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A Superior Emotional UX in Product Design by Structural Colours

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ABSTRACT

In this research, in order to find the most effective colours, we reached natural and non-pigmented colours called structural colours, and after reviewing the research done on them, we tested their quality and quantity of effectiveness to ensure their higher effectiveness (physical, emotional, perceptual and aesthetic effects). After that, we extracted to the important points and the appropriate product level to apply their advantages. These colours can create golden opportunities for the designer due to their different effectiveness especially in creating a user experience in emotional design. This article is to draw attention of industrial designers to the possibility of using the results of structural colour research despite all limitations.

Keywords: Product colour, Emotional colour, Emotional design, User experience, and Structural colour.

INTRODUCTION:

Colour has many different definitions from every perspective which in most of them, the nature of colour is not separate from light. A general definition is that colour is the property we perceive based on the way an object emits or reflects visible light or how the surface of matter interacts with light. It is a psychophysiological phenomenon, it has both psychological and physiological effects, and is also one of the most important environmental stimuli, but what kind of colours are the most effective colours? Today, we know the role of colour in psychology and the importance of colour psychology in creating a user experience, that one of the main areas of it is web design, but the question is, what is the importance of colour-focused user experience in web design compared to other design fields? The importance of colour in this field is due to the difference and high quality of the colour on displays compared to non-backlight colours, such as colours in the body and components of products. As the colour effect of displays is greater due to the optical nature, the psychological effects of colour on the user also increase. So in this research we introduce and investigate colours that are similar to the colours produced on displays but are produced in another way and they can be used to enhance the colour user experience in product design, where there is not necessarily backlight and the only available light is ambient light, they are called structural colours. Structural colours can increase the opportunity for the designer to create a great emotional user experience without any backlight (Pathiranage, 2021).

These colours have a high emotional quality and as we know, the involvement of emotions play an important role in the user interaction with the product and consequently the user experience (Sokolova & Fernández-Caballero, 2015). So we are going to use these colours

on the surfaces and body of the products to create an emotional user experience, aesthetics and visual persuasion (Lindgaard, 2007). To identify the best colours according to bionic principles, we went to nature and biological species and we came to structural colours (non-backlight supported colours) that can compare with the colours produced on displays (backlight supported colours). According to the bionic method, nature is source of the most complete and optimal phenolmena, so we looked for the best colour effects of biological species. According to researches on the best colour effects in nature (In terms of the production mechanisms, durability, visual quality and aesthetics) the most obvious is related to structural colours, which are seen in the colourful feathers of birds, butterfly wings and crust of some insects and so on, colours with superior visual effects and great emotional quality, high durability and excellent stability.

The colours we usually use in the arts and industry, in general they are inks or pigments but in nature, there are structural colours in combination with pigments or independently that are fundamentally different from each other. Although many years of researches has started in structural colours, but it has not yet been used in industrial design (product design), while the benefits of these colours are so in line with industrial design aspirations. So in this research, we try to identify the proper principles for applying their benefits in product design after examining the aesthetic and effectiveness of these colours.

To do this, we first need to know the differences, similarities and limitations in each colour group (pigment colours and structural colours) and then align with the technology and production constraints and design requirements.

Fig. 1: Some exampels of structural colors.

Research method

This is an applied research conducted in two phases of literature review and cross-sectional research. In the first part, some samples of papers about the nature of the colour and the colour production mechanism in the best colourful effects of biological species were deliberately selected and studied (According to the Bionic method) (Biró *et al.,* 2009; Dumanli & Savin, 2016; Ghiradella & Butler, 2009; Michielsen *et al.,* 2009; Seago *et al.,* and Vignolini *et al.,* 2011; Vukusic & Stavenga, 2009; Yoshioka *et al.,* 2007) and the summary of the relevant cases is given in the discussion. In the second part, we used the followings to obtain information to compare three general features (F1, F2, F3)[1] in the three groups of colours (G1, G2, G3)[2]

1) F1 (Visual quality): To compare the attracting attention or visual persuasion level of all three groups, 100 persons were selected equally by quota sampling from two groups of men and women (20 to 50 years old) and we showed them three colour samples of the same hue but of a different natures (G1, G2, G3) and we asked them to choose the most attractive and beautiful one.
2) F2 (Emotional and perceptual quality): We interviewed them to find out their emotional and perceptual qualities from the three colour groups and their reasons for the selection.
3) F3 (Physical reactions): To compare physical reactions, we designed an experiment by using VR technology (virtual reality) to simulate structural colours effects (Despite of limited facilities and funding), so we were able to simulate the colour characteristics of each colour group, and finally we exposed them to three colour groups for a certain period of time and recorded their body changes and reactions (The range of body

temperature changes and the amount of body movements and reactions).

RESULTS:

The information obtained from review of the articles showed that in the most premier colourful effects in terms of visual and emotional quality, there is a trace of structural colours (Independently or in conjunction with pigments) this part led to the identification and classification of similarities and the differences as well as the advantages and limitations. The second part showed that, most interviewed found the independent effect of structural colours (G2) to be somewhat milder than their effects with pigments (G3) and stronger than (G1). Other information obtained from the interviewees led to a comparison of three categories of motivational characteristics of colours (**Fig. 2**).

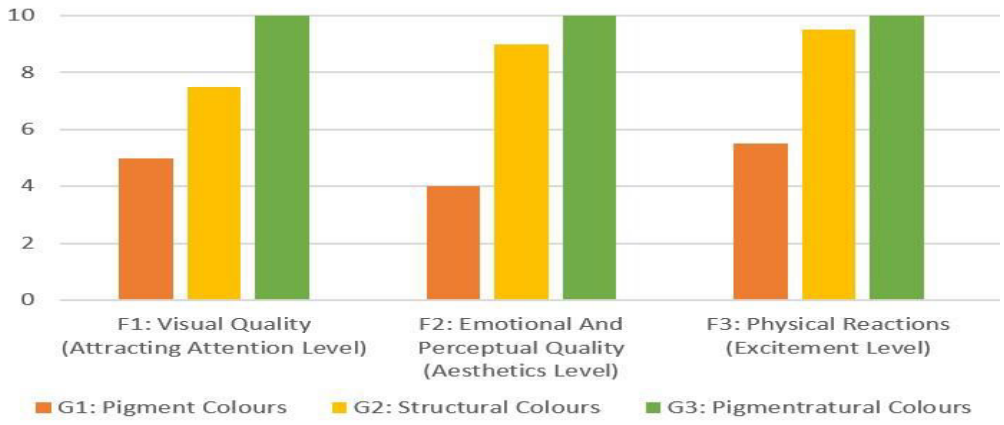

Fig. 2: Comparison of the motivational characteristics of pigment colours, structural colours and pigmentratural[4] colours.

1) G1 (Pigment colours): The results showed that the pigment colours (G1) which produce colour by the absorption and reflection mechanism, attract less attraction compared to the other colours (G2, G3), they also had lower emotional and aesthetic quality for participants and created a lower rates of physical changes.
2) G2 (Structural colours): The results of this step showed that the structural colours which produced purer effects by the mechanism of diffraction and refraction attract more attraction than the (G1). The participants also rated the emotional and aesthetic quality of these colours more than (G1) because of their luminosity and dynamic effects. They also stated that these colours evoke some sense of preciousness and originality, luxury and uniqueness. The physical changes they made were also greater than the (G1), because of their optical nature.
3) G3 (combination of G1 and G2): This group was better in all cases because of the characteristics of both groups simultaneously (G1 + G2).

The results of the above comparison chart can be summarized in the following table:

Table 1: Comparison of motivational characteristics of pigment, structural colours & pigmentratural colours.

Features Groups	F1: Attraction level	F2: Aesthetics level	F3: Excitement level
G1: Pigment colours	Medium	Medium	Medium
G2: Structural colours	Medium	High	High
G3:Pigmentratural colours	High	High	High

DISCUSSION:

The results showed that the colour production mechanisms based on absorption and reflection of visible light (pigment colour mechanism) produce different colour properties compared to the colour production mechanisms based on refraction and diffraction of light (structural colour mechanism) in terms of physical and mental properties (F1, F2, F3). **Table 1**

shows that, the independent qualities of the structural colours are stronger than the pigment colours, because the hues in the structural colours are purer and softer (Zhao *et al.,* 2012) because of the wavelength nature.

But the superior qualities of the pigmentratural colours are quite evident in comparison to the pigment colours, because these colours have both natures at the same time (absorption-reflection and refraction-diffraction). G2 and G3 can also create a stronger colour user experience in product design, because their colour quality is more optical nature compared to the pigment colours, so they have more potential for energy exchange and emotional stimulation, in other hand pigments turn dark when combined, their hue's quality decreases; (Subtraction effect), but coloured lights are not like that, they do not darken when combined rather, they become bright and radiant and turn to visible light (Additive effect). According to the results, G2 and G3 evoke a sense of preciousness and originality for the viewers because the manifestations of nature in our collective unconscious are always acceptable and pleasant, and these are the things that the industrial designer can use intelligently to create a superior colour UX in product design. So based on this study, colours can be classified in terms of the production mechanism in three groups (G1, G2, G3) and according to the features of each of group, their differrences and similarities can be extracting to manage their application in design.

Pigment colours (G1)

In the group of pigment colours, the colour effect is the result of solid particles which based on its chemical properties absorbs some parts of the visible light and reflects the other part, and we see and understand the reflected part as a colour. In the other words chemical or pigment-based colourations involves photoelectrical energy consumption and conversion (Zhao, 2016). So in this group, the emotional quality, aesthetics and excitement level depends on the chemical quality of the pigments, it means the main variable in this group is the chemical quality of the pigments and the sub variables are hue, saturation, value ,subtractive effect, additive effect and so on. These are the same colours that are commonly used in most products and their wide range of usage is not the subject of this research. In this study, we investigate the structural colours and their potential in creating a stronger user experience in product design. The advantages of (G1) are the variety of types, reasonable prices and always availability and their limitations are their chemical nature (Probability of environmental pollution), less effectiveness and durability compared to the G2 and G3.

Structural colours (G2)

These are coloured lights which are resulting from diffraction and refraction of visible light in very dense and delicate nanometer bio structures, and create a rainbow or seven-colour effect (**Fig. 3**). The features of this group are having a purer hue with controlled brilliance and high durability, which ultimately creates a beautiful and attractive effect (**Fig. 3**). High durability of these colours is due to the non-dependence on pigments, and as long as the light scattering structures are healthy inside the bio materials, they will continue to produce a colourful effect, like very old fossils that still retain parts of their structure and still continue to produce colourful effects (**Fig. 4**), durability of the colour in old coloured fossils is due to their nonpigmented nature, some parts of three-dimensional structures are preserved in the fossils and continue to diffract light and produce colour effects. On the other hand, the reasons for their emergence in the nature in cambrian explosion also emphasize to their superiority and development (Zhao, 2016). An age in which organisms had to evolve to survive, so structural colours emerged to help draw attention to mating. So the emotional quality, aesthetics and excitement level in this group depends on the nanoscale structures and the amount of light diffraction of them. Namely, the main variable in this group is the geometry of nano scale structures and it can be designed and controlled by material specialists and applied in the product design and create different user experience. Using these colours in product design can create a superior user experience in the field of colour without the presence of backlight in the body of product. It means more effectiveness than pigment coloration. The limitations of these colours are fluctuations in the colour spectrum as the viewing angle changes, which can be a bonus if consciously incorporated into the design, although structural coatings colours with self coloidical control and angle-independent, are under-way (Magkiriadou *et al.,* 2012).

Fig. 3. Examples of the visual quality of structural colours in biological species.

Fig. 4: Examples of the oldest coloured fossils dating back more than 40 million years (McNamara *et al.,* 2012) Stability and durability of colour due to the structural nature of the colour.

Pigmentratural colours (G3)

These colours come from the conjunction and proximity of the two previous groups, and in this article are briefly called "Pigmentratural colours", (pigment + structural = pigmentratural) with the features of both groups; mild to strong hues, high effectiveness, more controlled shine and more energetic (more energy exchange in effectiveness) which results the appearance of superior, more stable, and more effective colour qualities. The emotional quality, aesthetics and excitement level in this group depends on the two previous variables; the presence and the chemical quality of pigments with the presence and the physical quality of the nanostructures simultaneously which enhances the characteristics of the two previous groups. As the effect of light and colour on physiology and psychology and its role in arousal has been known for many years, and such effects depend on the wavelength of light (Elliot, 2015) and given that each wavelength produces a certain colour, the coloured lights will have different arousal capabilities than the pigment colours. It is here that the psychology of colour becomes more important for applying structural colours in the product design because their psycho-physiological effectiveness is greater than pigment colours due to the optical/ light nature.

Fig. 5: Examples of the pigmentratural colours in biological species.

All three types of colours mentioned above, regardless of their production mechanism and nature, have physiological and psychological effects that the quantity and quality of these effects vary across groups. That is in pigment colours, chemical dimension and in structural colours, physical dimension and in pigmentratural colours, both physical and chemical dimensions lead to physiological and psychological effects. Therefore, the first and second groups can be called one-dimensional colours, and the third group can be called two-dimensional colours, which is again a reason for their superiority and more effectiveness. Proper use of these colours can be effective in product selection and visual persuasion (related to the first level of emotional design), and it can enhance the colour UX in product design if combined with other principles of user experience. So the use of pigmentratural colours will be effective in a wide range of products as external parts or some strategic parts of the body of the product.

Superior features of G2 and G3

1) High emotional and aesthetic level compared to pigment colours, it means they have more mental effects which cause more psychological and physical reactions. Those effects that lead to changes in amount of physical reactions are the variables of change in the quantity of emotion (physical reactions), and those effects that lead to a change in the type of emotions are the variables related to the quality of emotions (perception and aesthetic quality) and that means their high level of aesthetic stimulation (Nanay, 2016).
2) High level of attracting attention (visual persuasion) due to high visual quality, dynamic and multicolored effects compared to pigment colours. They create beautiful, attractive, dynamic, energetic and durable colours (changeable and multihues effects).
3) Matching the features of these colours with industrial design approaches:
   a) Their quality of visual, emotional, and aesthetics make them more effective and attracting attention so they can create a higher colour user experience, this is in line with the first emotional design level, and this feature can be used with design decisions in the emotional design approach. On the other hand the involvement of emotions plays an important role in the user's interaction with the product so it is also effective in creating the user experience (high colour UX).
   b) High durability of these colours is consistent with the ideas of the sustainable design approach. This means that as long as the colour-producing structures in the surface of the product are healthy, the colour quality of the product will not decrease. Like those old coloured fossils that continue to refract light and create colour due to the preservation of their colour-producing structures, in other hand the durability of the emotional and aesthetic

qualities of these colours creates a sense of luxury, uniqueness and preciousness in the user and that means a golden opportunity for a profitable and unique design in the luxury product category.

c) More optical and mechanical nature of these colours, compared to the pigment colours, reduces environmental pollution, which is in line with green design ideas.

General principles of use

For the proper use of these colours in product design, interdisciplinary collaboration between industrial designers and some other specialists is required:

1) Physical phase: necessity of controlling shine and glossiness which focuses on the material and geometric design of three-dimensional nanoscale structures, related to optics and material specialists and depending on the shape of the surfaces or the surface geometry which must be controlled and planned by the designer. For example by designing an appropriate 3D texture to reduce or control the extra shine and glossiness like the natural solution found in one species (**Fig. 6**).

2) Chemical phases: necessity of controlling the basis of colour factors such as; hue, value, saturation, brightness and etc. Due to chemical quality of pigmentation for G3 and for the basic colour of the materials which three-dimensional structures are created on (G2)?

3) Psychophysiological phase: need to control the level of energy exchange, qualitatively; focusing on the psychology of colour that is to know which colours stimulate which emotions? Which emotions do we need to create a good user experience in terms of product performance and user interaction? And which ones do we not need? Which colours enhance the user's desired emotions and which ones reduce the user's negative emotions? ... And quantitatively; depending on the shape of the coloured area, this means how much structural coloured surface is in what shape of the surface? And how much emotion it creates? This is about the creation and control of emotions associated with colour and must be planned and controlled by the designer, according to product function and design requirements, for G2 and G3. As mentioned, the reason for the emphasis on colour psychology in the use of structural colours is their high irritating power compared to pigment colours.

Fig. 6: Structural colour with 3D texture.

Economic level and production technology

These colours can be manufactured under three general areas of technology (Physical, chemical, and biological) each has different methods and different costs and most of them are possible under nanotechnology which gives them many other benefits and of course, high production costs. Based on the aesthetics qualities as well as production costs, which is technically feasible under nanotechnology, it seems that the class of luxury products is a good place to apply structural colours (Before the production of these colours became widespread and affordable) such as jewellery

design, it means that they can be used in jewellery design to simulate beautiful, luminous, colourful and durable effects without use of rare stones and diamonds, or to create structural colours in the body of small products and luxury accessories or parts of larger products (As secondary colour or as emphasizing colour) and for economical use of these colours in the non-luxury product class, they can be used at the golden point or strategic point of some products as a high effective accent colour[4] to impress the user.

- Mechanical methods: This method involve the creation of physical nanostructures on the surface of appropriate materials that refract light and create colour effects, by some kinds of 3D printers, lasers and etc. In this method, we can create colourful and permanent nano-engravings on parts of the product, such as engraving the brand name or colourful barcodes or permanent and beautiful QR codes and so on. In this way, any unique identity information about a luxury product or any kind of design and pattern can be permanently, beautifully, luxuriously and safely recorded on its body (Inducing a unique feeling).
- Chemical methods: These are liquid coating colours, like as common coatings colours and they can cover on different surfaces, like all conventional coating colours. In chemical methods, unlike physical methods, structures that create structural colours are not built on surfaces, but after placing dye on the desired surface, three-dimensional structures that produce structural colour are formed in the molecular arrangement of the dye by colloidal self-control (Wang *et al.,* 2020). In chemical production methods, chemists control molecular arrangements to create different hues. So these can be used for larger levels of luxury products as dominant colour.
- Biological methods: In biological production methods, biologists create colour structures by cellular self-control. These methods are so costly and they can be used in medical beauty industry products, like producing cosmetic lenses with structural colours and so on.

Considering the superior features and the limitations as well as the compliance with the economic progress value chart (**Fig. 7**), the position found for the current use of structural colours seems to be approved. This means that as we increase personalization, we are going to increase quality, create superior experiences and transformation, and for this purpose we must create a different and superior competitive position, and this requires a high cost, and this is what can achieved by the correct use of structural colours uniquely, of course along with other design arrangements.

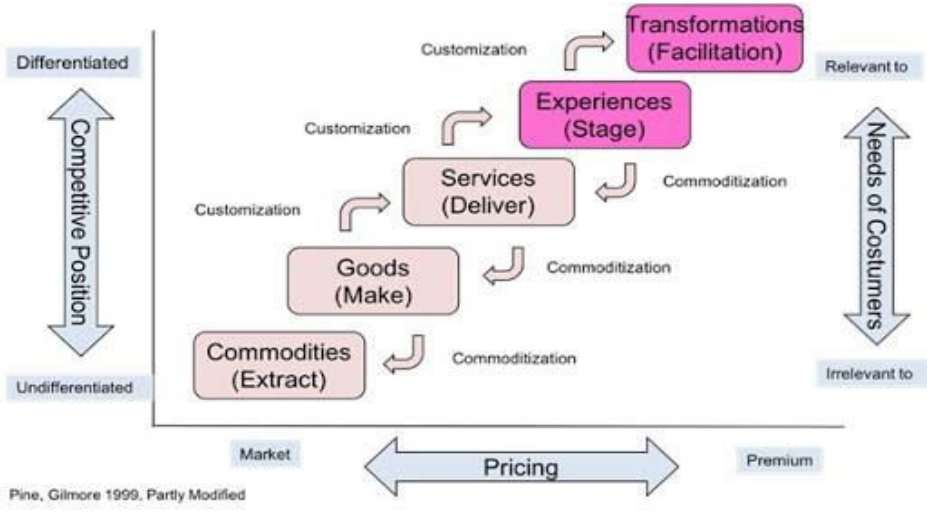

Fig. 7: Eeconomic progress value.

CONCLUSION:

According to this study, the quality and quantity of effectiveness in structural colours are higher than non-structural colours, so it is not unreasonable if we call the structural colours as super colours or emotional colours and emphasize to apply the advantages of them

in product design, because these are more emotional, effective, optimal, creative, attractive, durable and dynamic colours and also can create a superior colour UX, if applied in the right position and comply with design and production restrictions.

Advantages:

- High emotional and aesthetic level (Associated with a sense of uniqueness and preciousness, unconscious pleasantness and acceptance)
- High level of attracting attention (Visual persuasion due to high visual colour quality)
- Coordination with current design approaches in the world such as emotional design, sustainable design and green design.

Principles of use in design despite limitations

- controlling shine and glossiness
- controlling the basis of colour factors
- controlling the level of energy exchange
- Finding the correct scale and position of use

At the end, a suggested pattern for using pigmentratural colours according to its intensity in terms of energy exchange level and the cost of production is based on the control of the coloured area, a colour pattern which specifies the percentage of colours used is: (dominant colour %60, secondary colour %30 and emphasizing colour %10). The best way to use pigmentratural colours in this pattern is, first of all, as an emphasizing colour in a product, sometimes as a subsidiary/secondary colour and rarely as the dominant colour (In small products), more use of these colours in product design requires the designer to be more careful about the mentioned factors, for example in accessories that are relatively small can be freely used but the use of these colours on a larger scale requires more control. With these colours we can create more attractive surfaces in the body of the products which in addition to the high aesthetic quality have high durability too, for example, the body of a mobile phone which in addition to its beautiful appearance needs colour durability or we can highlight and emphasize an important part of the product with these colours, we can also have the brand name or colourful barcodes or permanent and beautiful QR codes or any unique identity information about a luxury product or any kind of design and pattern permanently on the product. In products which colours have functional performance in, these colours can be used as the dominant colour with a higher percentage, for example therapeutic use in energy therapy and colour therapy products (For small products). In terms of ergonomics, the use of these colours on large and polished surfaces will cause harassment or damage, and it's better to use on textured surfaces that control the amount of reflection and shine, and of course it should be noted that due to the different nature of the coated colours (G1) with the structural colours (G2, G3) these groups will be differ in ergonomic characteristics, which can be an independent research topic. It should be noted that the structural colours examined in this study from an aesthetic view, it can be done from other points of view, for example focusing on the application of colour in conveying different concepts according to the way perception and vision are perceived in any biological species which will have different results, or modelling large-scale colour-generating nanostructures can be interesting in environmental design. Of course many of production methods are not yet suitable for industrialization, but the future of structural colours will be bright given the excellent advantages and relative readiness of the technological platform. Colours from the distant past for the near future …

Notes

1) F1: Visual quality, F2: Emotional and perceptual quality, F3: Physical reactions
2) G1: Pigment colours, G2: Structural colours, G3: pigmentratural colours (combination of G1 and G2)
3) In this paper the combination of structural colours along with pigments is called "Pigmentratural" colour
4) Accent colours are colours that are used for emphasis in a colour scheme.

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CONFLICTS OF INTEREST:

We have no conflicts of interest to disclose.

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