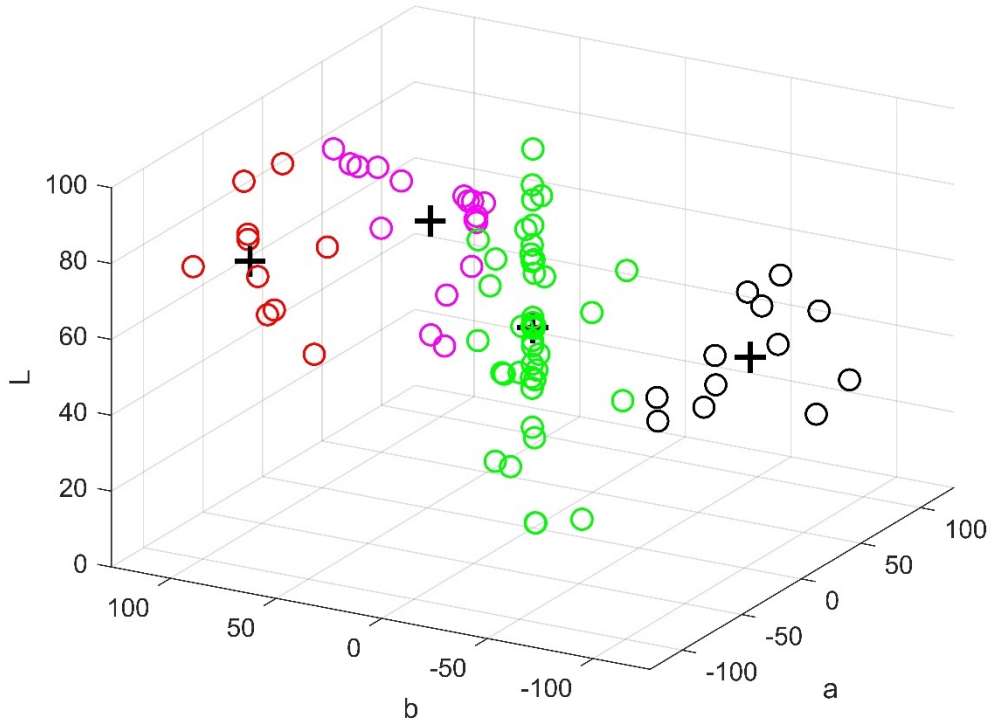

Silhouette Value
Number of Clusters
0.630521
0.710606
0.639239
0.661652


L
a
b

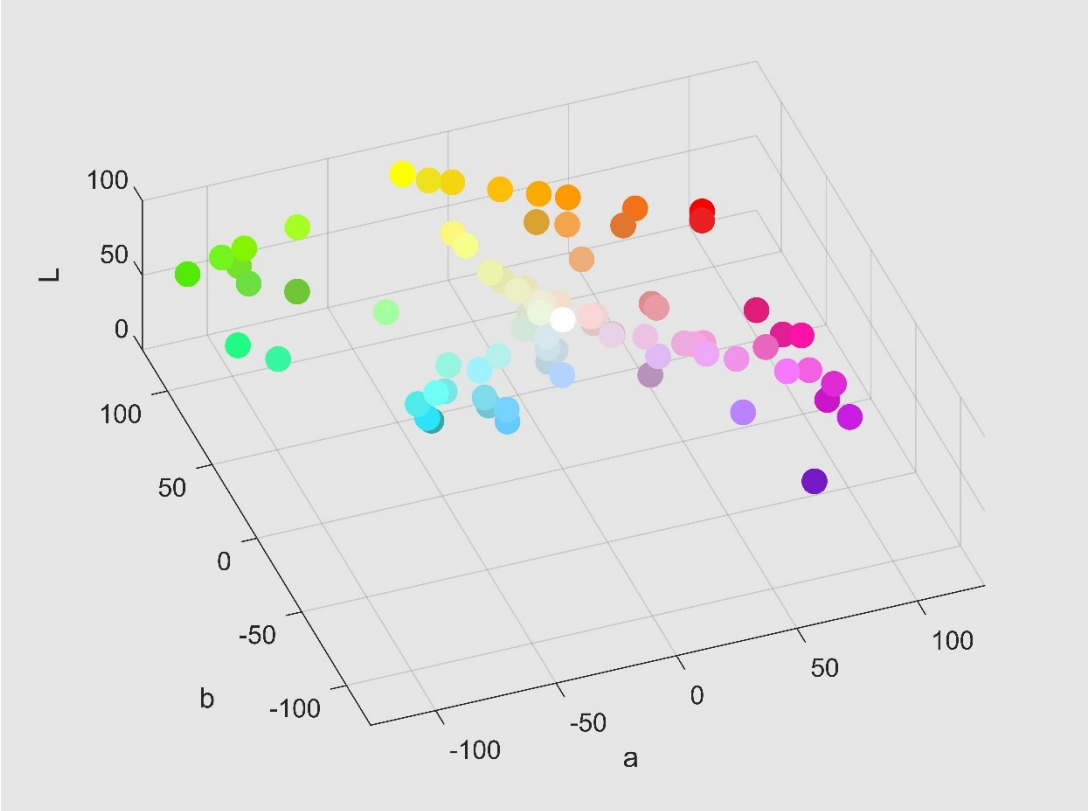
29. urban

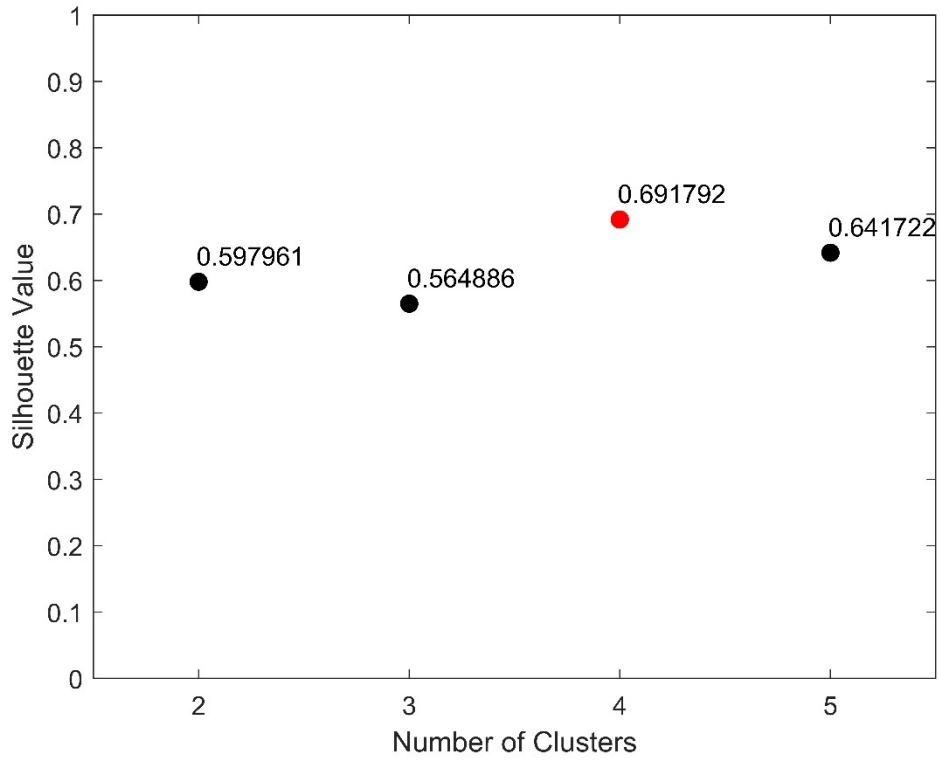

L
100
80
60
40
20
0
b
100
50
0
-50
-100
a
100
50
0
-50
-100

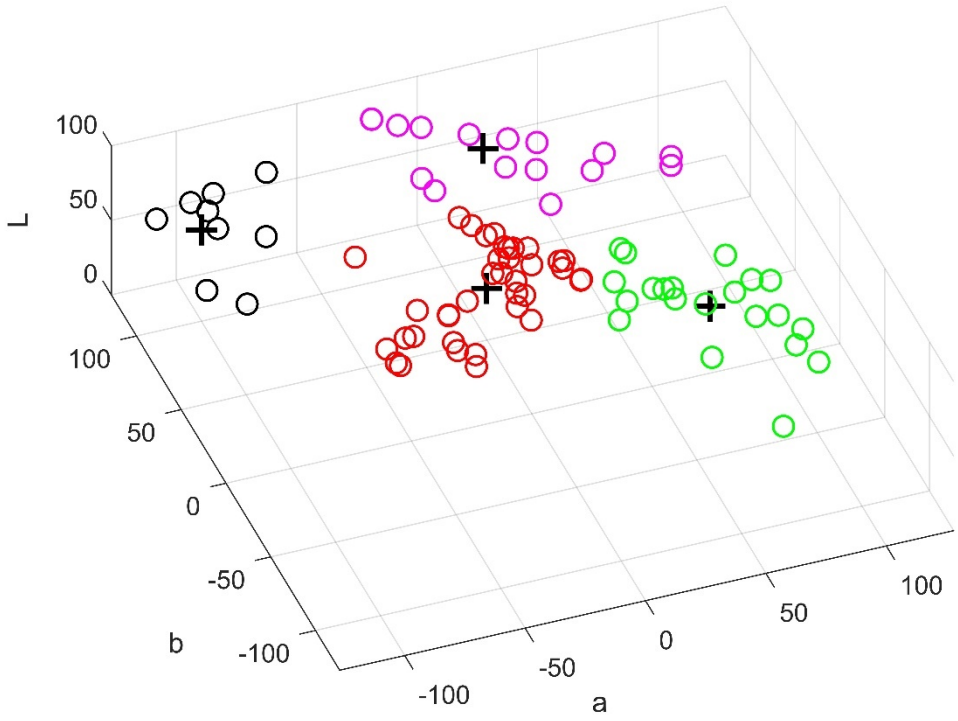

Silhouette Value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.706344
0.654197
0.735859
0.594306
2
3
4
5
Number of Clusters


L
100
80
60
40
20
0
b
100
50
0
-50
-100
a
100
50
0
-50
-100

30. young


L
100
50
0
b
100
50
0
-50
-100
a
100
50
0
-50
-100


Silhouette Value
Number of Clusters
0.597961
0.564886
0.691792
0.641722


L
a
b