

Biomimetics: Imitating Nature's Best Ideas to Create Sustainable Textiles

Anna Eynon

2004102

Surface Pattern Design

Catherine Hammerton

Word count: 4690

This independent project will focus primarily on the use of biomimicry within the fashion and textile industry. Nature can play a huge role in the innovation for new, sustainable textiles and I will unpack this through the ideas of Janine Benyus and the work of designers such as Julian Melchiorri.

Humans have been being inspired by nature for many years. From making shelters based on the forms of tree canopies, to computer systems being based on plant cells. The results of nature-based innovation is apparent in day-to-day life (Adam Scott, 2013).

Biomimetics is the imitation of natural biological systems. The term biomimicry was introduced by author and naturalist Janine Benyus in 1997. It refers to the “rapidly growing discipline that identifies, analyses and adapts natural strategies to solve technological problems”. Biomimicry is not just design that copies nature, it is design that understands the mechanisms in nature’s abundance of solutions, then uses that understanding to solve problems (Harman, 2013, p. 18).

In *Biomimicry: Innovation Inspired by Nature*, Janine Benyus states that doing things the way that nature does can have the potential to change the way that we grow food, harness energy, make materials, heal ourselves, grow business and store information. She describes biomimicry as ‘innovation inspired by nature’ (Benyus, 2002, p.2), in other words nature has a powerful influential role in order for us to introduce and create new ideas and inventions. In a biomimetic world, we would function in the way that animals and plants do, using sunlight and simple compounds to manufacture biodegradable fibres, plastics, ceramics and chemicals.

One of the core ideas within biomimicry is survival. Realising that organisms have adapted over billions of years to survive in their environments through evolution is important, because clearly they have learned what works best. Janine Benyus (1998) says that “We realised that all our inventions have already appeared in nature in a more elegant form and at a lot less cost to the planet”, Biomimicry is recognising that nature knows best, and has the key to survival, so the question is why are we not copying what nature is doing, and has been doing? The inspiration is right in front of us. It is worth realising that we may not need to come up with new ideas, as the best ideas might not be ours, but the best ideas have already been invented (Biomimicry Institute, 2022).

During a trip to the V&A museum, I came across a piece of work called “Exhale” by Julian Melchiorri. It is a chandelier that is formed of ‘Bionic Leaves’, the leaves hold living cells called microalgae. Algae are photosynthetic organisms and produce roughly half of our atmospheric oxygen as a whole. (Masojídek et al., 2013). The microalgae are fed water, and with sunlight they absorb carbon dioxide and produce oxygen, and therefore purify the air that we breathe.



Figure 1. *Exhale* by Julian Melchiorri

Julian Melchiorri's aim within design has a social and environmental ethos, looking to create solutions for related issues, such as sustainability and pollution. As an engineer as well as a designer, he explored how advances in engineering combined with biotechnology can be applied to architecture and everyday objects to improve our quality of life. "Exhale" follows the design principles of biomimicry; replicating the functions within nature, in this case photosynthesis within a leaf to create new, sustainable design features. Melchiorri's bionic leaves are very adaptable, they can be applied to the rooftops of building or even the exterior walls. But, for his residency at the V&A, he questioned how he could adapt this design into an indoor environment so that it was suitable for the V&A's space and the visitors within it. After exploring the V&A's space, he thought of the idea to make the world's first bionic chandelier. The chandelier was installed in front of a large window, in a busy stair well so that it can function to its best ability.

Exhale takes its appearance from nature, and was inspired by the Art Nouveau and Islamic Art collections in the V&A which also have a nature focussed style. Islamic art demonstrates geometry mixed with natural patterns like botanicals and flowers.

Continuing his biomimetic approach to introduce nature's efficient technologies into the man-made, Melchiorri has conducted experiments with the aim to make photosynthesising materials and explore the possibility of their applications. Silk Leaf has been the first outcome of this, as a prototype, it has the potential to introduce how photosynthesising materials can have an impact on our everyday lives. Silk Leaf is made of a biological material, mainly composed of silk protein and chloroplasts. In the same way that the bionic leaves perform, the Silk Leaf absorbs carbon dioxide and releases oxygen with organic compounds, due to the chloroplasts inside the silk protein and its photosynthetic ability. Light and water is a necessity to enable photosynthesis, so another technology has been introduced that delivers water to the chloroplasts, much inspired by how a

normal leaf would work. The water also has the ability to remove chemical residues and sugars through osmosis, and also introducing the idea of energy generation, another naturally occurring process that can benefit us within our technologies.



Figure 2. *Silk Leaf* by Julian Melchiorri

The level of oxygen generation has the potential to increase depending on the amount of algae, sunlight and water that is embedded into the fibre technology. Ultimately, the quantity of chloroplasts within the silk will affect the levels of photosynthesis that takes place (Melchiorri, 2014). Melchiorri (2014) notions towards a nanotechnological approach to further improve chloroplast's photosynthetic efficiency. Recent scientific studies have shown that nano-bionic interventions on chloroplasts increase their photosynthetic efficiency by 49%. He suggests that further research surrounding this area and on genetic modification could make a huge improvement on their efficiency.

Melchiorri's work explores a new concept of living objects. We can recognise the importance of plants, inside and outside the home because they photosynthesise and allow us to live, and breathe pure air. But, Melchiorri's innovations allow us to use the benefits of plants in domesticated products that we would already use day-to-day such as lighting, as he has already shown. These possibilities are hugely interesting for the future development of the Silk Leaf textile which could extend its use into performance wear, outdoor gear and interior spaces. The Silk Leaf could make revolutionary changes to the benefits of performance wear, especially in areas with lower oxygen levels like in high mountains. Imagine a raincoat, tent and sleeping bag that purifies the air around you where oxygen is low. The application to sportswear has the potential to fuel cyclists and athletes with oxygen while performing.

Silk Leaf has more scope to be used within interior settings. Building up on the benefits within performance wear, using this innovation within the home for textile application could be an amazing discovery. If the Silk Leaf is applied within domestic settings on items such as lampshades, curtains, furniture and upholstery we can all be living in homes, or working in offices where the air we breathe is pure. We can better improve our overall health as a population, especially in areas where air pollution is a big problem in large cities. The products would need to be accessible to all, ideally what would be found in a home anyway so lampshades, curtains and furniture would be ideal

targets for the Silk Leaf. It is important to note the functionality of the silk leaf, to be more suitable for the fashion and interior market the appearance of the silk leaf would have to be disguised to become more adaptable into wearable or desired elements within the home. This has not been seen from Julian as of yet but this doesn't mean it isn't in sight for the future. Julian himself suggests that his innovations should be used in many different applications where the level of carbon dioxide is particularly high, or where oxygen is needed, such as inside ventilation systems. He visions these to be a part of our indoor environment and urban environment to better improve our health and maintain a sustainable environment (Melchiorri 2014).

Demand for durable and functional textiles that are manufactured in a sustainable way is high. This has created an opportunity for technology to be integrated into textile manufacturing. The aim is to introduce stain repellent, wrinkle free, electrical conductivity and static elimination to fibres without reducing their comfort, flexibility and texture (Yetisen et al., 2016). Initially, the human need for textiles and clothing was related to protecting us from elements of nature, for example weather and cold temperatures. Conventional textiles provide the basic need for us to keep warm, be comfortable and maintain dignity. Following this, the main drive for our selection of clothing became aesthetically lead. Clothing has become used to demonstrate wealth and status. In addition to this, people's particular fashion choices are a way of self-expression. Nowadays, people subconsciously express themselves through what they wear every day and clothing has gone beyond that basic need of shelter (Yilmaz, 2018).

Creating a world where smart textiles become a majority of textile consumption, will be beneficial to us and the planet. Sustainability within products that we use and clothes that we wear has been a worldwide area of concern, and we know that attitudes have to be changed. By producing smart textiles that demonstrate higher qualities, such as being carefully made, better durability and longer lifespans, we can drastically reduce the amount of textile waste in landfill.

Scientists are looking towards nature for waterproof material innovation, the lotus leaf is known for its superhydrophobic surface. The lotus effect refers to the self-cleaning properties that the lotus flower holds, this is due to the ultrahydrophobic surface of the leaf. This means that it is very difficult to get wet, and therefore difficult to get dirty as the surface repels water. Water droplets pick up the dirt particles due to the micro and nanoscopic surface structure (Jordan, 2016).

Technologies similar to how the lotus leaf works are imbedded within some performance wear. EVODry is a waterproof technology developed by Marmot for outdoor gear that provides protection against the rain (Marmot, 2022). Their water-repellent features rely on AquaVent technology in which the fibres are bonded at the molecular level to stop leakage. Also, a Durable Water Repellent (DWR) permanent finish is applied to the fibres and not just the surface of the fabric as this would make it likely to break down and weaken over time. AquaVent increases the durability of the fabric so that the wearers are protected from the weather for a much longer time, also without the need for reapplication of the DWR (Casual Geographical, 2020).

There are many products on the market that can be applied to clothing so that they become waterproof. NikWax is a treatment that extends the life of all weatherproof fabrics by restoring and protecting the waterproof qualities. It contains elastic water-repellent polymers that bond to the fibres, whilst leaving spaces in between to maintain the breathable qualities (Nikwax, 2022). These waterproof products that are, either in treatment solutions or gear that you can buy with the

technologies already imbedded within them, all perform in the same way that the lotus leaf does. When force is applied to the fabric, such as rain hitting the surface, the water resists contact with the water-repellent fibres and slides off.

It is reassuring to know that technologies can be imbedded into our fashion in order to firstly, provide to our needs. In this case, relying on waterproof and weatherproof clothing to make our lives easier when going about day-to-day life in strong weather conditions, and enabling people to continue with their hobbies while staying protected. But, also that we can have improved durability and quality. Knowing that the clothes we buy are going to last, maintain a good quality and are going to do what they say they do will ensure that less textiles are adding to our landfill. Also, the technologies that we are using seem to be taken from nature's processes, especially in this case. It proves that nature plays a big role in our innovations and that we should be paying attention to it, supporting Janine Benyus' theory that nature has our best inventions.



Figure 3. Michael Phelps wearing the Speedo swimsuit at the 2008 Olympics in Beijing

Following on from biomimicry in performance wear, in 2000 Speedo released their Fastskin swimsuit with the goal to help swimmers glide through the water faster, all inspired by sharks (SwimSwam, 2019). Rob Blenkinsopp, the Head of Research and Development for Speedo says "If there is one of the greatest designers out there, its nature" (SwimSwam, 2020). Here he is suggesting that nature has the best solutions to our problems, further supporting Janine Benyus' theories. He says that through natural selection over billions of years, nature has tested and challenged the secret to survival, therefore creating the most optimum designs for life.

One of shark's most reputable attributes is its speed; in short bursts, they can swim up to 43 miles an hour. This speed has come from 3 billion years of evolution, making sure they can catch prey and attain a dominant status within the water (Kennedy, 2019). As humans, we value speed for different reasons such as efficiency, convenience and productivity. Therefore, scientists are gaining inspiration from life underwater to create new technology and innovations.

Shark skin is made up of many dermal denticles which are tiny scales that overlap, each of these have microscopic grooves that run along it horizontally in alignment with the water flow. The

grooves speed up slow water by pulling fast water towards the shark and onto its skin, mixing it with the slower water. In summary, dermal denticles average out the speed of the water surrounding the shark, causing less turbulence so the shark is able to glide through water at an increased overall speed (Li, 2017). So, the aim is to actually 'rough up' the surface of the swimsuit to create a small turbulence to improve the drag.

The first release of the Fastskin swimsuit had an application of a texture woven into it across the whole of the swimsuit to reduce the drag. Through further research and testing, the second swimsuit was released with improved features. The texture of a shark's skin actually changes throughout its body, from front to back. This is because the shape of the shark's body changes because the shark has evolved to channel the water in different ways as it swims along the surface. Mirroring nature, the design team questioned how do we apply texture in certain places where we need to do certain things with the water to improve the track. The sharkskin texture was now applied to the chest and lower back for women's suits and the lower back for men's suits, to perfectly mimic the shark's structure.

What enabled Speedo to keep releasing new and improved suits was collaboration with other industries. Working with London's National History Museum provided a deeper understanding into animals, specifically sharks. They were able to attain knowledge into the areas of aerodynamics and hydrodynamics by working with experts from Formula 1 and with companies that apply paint on ships to reduce the drag on ships. One of the key factors toward innovation is combining knowledge from different areas of industry. Rob Blenkinsopp describes how the different understandings from the different industries were essential for the development of the Fastskin tech. If you apply the same thinking to something, you are going to have the same results. Whereas, if you bring people with other knowledge, understanding and ideas that is how you really push on and make a difference (SwimSwam, 2020).

Supporting this point, Fletcher et al (2012) describes how biomimetic developments often involve highly technical engineering and that innovations are mainly housed within labs. This results in fashion designers often becoming frustrated with the lack of access and means for bringing biomimetic innovations to life. These frustrations reflect old habits where designers fulfil industry expectations, working from their studios. However, if we are to follow nature correctly we would be opening up and breaking out of these old habits, as nature is described as "complex living organisms that evolved in and function best in a dynamic and diverse environment" (Fletcher et al., 2012 p 116). It is important to note how Speedo's discoveries may never would have been possible if it were not for the input of others' ideas, knowledge and background. How would they have known the true textures of a shark if it weren't for the National History Museum? Or the principles of aerodynamics without the Formula 1 team? Working across sectors, just as natural systems do, really pays off in the development of biomimetic innovation.

Speedo's innovations shows that we can, and have been, replicating what is already readily available to us within nature to create solutions to our problems. Or, to make new innovations to better improve our lives. Biomimicry has the power to create a new normal within the fashion industry, to better improve our performance through sportswear.



Figure 4. Stella McCartney x Bolt Threads Microsilk™ dress

Biomimicry as an innovation for sustainable textiles is becoming more aware within the industry, this is very promising as more and more designers and companies are adapting this mindset. With more knowledge of biomimicry as a solution to environmental problems, the more it should become more of a normal approach. Stella McCartney and Bolt Threads, a biotechnology company has collaborated to create a one-off custom dress made of Bolt Microsilk™ yarn. This partnership has set off the future of environmentally friendly luxury textile innovation. The production of the yarn mimics spiders' incredible ability to produce silk fibres, without the actual spiders meaning that the silk is vegan, ethical and made from purely yeast, sugar and DNA. The Microsilk™ is produced in a way that has less of an impact on the planet than regular silk, producing less pollution and creating cleaner, closed-loop cycles for manufacturing that uses green chemistry practices. The natural process produces desired properties within fabrics, such as high strength and tension, elasticity, softness and strong durability which means that Microsilk isn't any less functional or practical compared to regular silk. The company has developed a technology that replicates this naturally occurring process on a large scale, while encouraging sustainable practices (Katcher, 2017).

Stella states that change is needed within the industry, "The fashion industry to me is extraordinarily old-fashioned" (Arthur, 2017). We cannot stick to old habits and practices, we need to keep moving with the times. Old practices using toxic chemicals, high energy and water consumption, producing large masses of waste, whilst also following unethical principles regarding sweatshops and animals are clearly unsustainable and unethical. So, why would we not be innovative and create new technologies? It is essential for the future of us and the planet.

This new technical innovation has the potential to change the way we make everything. If we can make silk without spiders and worms, then we can apply this approach to pretty much anything. This modernised approach is replacing the ways that we have previously been producing textiles. Some of our most pressing challenges within fashion can be solved, regarding pollution, textile waste and ethical principles. The Microsilk has the potential to biodegrade as it is protein-based, making it a renewable fabric unlike other synthetic fibres that contribute to microfibre pollution.

Stella McCartney went on to design a Microsilk™ tennis dress with Adidas (Block, 2019). The adaptability of the Microsilk™ has been proven here, we can make two completely different garments using the same materials. One being a beautiful dress that is made to highlight beauty and elegance for a smart occasion, using strong colour that catches the eye. Whereas another fitting a purpose for sports so that the athlete can perform as they need to. This insights a really positive future for Microsilk™ because we can ensure that all sectors of clothing can be made to biodegrade, due to the versatility of the silk.

The collaboration with Stella McCartney x Bolt Threads and Adidas is really interesting. We are combining a high luxury brand with an extremely well known, affordable brand like Adidas. The partnership means gaining awareness from popular brands that may not be known for their sustainability, this collaboration will create huge benefits for the means of sustainable fabrics, like Microsilk™.

Following this release with Stella McCartney, Adidas have integrated waste reducing motives into their business. According to the senior member of the innovation team at Adidas, Dharan Kirupanantham says they are embracing the circular and closed-loop economy. They made a fully recyclable trainer shoe which was their first leap into the concept of a closed-loop system. It is made of thermoplastic polyurethane, a single recyclable material. The plastic will be ground up and reused at the end of its life (Fairs, 2019). Creating closed-loop products is going to be key towards turning our economy into a circular one, where waste is reduced and our natural systems are restored. Adidas say they “look forward to a future where every adidas product is fully circular” (Adidas, 2019).

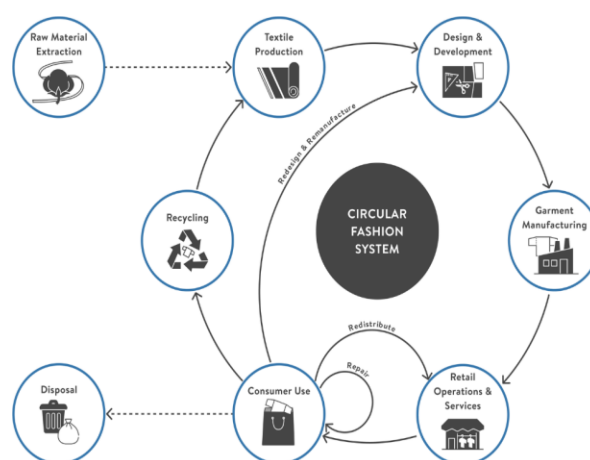


Figure 5. Circular Design System

There is growing interest to transform the way that we consume and produce, into a circular economy. It is important to sustain this mindset throughout everything that we do, but particularly within the fashion industry, as it is the second largest polluter in the world (Johnsen, 2020). The Biomimicry Institute (2022) defines a circular economy as “an economy that is regenerative by design.”

Biomimicry is one of the concepts that originally inspired the idea of a circular economy. Ideally, our economy would function just as a natural system does. To create a system that is regenerative, we should embrace our already existing relationship with nature and emulate its cycles.

Taking a broader view can help us tackle smaller problems, such as what we as humans should be wearing. There are two basic materials in nature: materials that grow, that are biodegradable and re-grow. And materials that are finite and do not grow. The materials that grow are renewable, and the other non-renewable. The main concept is that there is no waste in nature, and one process leads to another (Blackburn, 2009, p. 16).

Cradle to Cradle design is a biomimetic design approach that supports this thinking, created by William McDonough and Dr. Michael Braungart. It aims for a redesign of traditional design and manufacturing systems into a closed loop system where materials move through a continuous use and reuse cycle, as shown in Figure 5. The authors say that “waste is food” (McDonough and Braungart, 2002). Within the natural world, the “waste” of one system will become food for another system. For example, when a bird eats a berry or dies, this waste will decompose and return into the soil as nutrients for the next plant or tree to grow. These plants will then combine these nutrients with carbon dioxide from the air and energy from the sun, through photosynthesis to begin the cycle all over again. Just like within the natural world, Cradle to Cradle aims to replicate these natural processes so that each material will instigate another cycle after its useful phase is over (McDonough & Braungart, 2009).

Natural materials have an endless cycle, Pangaia is a brand that creates a wide range of biodegradable materials. C-Fiber™ uses wood pulp from eucalyptus and seaweed powder from SeaCell™, turning nature into fabric. The eucalyptus pulp gets turned into a biodegradable man-made fibre called lyocell, made entirely through a close-loop production system. Seaweed is a naturally regenerative resource as it grows under the sea, resulting in no additional water being used in the growth stage (Pangaia, 2022).

The future of fashion is in desperate need for regenerative sourcing. The Oxford Dictionary defines regeneration as “The securing of the repair and conservation of older structures to ensure their future viability” (Oxford Dictionary, 2022). Taking a nature-positive approach to farming and fibre production ensures that the processes do not destroy our land and soil, instead it will rebuild and restore it. Nature-positive is a term used to describe “a world where nature – species and ecosystems - is being restored and is regenerating rather than declining.” (University of Cambridge, 2021).

EcoVero™ is a brand that supports regenerative sourcing. EcoVero™ fibres are fully biodegradable in soil, water and compostable in home and industrial environments. Their striking slogan states “derived from nature, returns back to nature” (EcoVero, 2022). Which simply shows that their brand is regenerative and follows Cradle-to-Cradle design principles. EcoVero™ has less environmental impact compared to generic viscose. It has 50% less water impact and 50% lower co2 emissions.

They only use renewable wood as raw materials to avoid overexploiting natural resources. Irresponsible wood sourcing causes deforestation and forests are essential to the health of our species, climate and biodiversity. Therefore, EcoVero™ avoids sourcing from endangered forests to avoid taking away from the earth, but instead adding to it by creating biodegradable viscose (EcoVero, 2022).

Brands such as EcoVero™ show that it is not just about being careful with our clothing consumption and wastage that prevents harm to the planet. But it is about ensuring that the materials we are using are actually giving back to the earth, by biodegrading. Regenerative textiles are the way forward in making sure that there is no waste produced from the clothes that we wear, or the textiles that we use. It is inspiring to think that we can buy and wear a pair of trousers, but once we 'throw it away' we have actually produced zero waste. A nature-positive economy will ensure that our ecosystems are being restored, instead of damaged.

To conclude, Biomimicry has the potential to be a great solution to environmental problems within the fashion industry. Mimicking the way that natural systems work can ensure that we follow a circular design system within the fashion industry, meaning that we produce no waste and take a nature-positive outlook. By producing biodegradable items of clothing, we can reuse the materials to remake new products. Natural fibres have the ability to break down and provide nutrients for other organisms, like Pangaia's seaweed fabric. We have already discovered that designers like Stella McCartney and Julian Melchiorri, and brands like Speedo and Bolt Threads have already begun to innovate new sustainable textiles. Hopefully, this was just the push that was needed to give other brands the message that change is needed, and that biomimicry is the answer.

Not only does biomimicry influence us to live sustainably, but nature also provides us with amazing technology that can be used for enhancing other elements of our lives. Speedo's Fastskin swimsuit inspired by shark skin allowed swimmers to swim faster. As well as EVODry's waterproof outdoor gear allowing us to continue with our hobbies warm and dry. Mimicking nature's processes benefits us in many ways.

I discovered that innovations inspired by nature have great potential to better improve our health and wellbeing when applied to textile applications within apparel and our interior settings. Julian Melchiorri's Silk Leaf textile has the ability to purify our air, although he has not extended this innovation into wearable textiles I discovered the beneficial application to performance wear to aid the health of the user. Photosynthesising textile innovation has a huge possibility of integrating itself within apparel like Speedo's swimsuits and EVODry's weatherproof gear. EVODry's weatherproof outdoor attire would benefit from the application of Silk Leaf into it. Imagine a breathable, waterproof jacket that also purifies the oxygen around you when hiking in high mountains. It makes perfect sense to combine the two. Photosynthesising materials should be used to create items such as tents, backpacks and sleeping bags to cater for hikers or outdoor lovers when in areas of low oxygen levels. Or, in cities with high pollution we can integrate them within our furniture to live healthier lives.

Overall, nature has a high influential impact on us in the world of design and becoming more sustainable within the fashion industry. Biomimicry has proved itself of making that happen.

Bibliography

Adidas (2019) Adidas by Stella McCartney: Shaping a more sustainable future for Sport and Fashion, Adidas UK. Available at: <https://www.adidas.co.uk/blog/392090-adidas-by-stella-mccartney-shaping-a-more-sustainable-future-for-sport-and-fashion> (Accessed: December 13, 2022).

Arthur, R. (2017) Biotech gets the luxury nod with bolt threads x Stella McCartney tie-up, Forbes. Forbes Magazine. Available at: <https://www.forbes.com/sites/rachelarthur/2017/07/20/biotech-gets-the-luxury-nod-with-bolt-threads-x-stella-mccartney-tie-up/?sh=2d8724e133f3> (Accessed: December 12, 2022).

Benyus, J. M. (2002). Biomimicry: Innovation Inspired by Nature. Mariner Books.

Biomimicry Institute. (2022) A Journey of Design Inspired by Nature with Janine Benyus. 8 May. Available at: <https://www.youtube.com/watch?v=GD0qPaHEvYM> (Accessed: 28 November 2022).

Blackburn, R. (2009). Sustainable Textiles: Life Cycle and Environmental Impact. Woodhead Publishing Ltd.

Block, I. (2019) Lab-grown spider silk used for Adidas x Stella McCartney biodegradable dress, Dezeen. Available at: <https://www.dezeen.com/2019/07/31/biofabric-tennis-dress-adidas-stella-mccartney-bolt-threads-microsilk/> (Accessed: December 13, 2022).

Casual Geographical (2020) Marmot Evodry Water-Repelling Technology: Review & Performance: Casual Geographical, Casual Geographical | Outdoor Blog. Available at: <https://casualgeographical.com/marmot-evodry-review/> (Accessed: December 9, 2022).

EcoVero (2022) Lenzing™ ECOVERO™: Sustainable viscose fibers for fabrics, ECOVERO™. Available at: <https://www.ecovero.com/sustainability> (Accessed: December 12, 2022).

Fairs, M. (2019) Adopting circular design is "good for business" says Adidas Innovation leader, Dezeen. Available at: <https://www.dezeen.com/2019/07/17/adidas-circular-economy-closed-loop-design/> (Accessed: December 13, 2022).

Fletcher, K., Grose, L. and Hawken, P. (2012) Fashion & Sustainability Design for Change. London: Laurence King Publishing Ltd.

Harman, J. (2013). Shark's Paintbrush: Biomimicry and How Nature is Inspiring Innovation. White Cloud Press.

Johnsen, M.M.F. (2020) These facts show how unsustainable the fashion industry is, World Economic Forum. Available at: <https://www.weforum.org/agenda/2020/01/fashion-industry-carbon-unsustainable-environment-pollution/#:~:text=1%20Fast%20fashion%20makes%20shopping%20for%20clothes%20more,the%20second-largest%20consumer%20of%20the%20world%E2%80%99s%20water%20supply.> (Accessed: November 26, 2022).

Jordan, J. (2016) The lotus leaf: How nature makes water-repellent materials., Jeremy Jordan. Available at: <https://www.jeremyjordan.me/lotus-leaf-how-nature-makes-water-repellant-materials/> (Accessed: December 12, 2022).

Kapfunde, M. (2019) Stella McCartney x Bolt Threads: Eco-Innovation's Mindful Approach To Fashion., FashNerd. Available at: <https://fashnerd.com/2017/07/stella-mccartney-bolt-threads-sustainability-fashion/> (Accessed: December 1, 2022).

- Katcher, J. (2017) Stella McCartney thinks this technology will save the world, HuffPost. HuffPost. Available at: https://www.huffpost.com/entry/stella-mccartney-thinks-this-technology-will-save-the_b_59f51643e4b06ae9067ab93d (Accessed: December 4, 2022).
- Kennedy, J. (2019) Sharks are fast-but some are faster than others, ThoughtCo. ThoughtCo. Available at: <https://www.thoughtco.com/how-fast-can-a-shark-swim-2291556> (Accessed: December 4, 2022).
- Li, J. (2017) From shark skin to speed, USC Viterbi School of Engineering. Available at: <https://illumin.usc.edu/from-shark-skin-to-speed/> (Accessed: December 4, 2022).
- Marmot (2022) Evodry Waterproof Rain Gear Technology, Marmot. Available at: <https://www.marmot.com/evodry-waterproof-rainwear.html> (Accessed: December 9, 2022).
- Masojídek, J., Koblizek, M. and Torzillo, G. (2013) Photosynthesis in Microalgae, Research Gate. Available at: https://www.researchgate.net/publication/284079683_Photosynthesis_in_Microalgae (Accessed: November 2, 2022).
- McDonough, W. and Braungart, M. (2009) Cradle to cradle: Remaking the Way We Make Things. 1st edn. London: Vintage.
- Melchiorri, J. (2014) Silk Leaf. Available at: <https://www.julianmelchiorri.com/Silk-Leaf> (Accessed: November 14, 2022).
- Nikwax (2022) Welcome to Nikwax: Outdoor Innovation, Nikwax. Available at: <https://www.nikwax.com/en-gb/how-nikwax-works/> (Accessed: December 9, 2022).
- Oxford Dictionary. (2022) Oxford University Press. Available at: <https://www-oxfordreference-com.ezproxy.uwtsd.ac.uk/display/10.1093/oi/authority.20110803100410923> [Accessed: 1st December 2022]
- Pangaia (2022) C-fiber™, PANGAIA. Available at: <https://pangaia.com/pages/c-fiber> (Accessed: December 12, 2022).
- Primrose, S. B. (2020). Biomimetics: Nature-Inspired Design and Innovation. Wiley-Blackwell.
- Scott, A. (2013). The Limitations and Boundaries of Biomimicry
- SwimSwam. (2019) Speedo Fastskin - A History of the world's fastest swimsuits, SwimSwam. Available at: <https://swimswam.com/speedo-fastskin-a-history-of-the-worlds-fastest-swimsuits/> (Accessed: December 7, 2022).
- SwimSwam. (2020) SSPC: Why is the Speedo Fastskin Based on Shark Skin? 7 December. Available at: <https://www.youtube.com/watch?v=oRbJ5b7vouQ> (Accessed: December 7 2022)
- University of Cambridge (2021) Nature-positive hub, Cambridge Institute for Sustainability Leadership. Available at: <https://www.cisl.cam.ac.uk/resources/nature-positive> (Accessed: December 13, 2022).
- Wicker, A. (2020) Why does silk have such a bad environmental rap?, Ecocult. Available at: <https://ecocult.com/why-does-silk-have-such-a-bad-environmental-rap/> (Accessed: December 1, 2022).
- Yetisen, A.K. et al. (2016) Nanotechnology in textiles, ACS nano. U.S. National Library of Medicine. Available at: <https://pubmed.ncbi.nlm.nih.gov/26918485/> (Accessed: November 3, 2022).
- Yilmaz, N. D. (2018). Smart Textiles: Wearable Nanotechnology. Wiley-Scrivener

Figures

Figure 1. Exhale by Julian Melchiorri. [Photograph]
[Accessed on: 28th October 2022]

Figure 2. Silk Leaf by Julian Melchiorri. [Online image] Accessed from:
<https://www.julianmelchiorri.com/Silk-Leaf> [Accessed on: 14th November 2022]

Figure 3. Michael Phelps wearing the Speedo swimsuit at the 2008 Olympics in Beijing. The Guardian. [Online image] Accessed from:
<https://www.theguardian.com/sport/2012/mar/02/racerback-fastskin-swimsuits-swimming>
[Accessed on: 13th December 2022]

Figure 4. Stella McCartney x Bolt Threads Microsilk™ dress. [Online image] Accessed from:
https://www.huffpost.com/entry/stella-mccartney-thinks-this-technology-will-save-the_b_59f51643e4b06ae9067ab93d
[Accessed on: 4th December 2022]

Figure 5. Circular Fashion System. Redress Design Award. [Online image] Accessed from:
<https://www.redressdesignaward.com/academy/resources/guide/circularity-in-fashion>
[Accessed on: 5th December 2022]