Living Hues

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ABSTRACT

Nature's way of allowing creatures like cuttlefish, octopuses, and chameleons to change colour is fascinating. This paper looks at how chromatophores, iridophores, and leucophores work in these animals. By studying their nervous and hormonal systems, new ideas for materials and technologies used in dynamic decorations and adaptive wallpaper design were found. This paper also shows how warm and cold colours influence human emotions and the perception of the mind. Integrating biological science and engineering opens up new opportunities for developing an adaptive wallpaper based on nature.

Keywords: Biomimicry, Colour Change, Chromatophores, Iridophores, Leucophores, Cephalopods, Chameleons, Adaptive Materials, Smart Textiles, Industrial Engineering, Warm Colours, Cold Colours

I. INTRODUCTION

We as humans often pride ourselves on our intelligence and capabilities, however, the rest of nature might find this amusing. Despite our big brains and vast numbers, some animals possess extraordinary abilities far beyond our own. The power to change colour is one of those abilities.

Animals like cuttlefish, octopuses, and chameleons use biological mechanisms to be able to change their appearance for purposes such as camouflage, communication, and hunting. By studying these mechanisms, valuable insights can be discovered for application in various fields such as technology, interior design, and art.

This paper explores the specific systems that enable these animals to change colour. Through an in-depth analysis, we aim to uncover the principles behind these natural phenomena and discuss their potential applications in modern design. The Biomimicry Taxonomy was used to define the group, sub-group and function that we wanted to achieve in our design. These were defined as the following:

Group: Modify
Sub-group: Modify physical state
Function: Light/colour

For this paper, multiple different animals were researched, with the goal being to gain extra insight that can be used in the design process. The animals that were selected for this nature technology summary are cephalopods and chameleons. all have highly similar biological mechanisms that are responsible for their colour change. In spite of this, there are still some slight differences; these differences will be highlighted in the BDP and ADP section of this paper.

This paper furthermore details a concept based on these mechanisms. The concept represents a dynamic wallpaper adapting to its surroundings, changing its colour and design based on external factors like temperature and magnetism. This adaptive colour change aims to positively influence the environment by playing into psychological principles of colour perception of humans. The paper concludes with a conclusion and future steps when it comes to the design and concept.

II. RESEARCH QUESTION

To be able to accurately research the topic of colour change and its potential within design, we formulated the following research question:

How can the colour-changing mechanisms of chameleons and cephalopods be mimicked to create an adaptive wallpaper that positively influences mood?

This research question carries the following sub-questions:

How do the colour-changing mechanisms of chameleons and cephalopods work?

How can these biological mechanisms be used in a potential product?

How do different colours influence human emotions?

III. METHODOLOGY

In order to answer the posed research question and achieve the research objective, firstly, research was done into the relevant biological principles as they occur in nature; cuttlefish, octopuses and chameleons were researched for their colour-changing abilities and the underlying physical principles behind them. This research was conducted mostly by reviewing existing literature on scientific research. Through this research, by applying principles from biomimicry taxonomy, methods and mechanisms will be identified that could be used in engineering.

After identifying relevant and useful mechanisms and methods through biomimicry, further research will be done into possible design and engineering applications of these mechanisms and methods.

A particular promising application that was identified required extra research and underpinning. For this reason, additional research was conducted into the psychological effects of different colours on the human mind and perception.

IV. BDP (Biology design principle)

For the biology design principle, the cuttlefish will be examined. Cuttlefish are marine molluscs in the order *Sepiida* and share the class *Cephalopoda* with squid, octopuses, and nautiluses (Mindat.org, n.d.). They have eight arms and two tentacles with denticulated suckers for capturing prey, and an internal shell called the cuttlebone that helps regulate buoyancy. Additionally, they have large W-shaped pupils giving them a wide field of vision. Cuttlefish are highly intelligent and show complex behaviours like creating ink body doubles to evade predators. They typically range from 15 to 25 cm, with the largest species reaching up to 50 cm and over 10.5 kg. (National Marine Sanctuary Foundation, n.d.).

Cuttlefish are sometimes referred to as the "chameleons of the sea" because of their ability to quickly change colour and texture. They use this skill for communication, hunting, and camouflage. To change colour, Cuttlefish use chromatophores, iridophores and leucophores (Meyer, 2023).

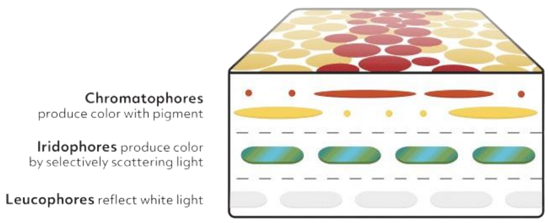

Figure 1: Three cell layers of Cuttlefish (Freeman et al., 2011)

Chromatophores

The first layer of skin of a Cuttlefish contains Chromatophores. Inside Chromatophores, pigment granules are enclosed in an elastic sac called the cyto-elastic sacculus. By changing the shape of these pigment-filled cells with muscular contraction, its translucency, reflectivity, or opacity changes. These muscles are addressed using neurons. Because chromatophores are under direct neural control, effects can be applied immediately (Meyer, 2023). Andres Laan et al. (2014) suggest that specific patterns are generated by specific brain circuits before motoric neurons control the colour-changing cells in the cuttlefish's skin.

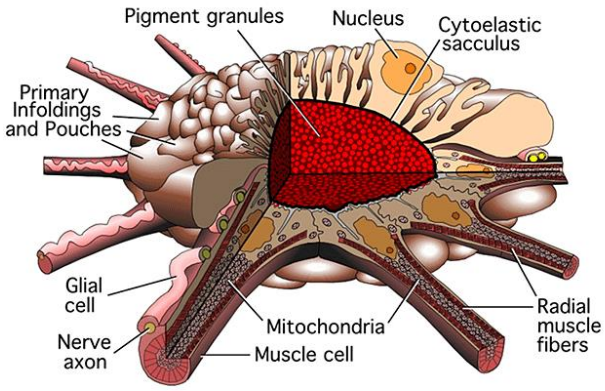

Figure 2 Chromatophore cell (Freeman et al., n.d.)

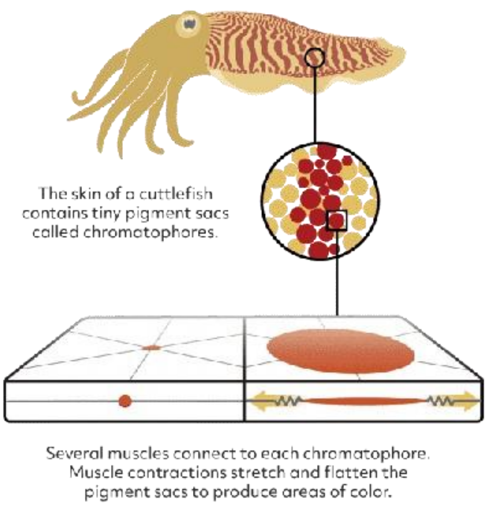

Figure 3 Chromatophore cell (Freeman et al., 2011)

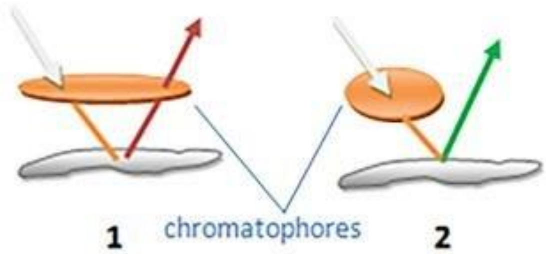

Figure 4 Working of Chromatophores (Ahmad et al., 2018)

Iridophores and Leucophores

Another animal with this same mechanism for changing skin colour is the chameleon. For years, it was thought that chameleons and other colour-changing organisms are able to change their colour solely with these chromatophores as described above. However, newer research shows that this is incorrect; it was found that whilst these pigment cells are present in a chameleon, they alone do not enable the chameleon to change colour. Instead, there is a layer of cells containing nanoscale crystals (~130 nm) underneath these pigment cells, called iridophores (Teyssier et al., 2015). These crystals together reflect a certain wavelength – and thus colour – of light, whilst the other colours are absorbed. Another natural example of this phenomenon is the wing of the Morpho butterfly, where the structure of its wings dictates their colour (Butt et al., 2016). Changes in the spacing of the crystals enables the iridophores to reflect different wavelengths – and thus colours – of light.

In a chameleon, the colour of the reflected light from the iridophores in combination with the layer of chromatophores above these iridophores results in a certain skin colour of the chameleon. For instance, the green colour of a chameleon is the result of the combination of a yellow colour from the chromatophores and blue light reflected from the iridophores.

Additionally, underneath the first layer of iridophores chameleons have a second layer of iridophores, containing crystals that are larger (200-600 nm), more spaced-out, and more disorganized. This second layer of iridophores reflects a substantial portion of sunlight (and thus heat), most notably in the near-infrared range. It is suspected that this enables chameleons to live in the bright, sunny habitats they tend to live in.

In addition to chromatophores and iridophores, and unlike chameleons, octopuses and cuttlefish also have leucophores. Leucophores, like iridophores, are cells that contain nanocrystals which scatter light. However, unlike iridophores, leucophores can move its crystals to such a position that it reflects a large range of wavelengths of light, and thus essentially reflect white light. This white light subsequently enhances the colour changes produced by the chromatophores and iridophores. They help octopuses and cuttlefish match the brightness and hue of their surroundings more effectively (Dave Hansford, 2008).

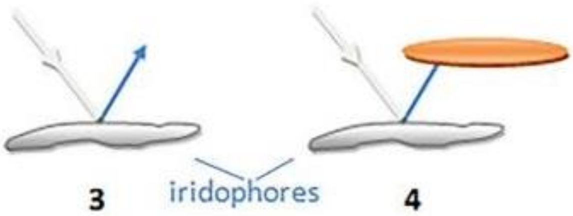

Figure 5 Working of Iridophores (Ahmad et al., 2018)

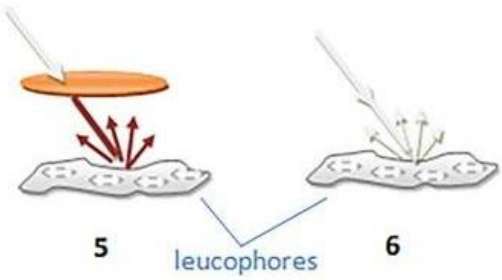

Figure 6 Working of Leucophores (Ahmad et al., 2018)

Life's principles

We as humans can still learn a lot from the ability to change colour. The life's principles connected to this skill can be seen as follows: one of the main principles applied by Cuttlefish is that its locally attuned and responsive. It uses camouflage to literally blend into its surroundings. It also uses readily available materials and energy; to change colour, a Cuttlefish only needs natural light, which is energy that is available in abundance.

Besides this, a cuttlefish is resource efficient; as said before, it uses a low energy process, only needing light. It also uses its skill for multiple purposes, communication, and camouflage, for example. The chromato-, irido- and leucophores have also evolved and adapted to its environment and are able to work together and create elaborate patterns and colours. With its iridophores it is able to reshuffle information by exchanging information and altering the light's iridicity, communicating with other Cuttlefish.

V. ADP (Abstracted design principle)

The colour-changing abilities of organisms like cuttlefish, octopuses, and chameleons are controlled by cellular mechanisms. Studying and abstracting these principles helps the development of innovative materials and technologies that emulate these natural processes.

In the aforementioned organisms, colour change is achieved through two main mechanisms. The first mechanism involves structures that can alter their shape, thereby changing their translucency, reflectivity, and/or opacity. The second mechanism involves layers that contain nanoscale crystals (~130 nm). These nanocrystals together reflect a specific wavelength—and thus colour—of light, while other colours are absorbed. In technical terms, the reflected wavelength constructively interferes with the crystals, whereas the absorbed wavelengths destructively interfere with the crystals (University of Connecticut, n.d.).

The spacing between these nanocrystals can be adjusted. Because of this change in distance between the crystals, a different wavelength – and thus colour – of light is reflected, whilst the other wavelengths are absorbed. Larger gaps between the crystals reflect longer wavelengths, while smaller gaps reflect shorter wavelengths. (Teyssier et al., 2015).

The combination of these two mechanisms enables colour change. An enhancement of this system can be made by adding elements that also contain nanocrystals. But, unlike the previous layers, these reflect a broader range of wavelengths, effectively reflecting the ambient light. This enhancement amplifies the colour changes produced by the other two mechanisms. A schematic of this combination of mechanisms can be seen in figure 7.

These changes can either be triggered with an electrical impulse or with a chemical impulse (neurologically or hormonally).

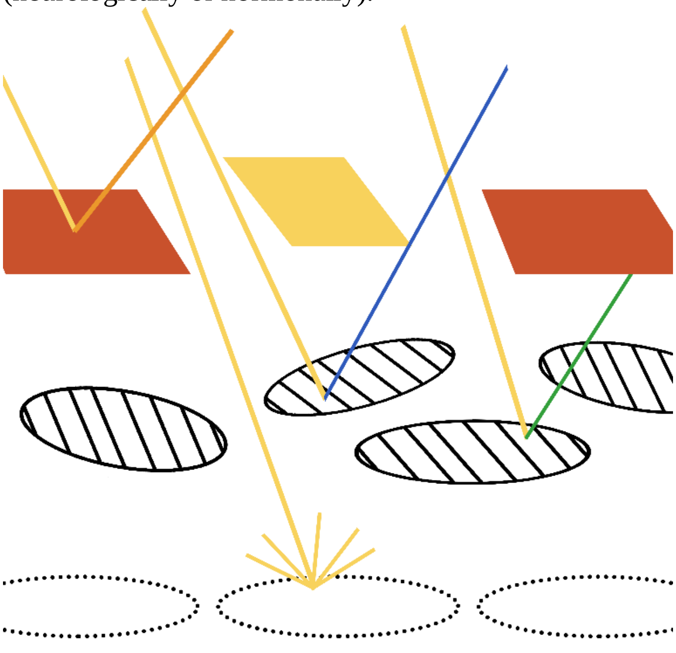

Figure 7 Schematic of the working of Chromatophores, Iridophores and Leucophores

VI. Neural vs. Hormonal Control

After looking into various animals, it became clear that different mechanisms for achieving colour change are used. Cuttlefish and octopuses as example primarily rely on neuronal activation to control their chromatophores, iridophores and leucophores for quick colour change (Montague, 2023), whereas chameleons use a combination of hormonal and neuronal activation involving nanocrystals in their iridophores (Teyssier et al., 2015). These variations in mechanism provide an understanding of how these organisms achieve their colour-changing adaptability.

VII. Colour Warmth and the Effects on Humans

Colour can make a huge impact on the emotional, cognitive, and physiological states of an individual. In a wider explanation, colours can be divided into 2 categories, warm and cold, each one having a different impact on human beings.

Warm Colours

Among the warm colours are red, orange, and yellow, which are supposed to exude warmth, energy, and comfort. These are called bold colours and arouse high emotion; they can produce psychological and physiological impact.

Emotional and Psychological Impact: supposedly warm colours are usually thought to create the feeling of excitement, enthusiasm, and stimulation. Other studies have shown that including red within the surroundings leads to a heightened heart rate, arousal and brings about a sharper perception of energy and urgency (Elliot & Maier, 2014). This means that warm colours are appropriate in environments where activeness and alertness are necessary, for example, in a gym or fast-food restaurant.

Cognitive Effects: Warm colours also have desirable cognitive effects. For instance, red can be used to encourage detail orientation; it improves functioning on tasks which demand acumen and thoroughness (Mehta & Zhu, 2009). However, it can incite anxiety in others, hence negatively impacting performance in more complicated or creative tasks.

Physiological Effects: Warm colours have the physiological effect of literally increasing body temperature and blood pressure, whereby the individual feels warm and cozy. Such effects are suitable for areas intended for socializing and relaxation, including sitting rooms and dining rooms(Elliot et al., 2009).

Cold Colours

Calmness, relaxation, and peace can be sent through cold colours. These colours have a dissimilar effect on the functionality of humans, especially if they are compared with warm colours.

Emotional and Psychological Effects: Cold colours create feelings of calm, tranquillity, and steadiness. An example would be blue, which is often used in places that are restful and peaceful, indicating a need for tranquillity, like bedrooms and healthcare facilities. This colour lowers stress and anxiety levels (Jacobs & Suess, 1975).

Cognitive Effects: Cool colours can also have mental effects, mainly on creative activity and solving problems. The research findings are such that the general population records improved creativity or complex decision-making when exposed to blue and green colours. These colours can soothe one into a state conducive to very abstract thought or creativity.

Physiological effects: Since cold colours lower blood pressure and heart rate, they induce a calming response and reduce physical stress. This quality makes them work best in places that are meant to be areas of relaxation and restoration, like spas and meditation rooms. (Devlin & Arneill, 2003).

The effects of warm and cold colours on human functions cut across the board to act through the emotional, cognitive, and physiological states. Knowing the effect of colour enables us to use it within every environment to purposefully desire an outcome: either to raise energy and focus or increase relaxation and creativity.

VIII. Dynamic Interior Wallpaper

By studying the colour-changing mechanisms in cuttlefish, octopuses, and chameleons, adaptations surfaced that could inspire solutions for real products. The difference between neuronal activation in cephalopods and hormonal activation in chameleons prompted consideration for autonomous colour change. Both groups use their ability to change colour to either blend into their environment or stand out.

Inspired by these natural processes, the concept of dynamic decoration emerged. Unlike an obvious application like camouflage, which aims to blend in, decoration generally seeks to stand out. A compelling application of this idea would be a dynamic interior wallpaper. This wallpaper utilizes special pigments that change colour based on ambient light and/or user interaction, creating an ever-changing visual experience. This can enhance the aesthetic appeal and mood of spaces such as living rooms, bedrooms, dining areas, as well as in commercial settings like hotels, restaurants, and offices. Public spaces such as art installations, galleries, and museums can also benefit from interactive and evolving designs, engaging visitors in new and innovative ways. Making different patterns is possible by including the multi-layer skin of cephalopods and chameleons next to the colour changing. The multiple layers make it possible to change the pattern the wallpaper shows.

Thermochromic change

Exploring different forms of dynamic wall decoration led to investigating materials like thermochromic pigments, which change colour based on temperature. This feature adds a deeper layer of functionality to the design. A thermochromic wallpaper for instance, can adjust its hues in response to variations in room temperature, creating subtle shifts evoking warmth or coolness depending on or even opposing the environment.

Patterns

Patterns can be created by the balls with a black and white side which turn using magnets. By putting these balls in a grid it could be seen as pixels in a screen and with this every pixel can be black or white. Combining this with the thermochromic change will create darker and lighter colours and so coloured patterns can be made.

Colour Range

The colour range applicable to the concept is based on the colour effect on humans mentioned previously in this paper. Warm colours will be used during cold temperatures to create a warmer feeling environment and cold colours will be used during warm temperatures to create a colder feeling environment. It does not physically cool or warm the environment but mentally it does let is feel cooler or warmer based on the colours displayed.

Technical Considerations

Ensuring the effectiveness and practicality of thermochromic wallpaper involves several technical considerations. The wallpaper must be crafted from high-quality materials that are capable of withstanding repeated temperature changes without degradation. It is essential to maintain the integrity and colour-changing properties over time. Utilizing non-toxic thermochromic pigments is also important for indoor environments, especially in homes.

For the black and white coloured balls, it is important that they don’t or minimally affect each other to not get distorted patterns. Other ways they could be made so that they purposely distort so it looks cool or different every time another pattern is created to keep an artsy and new vibe to each pattern of the wallpaper.

Moreover, the wallpaper should be easy to install and maintain, opposed to traditional wallpaper, with the potential for a protective layer to simplify cleaning and ensure longevity. Special pigments are needed that change colour in response to temperature variations, gradually shifting hues within the range of 10°C to 40°C.

By integrating thermochromic technology into interior design, spaces not only become aesthetically pleasing but also functionally responsive, catering to the evolving demands of modern living and work environments.

The concept

A visual representation of the concept's workings and how it will look in a room is shown down below. The first room shows a visualisation of a warm day where you can see that the wallpaper turns blue (shows cold colours) to let people perceive that it feels colder. The second picture shows the wallpaper on a hot day where it turns yellow/orange (warm colours) to give of the perception that is feels hotter. The pattern as seen is made up out of squares showing darker or lighter colours and creating a pattern.

Figure 8 Cold room warm wallpaper

Figure 9 Warm room cold wallpaper

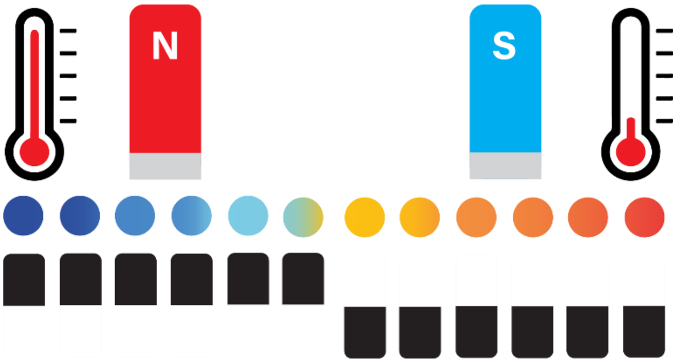

Figure 10 Working principle

IX. CONCLUSION

The study of colour-changing mechanisms in cuttlefish, octopuses, and chameleons reveals adaptations that can inspire real product solutions. By examining the neuronal activation in cephalopods and the hormonal activation in chameleons, biological principles have been identified that can be applied to develop dynamic materials and technologies responsive to environmental stimuli.

This paper has explored these biological colour-changing mechanisms, detailing the workings of chromatophores, iridophores, and leucophores. These insights have been translated into abstracted principles which in turn informed the development of a concept for adaptive wallpaper mimicking these natural processes, enhancing interior environments by positively influencing human moods.

The proposed dynamic wallpaper uses thermochromic pigments and a layered structure inspired by cephalopod and chameleon skin to create a responsive and aesthetically pleasing environment.

By changing colours based on ambient temperature and lighting conditions, the wallpaper can evoke emotional and physiological responses such as warmth (Red and Yellow tones) or coolness (Blue and Green tones).

Translating these biological principles into practical applications opens new possibilities in various fields. This Highlights the potential of biomimicry in modern design practices, to provide practical solutions and enhance human well-being.

X. FUTURE STEPS & DISCUSSION

To advance the development of dynamic interior wallpaper, the following steps are recommended:

Material Research and Development:

Conduct thorough research to identify and develop high-quality, durable materials that can withstand temperature fluctuations. Experiment with various non-toxic thermochromic pigments to ensure safety and longevity.

Prototyping and Testing:

Create prototypes of the dynamic wallpaper to test its performance in real-world conditions. Evaluate the durability, colour-changing responsiveness, and overall aesthetic impact. User feedback should be collected to refine the design and functionality.

Integration of Advanced Technologies:

Explore the integration of additional technologies such as light-responsive pigments and sensors that can further enhance the wallpaper's responsiveness to environmental changes. This could include incorporating smart home technology to control the wallpaper's colour/pattern via a mobile app.

Design Optimization:

Focus on optimizing the design of the rotating black and white balls to ensure they operate smoothly without unintended interference. Experiment with different patterns and configurations to achieve the desired visual effects.

Commercial Viability Assessment:

Conduct market research to identify potential applications and customer segments. Assess the commercial viability of the dynamic wallpaper, considering production costs, pricing strategies, and potential distribution channels.

Sustainability Considerations:

Investigate sustainable materials and manufacturing processes to minimize the environmental impact of the dynamic wallpaper. This aligns with the growing demand for eco-friendly products in the market.

Marketing and Awareness Campaigns:

Develop marketing strategies to raise awareness about the benefits and unique features of dynamic interior wallpaper. Highlight its ability to enhance mood and create a responsive environment, appealing to both residential and commercial customers.

Practical Considerations

For the dynamic wallpaper to be viable, several technical challenges must be addressed. The materials used must withstand repeated temperature changes without degrading. Non-toxic thermochromic pigments are essential for indoor applications, especially in homes. The wallpaper must be easy to install and maintain, potentially featuring a protective layer to simplify cleaning and ensure durability.

Additionally, the use of black and white balls that rotate to display different colours adds another layer of complexity. These balls must be designed to avoid unintended interference with each other, ensuring the patterns remain clear and distinct. Alternatively, designing them to create intentionally distorted patterns could add an element of surprise and uniqueness to the wallpaper, keeping the design fresh and engaging.

By following these steps, the concept of dynamic interior wallpaper can be transformed from a theoretical idea into a practical, market-ready product. This innovative approach to interior design not only offers aesthetic versatility but also enhances the well-being of occupants by creating environments that respond dynamically to their needs and preferences.

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XII. Figures