MANCHESTER 1824 The University of Manchester

Royal College of Art

MERC Exhibition: Colour Made Manifest

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COLOUR THAT LASTS

Nature-Inspired Dynamic Colour Adaptation

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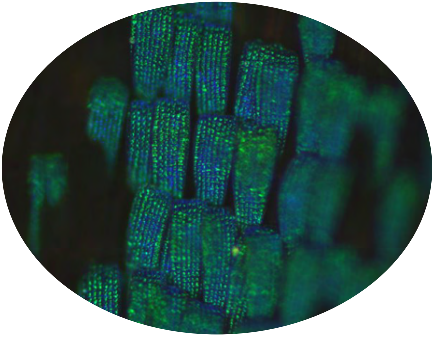
The Pump House Gallery, Battersea Park, London SW11 4NJ

Colour that Lasts Nature-Inspired Dynamic Colour Adaptation

Colour is the essence of our perception; it permeates our world with depth and diversity. It mirrors our emotions in both subtle and powerful ways. From the iridescent blue of the Morpho butterfly's wings to the fiery red of a sunset, colours evoke feelings and memories of experiences. In design and art, colour creates harmony, contrast, and emphasis, guiding our gaze and emotions. Understanding the science behind colouration mechanisms enables us to harness their potential, making them a significant aspect of creative expression and daily life. Carrying so much of the emotional connection, pigments and dyes are as important as the artwork itself. Such connection pushes artists and designers to create their unique colourants from different resources such as rocks, flowers or leaf extracts. However, artworks made with pigments are prone to fading – sometimes even within the artist's lifetime.

Nature, through evolution, has mastered the art of colour manipulation by creating characteristic structures that can purposely interact with light. Following nature's blueprints in our scientific research on structurally coloured materials, we exploit the materials' ability to self-assemble into periodic arrays with striking iridescent colouration, similar to those in butterfly wings and beetle shells. Using our research methods, our collaboration aims to transform the colouration in textiles. In this exhibition piece, to build structurally coloured pieces, we used additive manufacturing (3d printing), self-assembly, and surface engineering concepts that result in nature-inspired functionalities such as the ability to respond to environmental changes. Drawing inspiration from the colour-changing wings of butterflies, in this installation piece titled "Wings of Light", we explored the 3d printing of hydroxypropyl cellulose (HPC) into sequin-like features with pinholes of varying sizes and thicknesses. Presented in the form of an abstract butterfly, this work invites viewers to interpret the butterfly's stunning colours as a representation of transformation, diversity, and the intricate complexity of life. We experimented with different arrangements, connecting them with threads, referencing the large-scale installation "Unwoven Light" by artist Soo Sunny Park. The sensory interaction is revealed on the butterfly's surface, visualised by the thermochromic quality of liquid crystals, extending the microstructure of colour to the macro level. In this exhibition, our installation based on a butterfly demonstrates the potential of scientifically created structural colour as a tool for artistic expression and more. This work aims to showcase the profound interplay between art and science, inviting viewers to explore and appreciate the vibrant world of colour.

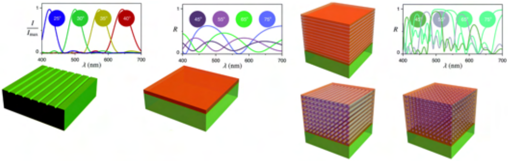
Optical Microscopy Image of a butterfly’s wing



Structural Colour

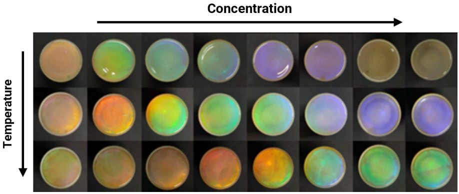
Structural colour is an intriguing phenomenon that arises from the sub-microstructural arrangement of materials that can readily interact with light rather than absorbing it (like pigments or dyes). When matter is ordered on the visible light length scale (from 200 nm to 800 nm), such as the ridges seen in butterfly wings or the multi-layers in nacre or the photonic structures on peacock feathers, light can interact with those regular arrays of matter. This constructive interaction with light can cause striking visual effects such as iridescence and metallic or opaque appearances. Unlike pigment-based colouration which relies on absorption of light at certain wavelengths, structural colours are produced by the interference, diffraction, or scattering of light waves. The study of structural colour deepens our understanding of natural beauty and inspires innovative applications in art, design, and technology, including the development of colour-changing materials and surfaces.

Light-matter interaction from periodic surfaces and structures- a diffraction grating like the blue ray CDs, Thin films like the soap bubbles and oil spilt on water and 3-dimensional photonic structures such as the natural opal stones.



Producing structural colours with liquid crystals

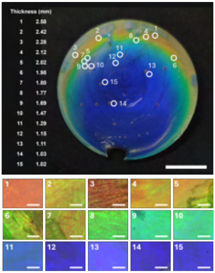
Effect of concentration and temperature on HPC



In this work we used a biopolymer extracted from plants called hydroxypropyl cellulose (HPC). HPC is a sustainable cost-efficient, and bio-compatible cellulose derivative that forms cholesteric liquid crystalline phases in highly concentrated water solutions that reflect light spanning the wavelength range from ultraviolet to visible and infrared. In liquid samples of HPC, the observed colour is a function of temperature and concentration. The colouration comes from the unique twisted crystal structures in HPC as given in the electron microscopy image. The highly ordered layers define the colour response and controlling the spacing of the between these layers is the key to control the final colour.

In our labs at the University of Manchester, we investigate the fundamentals of the liquid crystalline phase formation and manipulate both the printability and response of the HPC to different external stimuli. Such research enables us to develop functionalities including sensitivity to temperature, humidity, presence of other chemicals, electrolytes and even electric and magnetic fields. The playful colour palette is not only a source of beauty in itself, but also an exciting vehicle for artists to explore alternative colour sources and tap into the world of bio-inspired design.

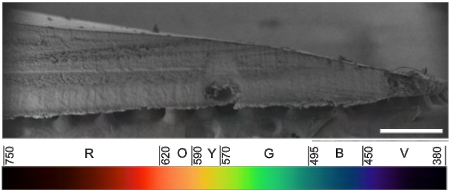
Effect of thickness on HPC



Through our research we investigated the fixation of certain colours and discovered that even simple steps in processing can yield different colouration.

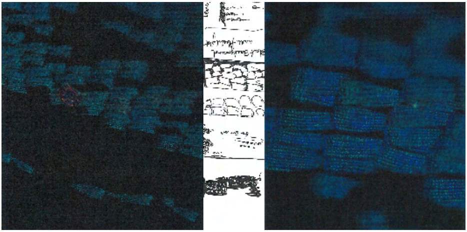
For example, during casting of the HPC on to a flat surface, if the surface is slightly tilted the polymer solution self-assembles to form layered structures following a thickness gradient. This change in the thickness creates an effect during the drying process, i.e. the thicker parts of the sample shift its colour to red and thinner parts shift the colour to blue.

The thickness gradient created during sample curing



The Design Concept

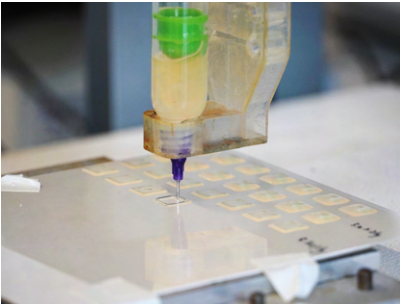
This art piece draws inspiration from the Morpho butterfly; not only from its colour but also from its structural patterns that display petal-like building blocks providing diversity, and beauty.



Our conceptual design reimagines the scales as the sequins

Wings of Light represents our experimentation on liquid crystal building blocks to reflect how light and shape affect our perception of an architectural structure. The main body of the installation is an abstract sculpture crafted from lightweight, textured textile materials. The abstract shapes are decorated with 3d-printed structurally coloured sequins, enabling the structure to change colours and patterns in response to the change in viewing angles. The installation piece rotates on the base to highlight this functionality to viewers. Through our collaborative work between the researchers (Dr Dumanli-Parry and Miss Ren) and designers (Miss Tan and Miss Zang under Dr Ozden-Yenigun's supervision), we explored the applicability and adaptability of nature-inspired scientific work to textile and soft matter interfaces.

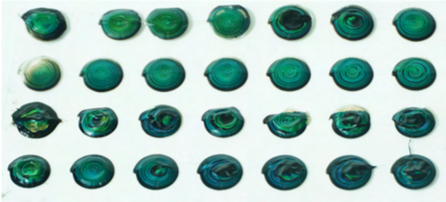
3d printing of the HPC



HPC's spontaneous ability to create colouration was exploited through blending with high contrasting agents such as carbon nanotubes. This is another bio-inspired idea we implemented in our work; butterfly wings and bird feathers owe their vivid colouration to the use of natural dark pigmentation caused by the melanin- a biologically produced compound that naturally presents dark pigmentation. Though the use of highly light absorbing pigments the intensity of the structural colour increases significantly. Via 3d printing and post-processing, the team created uniquely coloured sequins reminiscing the butterflies' wing scales.

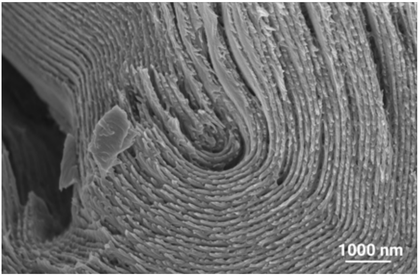
HPC sequins were produced through Direct Ink Writing (DIW), a simple 3d printing method in the additive manufacturing technology family. The DIW presented here involves extrusion-based deposition of HPC inks to create the defined shapes. This method utilises the rheological (flow) properties of HPC-based inks, allowing for the controlled fabrication of intricate patterns.

The colour response of the sequins was enhanced using an ultra-black background via the use of carbon nanotubes



The work conducted and the final products also have a clear focus on sustainability – the sequins found on the installation were produced through the use of highly abundant biopolymers capable of forming structural colours and green chemistry approaches.

Microstructure of the 3d printed HPC filaments captured by electron microscopy, showing highly ordered microstructure



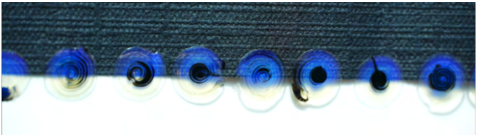
By manipulating the HPC-gel formulations as well as developing computer-assisted designs, 3d printers can be used to scale up our technology to create HPC sequins with desired shapes, thickness, and, thus, different colours for larger installations.

With their transparency and angle dependence, HPC sequins create a complex combination of colour through both reflection and transmission following the waving fabric.

HPC's visual appearance depends on the surface curvature, background colour, and observation angle

When viewed from the side, the colour observed in the sequins is mainly due to light transmission.

That is also why on a black background, the observed colour is blue (from reflection) while the colour is slightly yellow on a white background (from transmission).



Transforming our interactions with matter via bio-informed design

Life on earth represents the transformation of non-living compounds to such striking diversity of living matter over 3.8 billion years of evolution. During this process, natural selection and environmental factors ruthlessly purged the flawed designs. Despite the growth and promise of biomimetic and bioinspired approaches, the analogy to biological form or function is often superficial or largely figurative. A truly bio-informed approach requires deep collaboration between many disciplines from biologists to chemists to material scientists, applied physicists, engineers, designers and artists.

From the colour perspective, a significant percentage of traditional pigments used in several industries rely on synthetic and toxic compounds that have an extensive carbon footprint. Unfortunately, the newly emerging photonic pigments and coatings follow a similar trend; in most cases employing synthetic materials or manufacturing processes with high energy demands during production and are hard to recycle for further applications. To address this problem and achieve a more sustainable and colourful future, the self-assembly of HPC can help to produce custom-shaped photonic structures in an aqueous environment at low temperatures, thus replacing traditional photonic pigments with fully sustainable natural pigments.

The use of structural colours will not only pave the way for significant scientific advancements in areas such as the development of new colourimetric sensors, smart windows, and security labels but it will also revolutionise the artistic and design interpretation of colour. By utilising new forms of matter and introducing innovative scientific processing routes, structural colours will offer artists and designers novel opportunities to incorporate colour in various forms into their work. This interdisciplinary approach will challenge existing paradigms to create a tangible impact, expanding the creative boundaries and leading to the development of visually captivating and functionally enhanced products.

Fabrics that never fade may reduce the need for harmful dyes and allow fashion designers to experiment with dynamic, colour-changing fabrics. Home decor, including wallpaper, furniture, and decorative items, can benefit from the vibrant and long-lasting colours provided by structural materials, maintaining their appearance without fading. Their playfulness is only highlighted by the edibility of such pigments. Consequently, structural colours in food coatings can offer visually appealing, non-toxic alternatives to current artificial colourings, signalling freshness or enhancing the aesthetic appeal of food products.

While the HPC shown here is a promising material for creating structural colours, other abundant resources like chitin, silica or plasmonic nanoparticles that interact with light strongly are also investigated in our research group. Consequently, structural colours through self-assembly will expand the creative horizons of both scientific and artistic communities, fostering a deeper integration of colour into functional and aesthetic applications.

There are, however, still several challenges, including the fragility and water susceptibility of these sustainable materials, which can alter or degrade their colours in everyday use cases. Enhancing robustness, developing water-resistant coatings, and ensuring consistent quality in large-scale production are crucial steps for widespread adoption. Additionally, processing these materials on a significant scale cost-effectively remains a key challenge, as efficient mass production processes still require development. Despite these challenges, we believe that the ongoing research in this field could be crucial to making structural colours a mainstream, sustainable choice in a broad range of industries.

About the Team

Dr Ahu Gumrah Dumanli-Parry is an Assoc Prof in Bio-inspired Soft Matter at the University of Manchester, Department of Materials. Dr Dumanli-Parry's research team BioFuM focuses on understanding the "pattern formation" at the nanoscale and "structural colour" concepts in Nature and the adaptation of bio-inspired strategies for the development of colourimetric sensors and smart materials. She often collaborates with artists and designers to challenge the colour concept in matter and design.

Dr Elif Ozden Yenigun is a material scientist interested in nanoengineered textiles, smart wearables, and novel 3D textile composites. Her research focuses on developing cutting-edge textile-based materials, that enable the design of more novel and innovative engineered soft systems, surfaces and products.

Miss Hongning Ren is a PhD student in nano and functional materials, and a part-time artist. She likes everything bright and colourful and that is why both her science and art are full of striking colours emerging from structural colours. In her "spare time" she is pursuing the translation of her scientific work into real products with her supervisor Dr Dumanli-Parry to commercialise edible colours and sensors.

Miss Han Zang is a London-based artist, who creates textile art and installations, working in a mix of media: fabric, ready-made, photography and moving images. She usually situates handmade textile pieces with the practice of photography and film. Haunted by her working experience in urban architecture in China, her work constructs a psychogeography of her experiences in a violently shifting urban landscape.

Miss XiaoTan is an artist who predominately works with textiles. Following a degree in Fashion Engineering in China, she completed her Masters degree in Textiles at the Royal College of Art, London in 2023

Acknowledgements

Dr Tadeusz Balcerowski is an EPSRC Doctoral Prize Fellow at the University of Manchester investigating the use of cellulose-based chiral reflectors for IR applications. During his PhD in the BioFuM group, he researched the formation and modification of the cholesteric phases that paved the way for the stunning structural colours observed in this exhibit.

Mr Zekai Zhao is a material science & engineering undergraduate student from the University of Manchester, participating in a summer research internship under the supervision of Dr Ahu Gumrah Dumanli-Parry and Dr Tadeusz Balcerowski, investigating the optimisation of the 3d printability of hydroxypropyl cellulose.

Miss Lola Sodipo is a PhD researcher specialising in sustainable material development, currently exploring structural colour with cellulose and biochemical strategies for textile recycling. Holds a background in material science with a specialisation in textile technology from the University of Manchester.

Wings of Light artwork emerged from a cross-disciplinary research and design collaboration effort (Animate Matter in Design) funded by the University of Manchester's Research Pump-Prime Award by the Creative Manchester and Sustainable Futures themes.