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Light as matter: natural structural colour in art

Cédric Finet[1]✉

Structural coloration is the production of colour by micro- or nano-structures fine enough to interfere with visible light. Structural colouration is responsible for the blues and greens of many animals, as well as for the gold, silver, and some purple-pink colours. These are often saturated and might be extremely shimmering and/or iridescent. The study of structural coloration is an active and interdisciplinary field of research where biology, physics and engineering meet. However, the fascination of humans for stunning structural colours is broader than the framework of science. Here, I provide a series of examples of the use of natural structurally coloured materials in art across the ages and places. I argue that the view from ethnozoology is necessary to gain a comprehensive understanding and appreciation of structural coloration.

Introduction

"All that glitters is not gold" warned Shakespeare of the illusion of glossiness (Shakespeare, 1600). Nonetheless, humans are attracted to shiny things. Some studies have shown that a glossy surface finish influences colour preference (Gelineau, 1981), and even the brilliance of the store display can positively impact the product on sale (Zhu and Meyers-Levy, 2009). This preference is thought to have existed since prehistoric times (Henshilwood et al., 2001), and might result from an innate need for freshwater (Meert et al., 2014).

While natural colours are predominantly pigmentary, many saturated colours are produced via selective light scattering by integumentary nanostructures, or sometimes a combination of both. "There are nuances between the blacks. I paint with black but I'm working with light. I'm really working with the light more than with the paint" playfully says the French painter Pierre Soulages (Siegal, 2019). Artists and engineers are endeavouring to recreate structural colours, but it is yet in nature, far from paintbrushes and workbenches, that the most vivid structural colours come to light. It is especially true for iridescent colours that change hue with illumination or viewing angle. In animals, blue colours are mostly structural (Bagnara et al., 2007; Umbers, 2013). We can cite the unrivalled metallic shades of the blue morpho, the sumptuous iridescent train of the male peacock, the warning blue rings of the deadliest octopuses, or even the brilliance of the blue coral-reef damselfish. Green colours often result from the interaction between pigments and nanostructures (Shawkey and D'Alba, 2017), which can lead to extreme glistening iridescent green hues in insects (Vukusic et al., 2000; Seago et al., 2009; Wilts et al., 2012a, 2015) and in birds (Durrer, 1986; D'Alba et al., 2012). But the range of structural colours does not stop there: extravagant reddish pink in birds (Durrer, 1986), metallic silver across the animal kingdom (McKenzie et al., 1995; Holt et al., 2011; Neville, 1977; Ren et al., 2020), metallic gold in insects (Neville, 1977; Kilchoer et al., 2019), and mother-of-pearl in nacreous molluscs and

[1] Department of Biological Sciences, National University of Singapore, Singapore, Singapore. ✉email: cedric.finet@ens-lyon.org

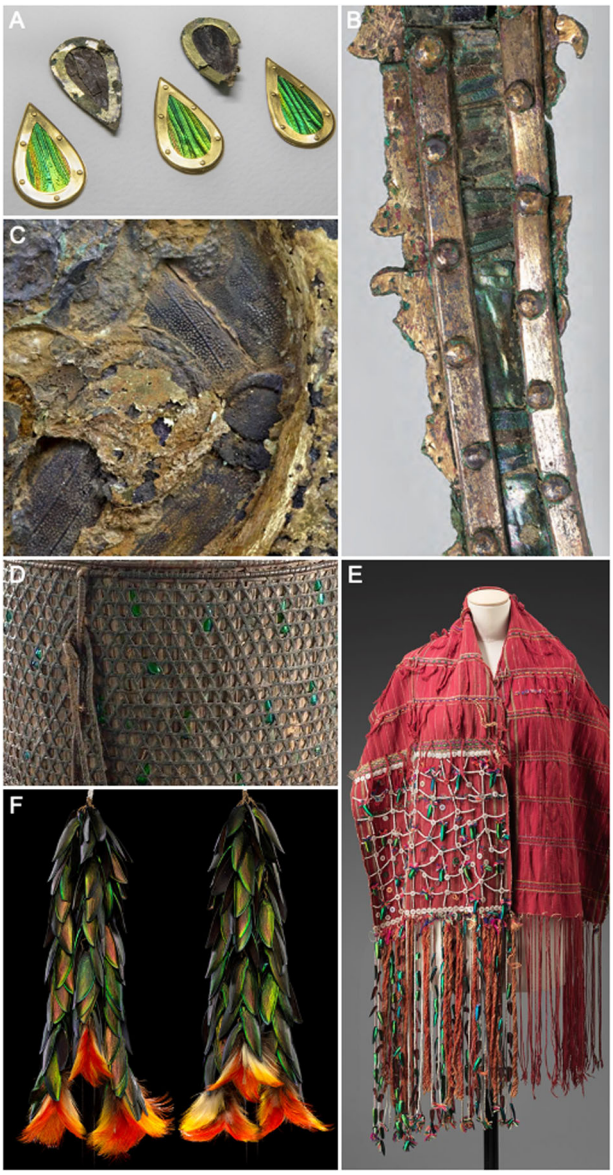

Fig. 1 Ancient and tribal uses of beetle elytra. A Ornaments from tomb No.44 in Gyeongju, and replicas, 5th century. Photo: Gyeongju National Research Institute of Cultural Heritage. **B** Saddle bridge from the gold crown tomb in Gyeongju, 5th century. Photo: National Museum of Korea, Seoul. **C** Horse tack found near the Funabaru burial mound in Koga, 6th-7th century. Photo: Koga Historical Museum. **D** Karen basket in bamboo and rattan, early-mid 20th century, Thailand. Asian Civilisations Museum, Singapore. **E** Karen singing shawl, mid-late 20th century. Museum of Fine Arts Boston. **F** Shuar ear ornament, ca. 1930, Ecuador. National Museum of the American Indian, New York.

butterflies (Jackson et al., 2010; Stavenga, 2021) are a few examples of the richness of the colour palette.

Understanding structural colouration is seen as one of the key frontiers not only in biology but also in physics and engineering (Cuthill et al., 2017). In the last few decades, studies have produced a wealth of data identifying the nanostructures and the physics underlying structural colouration in animals. Meanwhile, engineers build on this knowledge to develop new bio-inspired materials. As for biologists, the current and future challenges aim to understanding how these biophotonic nanostructures are built during development (Saranathan and Finet, 2021; Lloyd and Nadeau, 2021). However, it would be a mistake to limit the study of structural coloration to these disciplines. The goal of the present review is to tackle structural colouration from a totally different angle, namely the view of ethnozoology. The study of colour has become a familiar territory in social sciences and humanities. Under Michel Pastoureau's pen, the six primary colors became a collection of authoritative books that trace how culture impacts our perception of colour (Pastoureau, 2000, 2008, 2013, 2016, 2019, 2022). Our knowledge, however, concentrates on pigmentary coloration, and tends to subordinate colours to pigments. Moreover, noncolorimetric aspects to describe the colour (iridescence, saturation, glossiness) are sometimes more important than the colour in itself, as is the case in the Hanunóo and Candoshi societies (Conklin, 1955; Surrallés, 2016). Human uses of structurally coloured biomaterials, especially in art and craft, are therefore little known and should deserve wider attention. Here I present a series of examples of how structural—and often iridescent—colours, naturally found in insects, birds, molluscs and fish, have contributed to daily life embellishment across the ages. By combining past and recent studies within biophotonics, art history, archaeology and literature, the article aims for more transdisciplinary investigations, with the goal of building an anthropology of structural coloration.

Iridescent beetles and beetlewing

"Eternity is in the glitter on the beetle's wing"—W.B. Yeats

Jewel beetles (Buprestidae) are well-known for displaying remarkable glossy and iridescent colours produced by multilayer cuticle reflectors, chirped broadband reflectors, or circularly polarising helicoids (Seago et al., 2009; Sharma et al., 2009). Weevil beetles (Curculionidae) can also exhibit vivid structural colours when they bear scales that contain three-dimensional photonic crystals (Parker et al., 2003; Welch et al., 2007; Galusha et al., 2008). In beetles, structural colouration encompasses many biological roles in communication, mating, and camouflage (Seago et al., 2009; Wilts et al., 2012b; Kjernsmo et al., 2020). As visual animals, humans were attracted by such natural colours and developed beetlewing—a traditional craft technique that uses beetle elytra in textile embroidery or decorative fine arts. This technique originated in Asia, especially in Thailand, Burma, India, Korea and Japan.

Oldest artefacts. A prehistoric petroglyph of buprestid found in central Iran attests to the historical fascination of humans for jewel beetles (Kolnegari et al., 2020). The ancient Egyptians, however, were among the first ones to make good use of their structural colours. Crushed elytra of buprestid beetles, probably *Steraspis squamosa*, served as coloured powder to decorate a cane that belonged to the pharaoh Tutankhamun (ca.1341–1323 BC) (Keimer, 1938). The presence of buprestid beetles embalmed in tombs, and represented in amulets or on furniture adornments, reinforces the idea these insects were held in high repute in ancient Egypt (Kritsky, 1991). The second oldest known decorative use of jewel beetles dates back to the kingdom of Silla in ancient Korea. In Gyeongju, golden-edge jewel beetle ornaments were excavated from a late fifth-century tomb presumably belonging to a noblewoman (Fig. 1A); and jewel beetle elytra were identified on contemporary saddle flaps in the gold crown tomb (Fig. 1B). On a side note, the endemic jewel beetle *Chrysochroa coreana* was registered as a natural monument in South Korea in 2008 (Kim, 1978). In southern Japan, a horse tack decorated with jewel beetle elytra were also unearthed at an offering pit close to the Funabaru burial mound (Fig. 1C). This horse tack, dating to the late 6th to early 7th century, is reminiscent of the artefacts

Fig. 2 Beetlewing in the Victorian and Contemporary periods. A *Delighted at the Prospect: the Nayika Mudita* by Kripal, ca. 1665. San Diego Museum of Art. **B** Textile for application to a garment, elytra, metal spangles and gold-wrapped thread, ca. 1855, India. Victoria and Albert Museum, London. **C** Dress of cotton muslin, gilded metal thread and elytra, 1868–1869, Britain. Victoria and Albert Museum, London. **D** Beetle wing dress for Lady Macbeth designed by Alice Laura Comyns-Carr, 1888. Smallhythe Place, Kent. Photo: Steve Cottrell. **E** Queen Sirikit's jacket designed by Pierre Balmain, 1985. Queen Sirikit Museum of Textiles, Bangkok. **F** Wajima painting combining *tamamushi* and sprinkled painting. Photo: Unedaya Inc., Wajima. **G** Royal Palace in Brussels decorated by Jan Fabre, 2002. Photo: Belgian Tourism Board for Flanders & Brussels.

found in Korea, and highlights the exchanges between these two countries in ancient times (Park, 2007). Another noteworthy Japanese national treasure is the miniature *tamamushi* shrine that stands inside the Horyuji temple in Nara Prefecture. Attached to the edges of the plinth and the dais are bands of openwork bronze under which the metallic green elytra were applied. Built in the mid-7th century, the shrine contains a statue of Guanyin and small rows of seated bronze Buddhas and was probably made in Japan under the influence of Korean artisans from the kingdom of Baekje (Fenollosa, 2007). The word *tamamushi* refers to the Japanese jewel beetle *Chrysochroa fulgidissima*, whose elytra glow with different colours depending upon the light angle (Schenk et al., 2013). There is only a short step from the original meaning to the idea of *tamamushi-iro* that describes the deliberately ambiguous language of politicians.

Tribal art. The Karen people, who live in Burma and Thailand, use jewel beetle elytra (*Sternocera aequisignata*) to decorate everyday objects like bamboo field hats and storage baskets called *ku* (Fig. 1D). On funerals, young unmarried women from certain groups wear a long red and white striped cotton stole known as singing shawl. For single Karen youths who live in distant villages, funerals are indeed opportunities to meet each other. The shawl in question is adorned with inexpensive materials such as buttons, grain and glass beads, yarn pom-poms and beetle wings (Fig. 1E). The beetle wings are often attached on the fringe, swinging and tinkling with the girl's movement (Hinton, 1962); the jingling being important to repel evil spirits.

In his notes of travel in Ecuador, the geographer J.L. Hermessen mentions that the Shuar people fabricate necklaces with beetle elytra: "woven cane baskets, containing the men's finery—necklaces of berries and seeds of various kinds, and of the bored canine teeth of monkeys (*Cebus*), and decorative tassels of the feathers of Cuvier's toucan (*Ramphastus Cuvieri*) and the iridescent wing-cases of certain beetles (*Chrysophora chrysochlora* and *Euchroma gigantea*)" (Hermessen, 1917). In addition, elytra are used to fabricate ear ornaments for men (Fig. 1F) and shrunken heads—severed and specially prepared human heads used for trophies, ritual, or trade purposes.

The Naga People live in the mountains in Northeast India and in Burma. Their decorative use of jewel beetles is rare and restricted to the Angami, the Rengma, the Zemi, the Sema and the Konyak groups. The elytra, mainly from *S. aequisignata and Chrysochroa vittata*, found their way to the Nagas via trade from Southeast Asia. The privilege of wearing beetle wings represented a social elevation that could only be achieved by men, through head-taking and ceremonial feast-giving. Examples of cloaks, helmets, ear- and shoulder ornaments and necklaces have been described (Hodson, 1911). However, women assumed the right to wear certain garments based upon their husbands' or fathers' accomplishments, such as wrap skirts and breast cloths embellished with rows and fringes of elytra. More specifically, beetle elytra were sometimes used to mimic green eyes on wooden burial effigies (Woodthorpe, 1882).

Indian cradle. Art historians attest to beetlewing being in use in Basohli miniature paintings as early as the 17th century (Ohri, 2001). Besides its characteristic brilliant colours and line, a distinctive feature of Basohli school was indeed the use of green elytra to depict and mimic emeralds (Fig. 2A). However, beetlewing is likely much older and stems from the use of elytra in the domestic sphere. In line with this idea is the age-old tradition of beetle-wing embroidering *torans* (door hangings) in Rajasthan (Rivers, 2014).

The Mughal period (1526–1858) produced the most impressive works. Beetle-wing embroidery was performed all over India, but it became extremely sophisticated at the Jaipur court in the 18th and 19th centuries (Crill, 1999; Jain, 2016). The elytra were seldom used as it is but rather cut up into sequins and generally paired with gold embroidery. Examples of exquisite garments include, among others, turbans, sashes, jamas, shoes, sarees, cholis, and fans.

In Europe, contemporary to the Mughal India, Charles Germain de Saint-Aubin, embroidery designer to King Louis

XV, mentions a dress using animal fur and pieces of the iridescent wing of the so-called Spanish fly—the blister beetle *Lytta vesicatoria* (Saint-Aubin, 1770). The use of iridescent insect pieces will however remain limited in Western countries, and it was not until the Victorian era that beetlewing finally buzzed around Europe.

Victorian appetite. Victorian England and Europe showed a strong interest in curiosities from foreign 'exotic' lands. This is in India, which was occupied by the British Empire from 1757 until 1947, where the English discovered beetle-wing embroidery. Englishwomen in India had been wearing beetle-wing embroideries on white muslin dresses since the 1780s (Libes, 2021) before such garments reached England in the late 18th century. Embroideries were made in India with local styles, then exported as a flat textile to be made into Western clothing once it arrived at its destination (Fig. 2B). Around 1820, the high British demand for elytra dresses transformed beetle-wing embroidery (Libes, 2021). Contrary to Indian embroidery, the English style preferred to sew the whole elytron over the use of cut pieces, reinforcing the glimmering effect (Fig. 2C). Moreover, motifs that do not belong to the Mughal tradition soon appeared such as the imitation of live beetles. From unique pieces made for the Mughal elite, the beetle-wing embroidery became not only less fine, but the designs also became standardised. The rise of beetle-wing in India led to the development of the beetle-wing route since falling into disuse. The Cyclopedia of India (1885) refers to beetle wings as an article of commerce, harvested in Arakan (Burma), transported to Akyab (presently Sittwe), and then sent to Calcutta, from where the wings were further distributed.

Although it became less common, Englishwomen continued to wear elytra into the 1920s. A noteworthy gown is the Peacock dress of Lady Curzon during the coronation of King Edward VII and Queen Alexandra in 1903. The gown was made of gold wire woven peacock feathers, whose eyespots were embellished with beetle elytra. As for the theatrical and ball costume designers, beetle elytra were a valuable material. The most flamboyant instance is undeniably the costume dress worn by the actress Ellen Terry as Lady Macbeth (Fig. 2D), further immortalised in John Singer Sargent's canvas. This dress inspired Oscar Wilde to say, not without irony, that "Lady Macbeth seems to be an economical housekeeper and evidently patronises local industries for her husband's clothes and servant's liveries, but she takes care to do all her own shopping in Byzantium" (Robertson, 1931).

Contemporary creation. Nowadays, Thailand is the chief market for buprestid beetle elytra which are a by-product of eating insects (Hanboonsong, 2010). In the early 1980s, the Queen Sirikit of Thailand decided to save the traditional craft and established a beetle-wing art department at the Queen Sirikit Institute (Fig. 2E). The art has been successfully revived and jewel beetle farming turns to be an alternative source of income for some communities in Thailand. Ellen Terry's costume inspired more recent dresses seen in movies, such as the dress of the wicked queen in *Snow White and the Huntsman* (2012) and the green damask gown in *Elizabeth: The Golden Age* (2007). In Japan, only a few *urushi* masters (lacquerers) in Wajima still execute the art of *tamamushi* (Fig. 2F). In 2002, the artist Jan Fabre and his aides adorned the Royal Palace of Brussels with his Hall of Mirrors, covering the ceiling and chandeliers with the use of 1.4 million iridescent green elytra (Fig. 2G). In 2013, elytra made their entrance in Haute Couture with the *On Aura Tout Vu* designers Livia Stoianova and Yassen Samouilov and their collection "Cosmic Beetle".

Other body parts and whole beetles. Ornaments that incorporate iridescent beetle femora, horns, pronota, and mandibles have also been documented. A necklace made of beetle legs excavated from ancient Egyptian tombs traces back the use of iridescent legs to before our era (Keimer, 1938). Green figeater beetle (*Cotinis mutabilis*) leg jewellery was found at Bears Ears National Monument in southeastern Utah. The two necklaces, which date from 70 to 60 BCE, are associated with the early agriculturalist Basketmaker II society and were likely prestige goods and status symbols (Terlep et al., 2023). In his *Histoire Naturelle*, the French entomologist Pierre André Latreille mentions that women add *Geotrupes stercorarius* iridescent femora to their *coiffure*. Among aboriginal societies, the Shuars string the iridescent beetle legs into necklaces and bracelets; men in some Melanesian tribes wore necklaces of beetle legs they used as currency (Fig. 3A); the Nagas incorporate iridescent fringes made of beetle femora into their adornments (Fig. 3B).

Not only parts of the insect but the whole individual can be used. The Karen people sometimes tie green iridescent beetles to a string to amuse babies. Naga young men wear neck ornament of strung glass beads and iridescent beetles (Fig. 3C). In Papua New Guinea, men of the Kalam Tribe add hundreds of green scarab beetles on their hat; and those living in the Mount Hagen use elaborate adornments for religious and courtship activities (Fig. 3D). Moreover, iridescent green beetles, when contrasted with red and yellow materials, can easily draw attention to the face of the wearer (Strathern and Strathern, 1971). In the early 19th century, the priest and naturalist Juan Ignacio Molina mentions the taste of Chilean and Brazilian ladies for necklaces made of gold (Chrysomelidae) and diamond beetles (Curculionidae) (Molina, 1809). In Rio de Janeiro, gentlemen sported the diamond beetle *Entimus nobilis* as brooches. The business being very lucrative, many owners did not hesitate to send their slaves out to catch insects in the vicinity of the city. The most gifted slaves could catch five to six hundred beetles per day (Cowan, 1865). In jewellery, one of the most vivid examples is Lady Granville's beetle parure made by Phillips Brothers in 1884–1885. Not the detached wings, but the whole dried specimens of South American weewils (*Lamprocyphus augustus*) were mounted in gold (Fig. 3E). Another unique piece from Hispaniola, worthy of a cabinet of curiosities, is a ring adorned with a weevil *Tetrabothynus regalis* and the verse from Virgil's *Georgics* "wondrous pageant of a tiny world" (Fig. 3F).

Passion for jewel beetles took on a new dimension when they were worn and kept as pets. The entomologist Charles Howard Curran mentions that "*C. ocellata* of India and Ceylon […] is frequently kept by the ladies of India and used to decorate their clothing on festive occasions. After the celebration the beetles are bathed and fed and quartered in little cages where they are tended with a gentleness consonant with their importance" (Curran, 1945). A similar fashion was reported in the Philippines, where the ladies of Manilla used to keep the metallic green cetoniid beetle *Agestrata luconica* "as pets in bamboo cages and carry them about with them wheresoever they may go" (Baird, 1858).

Early humans used beetle iridescence to adorn objects, but also because these ornaments are thought to possess some of the beetle's spiritual energy. The Naga people used to keep skulls for the life force contained within. By wearing vibrant colours that survive the death of the beetle, the Nagas probably believe they can express such an inherent force (Rivers, 1999). In Papua New Guinea, Highlanders consider that wearing something bright not only expresses a quality of wealth but also attracts abundance (Strathern and Strathern, 1971). In the Amazon Basin, the Shuars

Fig. 3 Diversity of iridescent beetle body parts used as adornments. **A** Man's necklace of green beetle legs, collected in 1911, Saint Matthias Islands. British Museum, London. **B** Naga Konyak man's shoulder-ornament, ca. 1920, India. Photo: Michael Backman Ltd, London. **C** Young man's neck ornament, glass beads and beetles, collected in 1936, India. Pitt Rivers Museum, Oxford. **D** Headband, plant material and jewel beetles, New Guinea. Weltkulturen Museum, Frankfurt. **E** Lady Granville's tiara formed of weewils *Lamprocyphus augustus*, 1884–1885, Britain. British Museum, London. **F** Ring adorned with the weevil *Tetrabothynus regalis*, 18th century, West Indies. Natural History Museum, London. Photo: Lucie Goodayle/courtesy of Maxwell Barclay.

believe their ornaments enhance and protect their soul power (Stirling, 1938). Special ornaments are fashioned as objects of power and are restricted to certain members of the community during ceremonies carried out to enter into a relationship with the spirits (Karsten, 1923). The Japanese even say that putting *tamamushi* in your dresser will make your love come to fruition. However, humans are not the only ones to appreciate glittering beauties. During courtship, male bowerbirds build a structure and decorate it with bright-coloured objects in an attempt to attract a mate—metallic beetle wing cases being often part of the arsenal (Hansell, 2009). Birds too are famous for their vivid structural colours, and feathers have been particularly used in decorative art.

Vivid structural coloured bird feathers and featherwork

Iridescence is a common component of courtship displays in birds, and males can use the changing colour effect to attract females (Hill, 2006). Iridescent avian plumages are most commonly produced by an orderly arrangement of melanosomes in the feather' tiny branch-like filaments—known as barbules (Saranathan and Finet, 2021). Quetzals, ducks, and hummingbirds are some examples of birds that evolved such a strategy to generate angle-dependent colouration. In some rare cases, iridescence is due to the periodic matrices of air and keratin within barbs as found in manakins (Igic et al., 2016). To a lesser extent, kingfishers have structural coloured green and blue feathers that are iridescent. However, iridescence is produced by the cortical envelope of feather barbs and occurs only under illumination with a narrow-aperture light source (Stavenga et al., 2011). In nature with wide-field illumination, the feathers appear non-iridescent because of the isotropic nature of the spongy medulla inside the feather barbs (Noh et al., 2010). Sensitive to vivid and/or iridescent structural coloured feathers, humans developed featherwork—the working of feathers into a work of art or cultural artefact. Featherwork was developed in many places in the world, but this technique was particularly elaborate among the peoples of Oceania, Mexico, and China.

Tribal art. Feathers are part of human self-adornment, status and other values (Diamond, 1986). The most colourful and extravagant feathers are often in demand and among them the vivid structural coloured ones. In many Amazonian tribes, the non-iridescent blue and green feathers of diverse macaws and parrots are interwoven into headdresses. Tribes in the Highlands region of Papua New Guinea add green parrot and iridescent blue bird-of-paradise feathers to their traditional headdress (Healey, 1990). Among American Indians, the Alaskan people confected parkas with metallic green-violet, iridescent throat feathers of the pelagic cormorant (Rivers, 1999), the Karok female shamans wore headbands with hummingbird pelts (Rivers, 1999), and bluebird feathers have also been found in diverse artefacts. Cultures on Pacific Islands were admirers of bright structural coloured plumage. In Austral Islands, headdresses, which were the preserve of the chiefs, included the green feathers of the junglefowl (Kockelkoren et al., 2020). In New Zealand, feather cloaks were a sign of high social status, and could be made of diverse types of feathers, including kiwi and iridescent blue bush pigeon feathers (Rivers, 1999).

Featherwork in China. *Tian-tsui*, literally 'dotting with kingfishers', is an ancient Chinese art that incorporates feathers of kingfishers as an inlay for fine art objects (Jackson, 2001). This tradition can be traced back to the Spring and Autumn period (771-476 BC), with a description of the King Ling of Chu wearing "a leather hat, a feather robe from Qin, a cloak made of blue kingfisher feathers, leopard-skin boots" (Milburn, 2020). The development of *tian-tsui* continued during the Tang and Song dynasties (618–1279) and reached its height in the Ming and Qing dynasties (1368–1912) before disappearing with the Chinese revolution in the 1940s.

Sources from the Han to Tang periods mention that the kingfisher birds and/or feathers were already items of trade, being harvested around Guangdong and in northern Vietnam and then brought to central and northern regions (Roderich, 2012). In contemporary Tang poetry, kingfishers became associated with female elegance, as exemplified in Du Fu's poem *Fair Ladies: A ballad* (Owen, 2016):

Fig. 4 Featherwork in art. A Antique hairpin, 19th Century, China. Photo: Nalin Singapuri. **B** Hanging screen, kingfisher feathers, 17th–18th century, China. Palace Museum, Beijing. Photo: from Gu et al. (2021). **C** Reproduction of the Moctezuma II's 'headdress', quetzal feathers, Mexico. National Anthropology Museum, Mexico City. Photo: Steven Zucker. **D** *The Mass of Saint Gregory*, feathers on wood with touches of paint, 1539, Mexico. Musée des Amériques, Auch. **E** *Weeping Virgin* by Juan Cuiris, hummingbird and parrot feathers, ca. 1590–1607, Mexico. Kunsthistorisches Museum, Vienna. **F** Earrings, stuffed hummingbirds and bronze, ca. 1875. Victoria and Albert Museum, London. **G** Feather pelerine, ca. 1835, India. Te Papa Museum, Wellington.

On the third day of the third month, the weather is fresh,

by the waters of Chang'an are many lovely ladies.

Appearance voluptuous, their mood remote, pure and true,

their skin's texture, delicate and glossy, flesh and bones well-matched.

Embroidered gossamer gowns shine in the end of spring,

Peacocks done in gold appliqué, unicorns of silver.

And what do they have on their heads? —

Kingfisher-feather fine leaf tiaras dangling in tresses to lips.

Later sources from the Tang and Song periods state that 'people dry the flesh of these birds and sell it', an activity which is always associated with southern China (Roderich, 2012). In his *Zhu Fan Zhi*, the historian and politician Zhao Rugua indicate that kingfisher feathers came partly from the Zhenla territory, i.e. the Khmer lands, and that China forbade the use of kingfisher feathers in 1107, but merchants, faced with the continuing demand, neglected the rules. Another source mentions that the trade in feathers exceeded the route Southeast Asia-China with several ports around the Indian Ocean, especially in Thailand and Bengal (Roderich, 2012).

Tsian-tsui is complex and delicate: micron-sized feather fibres are pasted on support and adjusted to obtain the desired colour effect (Fig. 4A). It is only recently that the ancient Chinese craft revealed its secrets. Mass spectrometric analysis identified bovine collagen proteins as the adhesive used to bind the feathers to the support (Zhu et al., 2019). Bovine glue was obtained by prolonged boiling of connective tissue present in the skin, the bones and other cartilaginous parts of the animal. Moreover, spectroscopy performed on a Qing dynasty hanging screen (Fig. 4B) revealed the presence of several layers beneath the kingfisher blue feathers (Gu et al., 2021). Two of them are coloured black and red, due respectively to the addition of carbon black and ochre pigments to the adhesive. These coloured backgrounds were used to fine-tune the colour of the feathers. Thus, the interaction between structural and pigmentary colours was known for many centuries before biologists coin it with technical terms (Shawkey and D'Alba, 2017).

Featherwork in Mexico. The Aztecs were famous for their use of feathers in decorating all sorts of clothing and accessories. Feathers were valued similarly to gems and circulated through trade and tribute between the Aztec Empire and neighbouring countries (Berdan, 2006). Featherwork was performed by the *amanteca*, a privileged class of specialised craftsmen until it starts to decline in the mid-17th century when the old masters disappeared. The most sought-after feathers were those of the quetzal (*Pharomachrus mocinno*) that is endemic to humid forests ranging from southern Mexico to Panama, far from the highland valleys of central Mexico. The domestication of the quetzal was not feasible, the feathers were caught on wild individuals that were subsequently released. Quetzal feathers served to fabricate the *quetzalpanitl*, an elite ceremonial banner, and other headdress-like featherworks whose exact function is controversial (Fig. 4C).

Linguistic studies suggest that, in addition to the brightness of quetzal feathers, Mesoamerican were sensitive to their iridescence. In the *Florentine Codex*, the tail feathers are described as 'green, herb-green, very green, fresh green, turquoise-coloured. They are like wide reeds: the ones which glisten, which bend. They become green, become turquoise' (Russo, 2011). The awareness of colour-changing materials might partially explain the interchangeable use of the terms blue and green in contemporary speakers of Uto-Aztecan languages (MacLaury, 1997). It is noteworthy that Aztecs were using similar lexical methods to describe non-iridescent shifting colours in nature, suggesting that they were not classifying iridescent colours in a specific category. On the contrary, iridescence formed a unique and well-differentiated category of colouration for the invading Spaniards in the 16th century. Europeans have indeed a long

history of philosophy questioning the nature of sight, the nature of colour, and the link between perception and objective reality (McMahon, 2017). As such, the Spanish historian Antonio de Herrera y Tordesillas is not mistaken when he compares the quetzal's colours with highly iridescent satin (*tornasol*) fabrics: "The *totoquetzal*, which the rulers of the Indios put to death those that killed it: they are smaller than pigeons, with green feathers, like *tornasol*, and those of the tail so long that they are used in their celebrations, employed like we do the Ostrich feathers: they take them, and deplumed, they let them go" (Herrera y Tordesillas, 1615).

Besides quetzals, feathers came from other wild birds such as hummingbirds, cotingas, macaws, oropendolas, parrots, emerald toucanets, troupials, or domesticated birds such as ducks and turkeys. Hummingbird plumage was particularly appreciated for "such beauty especially because it acts like taffeta, of *tornasol* colours, that shades and makes lordly the feathers of this bird that are green, blue, golden, the colour of an ember or of flames" (Tezozomoc, 1994).

Evangelism added Christian themes to featherwork, which accelerated the introduction of Mexican featherwork across Europe and Asia. The *Mass of Saint Gregory* is the oldest dated featherwork with a Christian subject (Fig. 4D). This is a gift to Pope Paul III, whose 1537 decree defended the rights of indigenous people. Early featherworks were mostly released from the mission school of San José de los Naturales in Mexico City, and they did not include hummingbird feathers. Changes occurred when the epicentre of featherworking moved to the cities of Michoacán in the West, where hummingbirds were more abundant. The *Weeping Virgin* by Juan Cuiris is an example of the use of hummingbird feathers from Michoacán (Fig. 4E). These objects are all the more remarkable that their iridescence creates the illusion of animation when the observer kneels down in front of it—a visual manifestation of the doctrine of transubstantiation for some authors (Russo, 2011).

Besides conveying religious doctrine, featherwork images were also a way to introduce exotic birds from the New World, more accurately than conventional media (Fig. 4F, G). This is especially true for hummingbirds which could not be transported alive across the Atlantic due to their unique feeding behaviour. As such, the hummingbird became irremediably associated with religion as the "tiny bird that has painted plumage, of many colours, with which, mixed and recomposed with admirable artifice and subtlety, the Indians make images of saints, and other things" (Ximenez, 1615). More importantly, the iridescence of hummingbird feathers served as perfect vehicles to capture certain visual qualities that paint could not. In his *Comentarios de la Pintura*, the 16th-century Spanish art writer Felipe de Guevara praises Mexican featherworkers who "have brought to Painting something new and rare, which are the paintings [made with] the feathers of birds, changing [from] clothing to flesh". Hummingbird feathers were thus of great use to represent the mutability of the colour of human subjects. During the 17th century, the same qualities were found in mother-of-pearl to depict the changing colours of faces with the effect of emotion: "In his face, one saw indistinctly, /the living mother-of-pearl of lily and rose" (Lopez de Zarate, 1648). Mother-of-pearl is another example of iridescent natural material that was used in decorative art.

Iridescent mollusc shells and mother-of-pearl

Mother-of-pearl, also known as nacre, is an organic–inorganic composite material produced by many molluscs, including bivalves, cephalopods, and gastropods. Mother-of-pearl lines the inside of the shells and constitutes pearls. It is composed of stacks of transparent aragonite tablets separated by organic materials, including chitin and proteins (Song et al., 2003; Meyers et al., 2008; Sun and Bhushan, 2012). The iridescence of nacre is caused by multiple reflections through the stratified structure of nacre (Pfund, 1917; Rayleigh, 1923), and the thickness of these layers, as well as the viewing angle, determine the palette of colours (Snow et al., 2004; Ozaki et al., 2021). Contrary to pigmentary colouration that fades away over time, structural colouration can persist millions of years after the death of the organism. As such, exceptionally preserved iridescent nautiloid shells from Late Carboniferous have been discovered in Oklahoma (Seuß et al., 2009). By its iridescence and lustre, mother-of-pearl became a first-class material for personal adornments and fine artworks such as lacquer work and marquetry.

Oldest artefacts. Shell jewellery has been found in cemeteries in Central Europe dating from the Neolithic period (Séfèriadès, 2010). The Ancient Egyptians were using mother-of-pearl as early as the sixth dynasty (ca. 3200 BC), as attested by burial shells bearing cartouches of that period (Ogden, 1982). Nacre was also used by the Mesopotamians from at least 2500 BC (Fig. 5A). The biblical *Book of Esther* mentions the "mosaic pavement or porphyry, marble, mother-of-pearl, and stones" in the Persian king Ahasuerus' palace (486–465 BC).

Tribal Art. Objects using mother-of-pearl can be so diverse that it is difficult to summarise them (Rivers, 1999). The artefacts are sometimes cut out of the shell, and thus entirely made of mother-of-pearl. This is the case for some amulets found worldwide; the waist ornaments (*tikams*) worn by high-status men of the Igorot people in the Philippines (Fig. 5B, C); some traditional tribal necklace pendants in Papua New Guinea, in the Philippines, and in South America; some mourner's dresses in Polynesia; and some lancets in Kenya. Alternatively, mother-of-pearl can be inlaid into wood, or other material like coconut shell, to embellish decorative or utilitarian pieces. Wooden masks are such decorated objects where the use of mother-of-pearl is sometimes limited to the teeth (e.g., Balinese *topeng* masks) and/or the eyes (e.g., the Aztec mask of Xiuhtecuhtli). We can add headdresses, canoe prows, bowls, and altars from Pacific Islands and Oceania; sword grip and scabbard from Africa and the Philippines; pipe bowls and heishe bead necklaces from Native American tribes. Polynesians and then the Maori fabricated trolling lure fish hooks that comprise a polished abalone shell (Fig. 5B, C). The lure would be dragged behind a small boat to attract the fish with the iridescent mother-of-pearl shell shining in the sun to emulate the scales of a smaller fish.

Mother-of-pearl and powerful entities. In Aboriginal Australian cultures, the Rainbow Serpent is a deity able to bring life through its association with water, as well as destruction when angry. The Rainbow Serpent, a term coined by the English anthropologist Alfred Radcliffe-Brown (Radcliffe-Brown, 1926), is not always linked with a rainbow but is systematically associated with bodies of water that exhibit an iridescence of colours (McElroy, 1955). It is almost natural that iridescent organic and mineral material, like mother-of-pearl, would enter the ritual toolkit involving the Rainbow Serpent (Elkin, 1930).

The relationship between iridescence, material culture and beliefs has been thoroughly investigated by the Owa people in Eastern Solomon Islands. For the Owa people, optic phenomena, such as light reflection, diffraction, and iridescence, that occur in the atmosphere or on the surface of certain organisms and minerals, is the manifestation of powerful entities' effective

Fig. 5 Mother-of-pearl in art. A Box found in a royal tomb in Ur, inlaid lapis lazuli, mother-of-pearl, shell and stone mosaic, ca. 2500 BC. British Museum, London. **B** Maori trolling lure fish hook, 18th-19th century, New Zealand. Photo: Michael Backman Ltd, London. **C** Bontoc *tikam*, early 20th century, Philippines. Photo: Primitive Inc., Chicago. **D** Mother-of-pearl betel wooden box, ca. 1820, Thailand. Photo: Michael Backman Ltd, London. **E** Mother-of-pearl casket, 16th century, India. Asian Civilisations Museum, Singapore. Photo: Erlend Bjørtvedt. **F** Antique Damascus mother-of-pearl inlaid bride's chest, walnut wood, silver thread and camel bone, ca. 1930, Syria. Photo: Jean Bachoura. **G** Carved mother-of-pearl relief depicting the Nativity, early 19th century, Palestine. Victoria and Albert Museum, London.

capacity to intervene in the world (=their *mana*) (Revolon, 2012). By fabricating magical and ritual artefacts that reproduce those phenomena, Owa craftsmen aim to invoke the generative power of the associated *mana*. Mother-of-pearl from cowries, pearl oysters and nautiluses is particularly used (Revolon, 2018).

Mother-of-pearl work in Asia. In China, the combination of mother-of-pearl and lacquer has been practised since the late Shang dynasty (12th century–11th century BC) as evidenced by fragments unearthed from royal tombs in Anyang (Garner, 1979). But this technique was significantly enhanced only from the Tang dynasty (618–907) onwards. The first connoisseur's manual on the collecting of antiquities, Cao Zhao's *Geguyaolun* (1388), highlights notably the good quality of mother-of-pearl inlaid pieces of furniture made during the Sung period (960–1279). Over the 14th century, Chinese craftsmen refined their style by using smaller and thinner pieces of mother-of-pearl, and from the 16th century, they increased the diversity of mother-of-pearl colours to create an illusory picturesque effect.

In time, the combination of mother-of-pearl and lacquer was transmitted to neighbouring countries via trade routes. Mother-of-pearl inlay appeared as soon as the 8th century in Korea, where it became a dominant form of art until today. Korean masters initially copied Chinese models before developing new techniques and their own styles. Korean lacquerwork blossomed and reached its artistic peak during the Koryo dynasty (935–1392). According to the *Koryo-sa* annals, the Chinese court commissioned in 1272 an official Korean workshop to produce mother-of-pearl and lacquer manuscript covers to store the sacred Buddhist scrolls belonging to the Chinese empress. This illustrates the high esteem in which Korean art was held. After the invasion of Korea by the Japanese, Korean wares strongly influenced the Japanese mother-of-pearl works of the Momoyama period (1573–1615). However, Japanese pieces differed in that the shell used was thinner. Before their annexation by the Japanese, the Ryukyu Islands had a well-established mother-of-pearl inlaid lacquer industry, propelled by the natural abundance of mollusc shells in the area. The creation of the Shell-works Office in Okinawa in 1612 highlights the importance of this local activity (Garner, 1979).

Mother-of-pearl lacquerwork has also a long history in Burma, Vietnam, and Thailand. In Thailand, stucco inlaid with coloured stones, bits of ceramics or mother-of-pearl is reported for the Dvaravati period (Van Beek and Tettoni, 1989). The heyday of Thai mother-of-pearl inlaid lacquerwork was probably between the 16th and 18th centuries. A remarkable example is the door of the ordination hall of Wat Phra Chetuphon in Bangkok which illustrates scenes of the *Ramakien* —one of Thailand's national epics (Wenk, 2000). Mother-of-pearl inlay was also used by Thai manuscript makers to adorn manuscript chests and cabinets, manuscript covers, or seldom the text itself by using mother-of-pearl inlay on black lacquered sheets (Toomey, 2013). Thai lacquerware is usually classified into two groups according to ethnic origin: the Ayutthaya-Bangkok style with the use of gold and mother-of-pearl inlay on a black background (Fig. 5D); and the Lanna style with a colour scheme of red painted on black lacquer. During the early Bangkok period (1782–1824), mother-of-pearl inlay work was so popular that high-ranking members of the royal family were appointed to oversee its production in a bureau known as 'the Department of Mother-of-Pearl Inlay' (McGill, 2005). However, after the 18th century, the art of lacquerwork declined for the benefit of painting and sculpture.

Today, the city of Udaipur in Rajasthan is an important centre for mother-of-pearl inlay. However, it was Gujarat, Rajasthan's neighbouring state, that emerged as a centre of mother-of-pearl works in the early 16th century. In *The three voyages of Vasco da Gama, and his Viceroyalty*, the Portuguese historian Gaspar Correia relates how in 1502 the King of Melinde presented Vasco da Gama with a "bedstead of Cambay, wrought with gold and mother-of-pearl, a very beautiful thing". The workshops' commissions came from both the local Mughal royalty, who desired inlaid thrones, doors, and everyday artefacts, and foreign markets. Early records give an indication of the esteem in which the Indian mother-of-pearl work was held in Europe at this time, including that of a list of Manuel I's the wardrobe (1522)

mentioning "a casket from India inlaid with mother-of-pearl with 18 sheets of silvers", Francis I of France receiving a mother-of-pearl bed in 1529, and a casket belonging to the Elector of Saxony in 1602 (Jaffer, 2004).

Gujarati mother-of-pearl work comprised two types of work: objects either made of or covered in mother-of-pearl (Fig. 5E), and wooden items covered in a dark mastic with inlaid pieces of mother-of-pearl. The production of this second group was probably restricted to Northern Gujarat. In his *Ain-i Akbari*, the 16th-century Persian historian Abu al-Fazl mentions the existence of mother-of-pearl industry in Ahmedabad. Furthermore, there is evidence of mastic-inset and mother-of-pearl decorated domed cenotaphs in the contemporary tombs of revered Sufi Shaykhs next to Ahmedabad (Jaffer, 2004). However, the inspiration for Gujarati mother-of-pearl production remains unclear. A possibility is that European merchants imported Korean or Japanese wares to Western India, where the technique was emulated by local craftsmen.

In the Indian subcontinent, mother-of-pearl is also used as semiprecious 'stone' in the art of *parchin kari*, litteraly inlay work in Persian. This technique consists of inlaying semi-precious, and even precious gemstones, into designs carved into marble. It derives from *pietra dura* which was developed in Italy in the 16th century and was probably brought to the Mughal court by Italian craftsmen in the 17th century (Koch, 2006). A stunning example is the mother-of-pearl inlaid tomb of Itmad-ud-Daulah in the Taj Mahal.

Mother-of-pearl work in the Middle East. Mother-of-pearl inlaid furnishings evolved from a long tradition in the Middle East to become an important decorative art under the Ottoman Empire. Few early examples survive, but Marco Polo and Byzantine envoys reported inlaid thrones and other furnishings in the courts of Central Asia in the 13th century. In Egypt, at the same time, mother-of-pearl was an important decorative element in Mamluk woodwork and mosaics, embellishing important buildings like the Khanqah and Mausoleum of Sultan Barsbay built in 1432 in Cairo.

During the flowering of Ottoman art in the 16th and 17th centuries, artisans in Istanbul's imperial workshops produced works of astonishing splendour, contrasting the mother-of-pearl with tortoise shell, ivory, ebony and other luxurious materials. The portable throne built in 1610 for Sultan Ahmet I, and a Koran box from the mausoleum of Sultan Selim II, are two self-explanatory examples. A fascinating aspect of the 16th- to 18th-century Ottoman artwork is the large size of the mother-of-pearl plaques, larger than the pieces produced in the later 19th century in Turkey or elsewhere in the Middle East.

In the late 18th century, the Ottoman court developed a taste for foreign baroque and rococo designs, leading to a disinterest in mother-of-pearl inlaid furniture. But ironically, in the meantime, a vogue for Orientalism and exotic Middle Eastern styles swept across Europe. Islamic-inspired residences were erected in England and France, including Alexandre Dumas's Château de Monte Cristo, built in the Moorish style. Benefitting from the growing trade with Europe, both Damascus and Cairo emerged as major centres for inlaid furnishings. Over the centuries, the Syrians had perfected an intricate inlay technique in which the underlying wood surface is almost entirely encrusted in mother-of-pearl ornamentation, creating an elegant shimmering effect (Fig. 5F). With this technique, Damascene craftsmen met with enormous success both locally and internationally. In an illustrated review of the 1893 Columbian Exposition in Chicago, the writer Hubert Howe Bancroft states that "Turkish rugs and pearl inlaid furniture from Damascus take the lead among the collective exhibits from all the countries over which the star and crescent fly." As for Cairo craftsmen, they favoured darker, more iridescent mother-of-pearl set into ebonised wood. Marvellous examples of this ebonised look, together with an inlaid *mashrabiyyah* screen, can be seen in Cairo's Manyal Palace.

Globalisation of mother-of-pearl. At first mother-of-pearl shells were thought to be restricted to the Persian Gulf, the Red Sea and the India-Sri Lanka coast; then European explorers discovered their existence in tropical waters throughout the world. In the 16th century, raw mother-of-pearl from the Philippines would travel in galleons to Mexico and then across land to ships bound for Spain, and the French East India Company was importing raw shells from its colonies. Palestine also became a hub for mother-of-pearl craft after Franciscan monks introduced the art to Bethlehem in the 16th century, and craftsmen carved religious souvenirs to sell to pilgrims (Fig. 5G) (Yidi Daccarett et al., 2005). Mother-of-pearl reached its peak of popularity in the 19th century, while it could be found on any kind of everyday object. It is also at that time the fashion of wearing mother-of-pearl buttons reached its height. In France, the town of Méru developed a major manufacturing centre and became the capital of button making. In 1895, the first American pearl button factory opened in Muscatine to mine clam shells from the Mississippi River in Iowa. In England, the Pearly Kings and Queens popularised mother-of-pearl buttons when they began adorning their outfits with them.

Iridescent fish scales and *essence d'orient*

Many fish have silvery iridescent skins to camouflage themselves and communicate with conspecifics (Fujii, 1993). The different layers of the fish skin, from the external scales to the deeper dermis, can reflect light. Thus, the glossy appearance of the adult fish results from iridophores situated in the epidermis of the exposed margins of the scales (Nüsslein-Volhard and Singh, 2017), but once the scales are removed, the silver sheen remains due to the underlying tissue layer called *stratum argenteum*. In all these reflecting layers, platelets of guanine crystals with a thickness of ~100 nm can pile up (Denton and Land, 1971; Herring, 1994; Levy-Lior et al., 2010), thus forming a broadband multilayer reflector that produces an iridescent silvery colouration (Levy-Lior et al., 2008; Jordan et al., 2012). Some species, such as the European sardine and the Atlantic herring, have two types of guanine crystals in their skin that differ in having the optical axes either parallel or perpendicular to the crystal plane. When the two types of crystal are present, light is reflected at every angle, and the drop in reflectivity usually caused by polarisation is avoided (Jordan et al., 2012). Iridescent fish scales turned out to be a material of choice for embroidery, as well as a raw material to make the pearlescent preparation *essence d'orient*.

Fish scales used in appliqués or decorative objects. Fish scale embroidery was popular in 19th-century Britain, and resulting pieces of work were often exported (Morris, 1962). Thus, in December 1853, the Boston antislavery fair advertised "elegant fish scale ornaments for ladies, something entirely new" in the newspaper *The Liberator*. As regarded as the most iridescent, carp, goldfish and perch scales were preferably chosen. The scales were scraped from the fish, soaked in cold water until they become soft enough to be malleable, then pierced with a needle near the base. Fish-scale embroidery was often worked on silk, satin or velvet cloth, to create floral or other motifs. While many artefacts are associated with Victorian England, fish scale embroidery was developed worldwide with known examples in

Fig. 6 Butterfly and fish scales in art. A Brooch ornament made of fish scales, 1881, Barbados. Victoria and Albert Museum, London. **B** Matzah Bag, Girl's Orphan Home, ca. 1910, Jerusalem. Velvet embroidered with metallic thread and couched fish scales. Derfner Judaica Museum, Riverdale. **C** Apron, ca. 1890, Bohemia. National Czech & Slovak Museum & Library, Cedar Rapids. **D** Broken French faux pearl, glass bead coated with *essence d'orient* and wax filling inside 19th century. Musée Itinérant de la Perle Ancienne en France. Photo: Guy Maurette/courtesy of Marie-José Opper. **E** Glass-stained window from St. Paul's Episcopal church made by Lori Precious with butterfly wings, 2003. Photo: Lori Precious. **F** *Thistle, reptile and butterflies* by Otto Marseus van Schrieck, 17th century. Musée de Grenoble. Photo: Jean-Luc Lacroix. **G** '0 to 1' by Maximilian Prüfer, butterfly scales arranged under a microscope, 2018. Photo: Maximilian Prüfer. **H** *Hanging basket of flowers with butterflies* by Henry Dalton, viewed through a microscope, made of butterfly scales. Museum of Jurassic Technology, Culver City.

Australia, Europe, the Caribbean (Fig. 6A), Israel (Fig. 6B), New Zealand, and the United States. In Bohemia, where carp farming was a well-developed activity, villagers used fish scales to decorate folk costumes called *kroje*. The scales were cut into various forms before being sewn along with beads to represent flower patterns (Fig. 6C). In Azores Islands, local handicrafts include flower arrangements made from fish scales. On Santa Catarina Island, fish scales are used to make jewels whose "effect at night is that of the most brilliant set of pearls, and they are as much superior in splendour to the small specimens of fish-scale flowers manufactured in Ireland, and exposed in the Sydenham Palace, London, as the diamond surpasses the glisten of cutglass" (Kidder and Fletcher, 1866). Here, I cannot end this section without mentioning the folk artist Albert Smith who resided in St. Augustine, Florida in the early 1900s. Using fish scales, Smith created small mock-ups as the facsimile of the St. Augustine cathedral, but it is his house entirely covered with drum fish scales that made him famous. "Everybody in town knows Albert Smith, a coloured genius, who is perhaps alone as an architect who builds houses out of fish scales" (Jordan, 2012).

Processed fish scales. In the 16th century, Venetian glass blowers developed a technique for creating imitation pearls by filling tiny iridescent glass beads with wax. They could have gone one step further by putting old recipes into practice. Indeed, the mid-15th century manuscript *Segreti per Colouri* already explained how to make false pearls using shells and fish scales to give them lustre (Merrifield, 1849). It was not until the 17th century that Monsieur Jacquin, a Parisian rosary maker, rediscovered the potential of fish scales. The legend goes that Jacquin, while vacationing in Burgundy, watched his housekeeper scale a fish over a bowl of water and he noticed the subsequent iridescence of the water. Jacquin later discovered that mixing ammonia with the scales of the bleak led to a paste that imitates the lustre of pearl (Sauzay, 1884). *Essence d'orient*, nothing more than guanine crystals in suspension, was born. Because toxic mercury was then used by beadmakers, *essence d'orient* became providential. Initial trials determined that the pearlescent effect was not lasting when applied on the surface of glass beads. Jacquin found the solution in coating the inside of glass-blown spheres filled with wax (Fig. 6D). These 'Parisian or French pearls' met with real commercial success (Opper and Opper, 1996). The trade secret was closely guarded until 1716 when the French scientist Réaumur discovered the trick. In France, the production of false pearls became such an activity that its illustrated description appeared in the *Encyclopédie* published by Diderot and d'Alembert between 1751 and 1772 (Opper and Opper, 1996). Men specialised in blowing the glass beads, while women filled them. In his novel *Marthe, histoire d'une fille* (1876), the French writer Joris-Karl Huysmans gives the eponymous character the profession of faux pearl maker. *Essence d'orient* was also a good fit for cosmetics. In the 1920s, it was part of nail polishes and its use will extend to many make-up products like lipsticks, eyeshadow and eyeliners (Sabetay and Hunsdiecker, 1961).

Structurally coloured butterfly scales and lepidochromy

Butterfly wings display vivid structural colours that originate from tiny chitinous scales covering the wing surface. The diversity in colours is directly linked to the evolution of diverse optical nanostructures of wing scales (Lloyd and Nadeau, 2021; Prakash et al., 2022). For example, while the blue scales of the Blue Pansy have simple lower surface reflectors (Thayer et al., 2020), the green scales of the emerald-patched cattle heart contain internal complex 3D photonic crystals covered by a thick lamellar structure (Michielsen and Stavenga, 2008; Poladian et al., 2009). Structural colouration in butterflies has been proposed to act as conspecific signals (Rutowski et al., 2007; Bálint et al., 2012), as mate choice criteria (Robertson and Monteiro, 2005), and as a

proxy for direct and indirect mating benefits (Rajyaguru et al., 2013).

Butterfly wings have been used as natural material in contemporary artworks. The American artist Lori Precious recreates existing stained-glass windows with colourful butterfly wings (Fig. 6E). In a more abstract manner, the Mexican artist Gabriel de la Mora arranges pieces of wings according to their chromatic palette, allowing repetition, geometry and symmetry hit their mark. Despite the tiny size of wing scales (~100 µm long), some artists used the scales as raw material. In his *sottobosco* paintings, the 17th-century Dutch painter Otto Marseus van Schrieck sometimes directly transferred real butterfly scales on the canvas instead of painting them. This is the case for *Thistle, reptile and butterflies* that displays a peacock butterfly made of its own scales. The blue colouration of the ocelli is known to be structural, and the blue is still visible on van Schrieck's piece of work (Fig. 6F). However, in-depth analyses of the residual blue have revealed the presence of lapis lazuli pigments (Berthier et al., 2008), showing that van Schriek had to "embellish" reality. Indeed, the double-pass technique to transfer natural scales required the use of varnish that likely annihilated the blue interference colour. Since then, the technique of transferring has greatly improved. The German artist Maximilian Prüfer made sumptuous butterfly prints on white or black paper. Making good use of the differential colouration between the two sides of the morpho scale, Prüfer drew microscopic patterns of scales on glass support (Fig. 6G). Before him, the English scientist and micrographer Henry Dalton created stunning micromosaics made entirely out of the scales of butterfly wings from all over the world (Fig. 6H). In the *Popular Science News* dated from August 1886, a microscopist tells of painting microscopic slides: "The representation, when looked at with the naked eye, can scarcely be seen at all. It simply looks like a small shot. The bouquet, when you look at it through the instrument, contains, as you can discover, 82 distinct flowers of various shades and colours […] The entire bouquet, including all the flowers, leaves, etc., was made from the scales and hair of Brazilian butterflies. The dust from the wings of the butterflies was picked up and placed in position by Henry Dalton […] Although Dalton was dissipated, he excelled most of his imitators in his peculiar line of art […] This is what I call one of the wonderful achievements of the century."

Conclusions

Why limit oneself to one material at a time? It has been reported that women on Santa Catarina fabricate artificial flowers made with beetle elytra, fish scales, sea shells, and feathers (Kidder and Fletcher, 1866). In *Victorian Jewelry*, Nancy Armstrong mentions a French tulle gown strewn with beetles, butterflies, spangles, and mother-of-pearl. The Pitt Rivers Museum owns a Victorian fan with a carved ivory handle, macaw feathers and swansdown, two stuffed hummingbirds, featherwork roses and wired foliage decorated with beetle wings…

We can wonder why natural structural colours, and not artificial ones, were used in decorative arts and crafts. The answer is simply that iridescence—the "unnamed colour, such as that observed on the doves neck" of the French Renaissance writer François Rabelais (Rabelais, 1534)—is unique and hard to reproduce. As such, the colourations of the morpho butterfly and the Japanese jewel beetle were long considered a painter's challenge, until the development of paints with embedded light interference flakes (Schenk and Parker, 2011; Schenk et al., 2013; Schenk and Stavenga, 2020).

Fashion also moves toward the use of synthetic, bio-inspired structural colours. In 2010, the dressmaker Donna Sgro made a garment using Morphotex. Developed by Teijin Limited Japan, this fabric is woven from unstained structurally coloured synthetic fibres that mimic the microstructure of morpho scales. The Fall/Winter 2015–2016 collection of the Belgian designer Dries Van Noten featured clothes adorned with 3D blue-green paillettes, which are reminiscent of jewel beetle elytra. By recreating natural iridescence, it is to wonder if humans show creativity, technology, or pure hubris.

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Additional information

Correspondence and requests for materials should be addressed to Cédric Finet.