Better Future

Caroline Pile

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How are the traits of biomimicry being used in design to create a better, more sustainable future?

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Declaration of Originality

I declare that this dissertation was submitted as part of the degree BA(Hons) 3D Design - Spatial and Interior Design. The work is my own and where the work of others has been used or drawn on, it is attributed to the relevant source. The dissertation has not previously been submitted for a degree at this or any other institution for assessment for any other purpose.

Signed: ______________________

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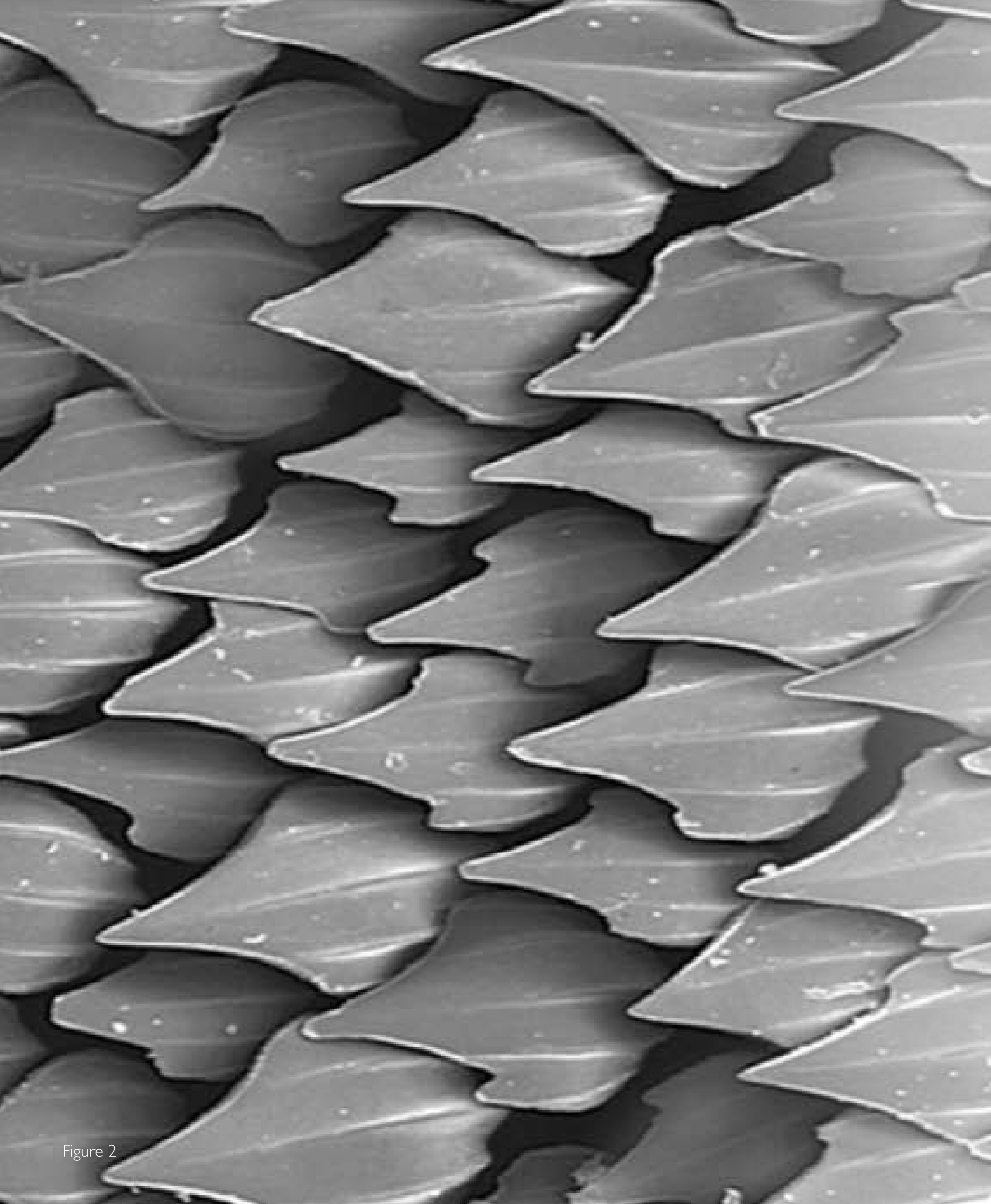

Figure 2

Biomimicry is innovation inspired by nature,[1] It is a new science that studies nature's best ideas, by understanding nature's models, measures and mentor. Thus, solving human problems by taking inspirations from nature's designs and processes. Biomimicry uses an ecological standard to judge the 'rightness' of the innovations.[2] Biomimicry is a design tool used in recent years mainly by designers and architects to create sustainable buildings, spaces and products. Taking nature as a blueprint is an innovative approach to spatial design to support sustainability. This study explores structures, material and toxic waste and how biomimicry can be employed to solve certain problems currently encountered in these areas. This study is conducted as a literature review in conjunction with two case studies about spiders and butterflies. Biomimicry is a modern term coined in the last 20 years but a number of designers have already been practising within this area, unknowingly. It has been used by designers in a number of disciplines for example: Frei Otto[3] was able to create masterpieces based around tensile strength, similar to that found in spider's webs. Additionally, Donna Sgro[4] was able to mimic the 'structural colouration' found in butterflies within textile design. Biomimicry is a beneficial element in design, as it is able to support a more sustainable solution within spatial design.

1. Biomimicry in Action, TED talk, Janine Benyus, TED, 2009.
2. Benyus, M, J., *Biomimicry: Innovation Inspired by Nature,* (U.S.A., William Morrow, 1997).
3. Otto. F., Institute for light weight structures, volume IL 1 to IL 32, dated from 1971.
4. Kapsali, V., *Biomimetics for Designers*, (U.K., Thames &Hudson, 2016), pg. 68.

"The best ideas might not be ours, they might already have been invented."[5] – Janine M Benyus

Figure 3

5. Biomimicry, film, Janine Benyus, Leonardo DiCaprio Foundation, October 2015.

Nature is an incredible resource as it holds the solution to many of mankind's problems, by mimicking nature, the most pressing problems may be solved. Many designers are and have been inspired by nature, especially when it comes to form, function and adaptability. As a species, we have a natural connection to organic shapes;[6] however, this does not always mean that the buildings or products we create from this connection to the organic, is sustainable or even good for the environment. As a result, designers have started to work together with biologists to look at nature from another perspective; they are interested in finding ways to emulate nature's time-tested structures and patterns to make items more sustainable, durable and attractive. Nature has evolved and developed over an estimated 3.8 billion years and design can learn from nature by studying how it develops details of form to sustain itself within given environments. This has resulted in the ideology of biomimicry and its resultant terminology, such as biometric and bio-inspired designs.

Biomimicry is a relatively modern term to the design world, as it was first mentioned in science literature in 1962, but grew in popularity during the 1980s with material scientists.[7] However, it was in the 1950s that Otto Schmitt first used 'biomimetics' and then in 1960s bionics was created by Jack Steele.[8] In the past 15-20 years, there has been a major increase in interest surrounding biomimicry because of three influential figures: Professor of Biology Steven Vogel, Biological science writer Janine Benyus and Professor of biomimetics Julian Vincent. Steven Vogel, has become a lead in the field of Biomechanics as his research has widened the minds of designers and architects alike. Janine Benyus crucial writing has inspired Biomimicry architects, and Julian Vincent has influenced material scientist from his book structural biomaterials.

The use of biomimicry has applications not just in design and architecture but in agriculture, engineering and medicine.[9] Biomimicry within the medical world has helped to implant and invent new biological technologies.[10] There are a number of designers and scientists on the forefront of this ideology and methodology. Janine M Benyus is one of the leading innovators within this field; she is the president of the biomimicry institute and has paved the way through with her book Biomimicry: Innovation Inspired by Nature. As a result of her paving the way, Architects such as Michael Pawlyn and Yaniv Peer have been inspired to set up their design studio 'Exploration', which specializes in nature-inspired buildings, and Grimshaw Architects, whose work has evolved to become more sustainable due to biomimicry and its influences.

6. Meredith Bethune, "9 Architectural Wonders Inspired by Nature" [online], https://www.nationalgeographic.com/travel/lists/biomimeticbuildings-inspired-by-nature/, [14/11/2017].
7. Bensaude- Vincent, B., Arribart, H., Bouligand, Y., Sanchez, C., 'Chemists and the school of nature', New journal of chemistry, Vol. 26, 2002.
8. Vincent, J., Bogatryrev, O., Bogatyrev, N., Bowyer, A., Pahl, A-K., 'Biomimetics: Its practice and theory', Journal of the royal society, Vol. 3, 2006.
9. Deolanker, P., Chani, P, S., Partha, R., 'Biomimicry in architecture: From human skin to building skin.', Architecture plus Design, Vol. 27, Issue 8, 2010.
10. From research within the field of biomimicry doctors have been able to make improvements in tissue engineering, a prime example of this is the tissue engineering skin grafts. 'have been designed to mimic the cell composition and layered structure of native skin.' - Jayarama Reddy, V., Radhakrishnan, S., Ravichandran, R., Mukherjee, S., Balamurugan, R., Sundarrajan, S., 'Nanofibrous structured biomimetic strategies for skin Tissue regeneration', Wound Repair Regen, 2012.

It has been suggested by Janine Benyus from her interaction with architects, designers and engineers,[11] that including a scientist within a design team, could be useful as they have a greater understanding of the natural world, with their knowledge, hopefully future structures will work better with the landscape. Additionally, they are able to suggest processes within nature that can solve design problems. However, designer/ engineers need to be more involved in the research, and be able to go out in nature to observe its solutions to design issues. Furthermore, building structures have not dramatically changed over the years, but with bio-inspired design firms they are making strides in this field. For example, more people are taking inspiration from beehives and using pentagons and hexagons for structural integrity.

Biomimicry literally translates into imitate life. However, it is a lot more complicated, it has been suggested by Dr Dayna Baumeister, who is the co-founder of Biomimcry 3.8, and has devoted her work to applied natural history;[12] that there are three essential elements within biomimicry, these are: ethos, (re)connect and emulate.[13] Each element is equally as important as the other, biomimicry ethos typically comes first because it is the ethics, intentions and underlying philosophy of an individual. Then, (re)connect is regaining an understanding of their connection with nature or their first connection with nature. Thirdly, emulate which is arguable the most difficult to follow as it is the reacting to and coordination with nature. The aim is to find out if a structure or product successfully achieves these three elements, are a they more sustainable, creating less waste and therefore, creating a better future.

Additional investigations examined why biomimicry is so important and how it can help to create a better, more sustainable future. In order to gain a better understanding of biomimicry an investigation was undertaken involving a variety of case studies; conducting in-depth studies into specific organisms like how butterflies create their mesmerising patterns and colours of their wings.[14] Focusing on how the designers can use these solutions within nature to solve their own design problems, additionally find out the potential applications for future projects revolving around the ingenious solutions solved by nature.

11. Biomimicry's surprising lessons from nature's engineers, TED talk, Janine Benyus, TED, 2005.
12. "Dr Dayna Baumeister" [online], https://biomimicry.net/bios/dr-dayna-baumeister/, [18/03/2018].
13. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices*, (U.S.A, Biomimicry 3.8, 2014), pg. 63-9.
14. Biomimicry in Action, TED talk, Janine Benyus, TED, 2009.

When looking at a peacock feather it can be seen as an array of beautiful blues, turquoises and greens. However, the human eyes are deceived because a peacock feather only uses the colour brown. This is due to something called structural colour, where an animal creates colour through the form and structure of the animal, instead of using a toxic pigment. As a result, things could potentially change colour depending on the time of day and how much light is in the room. Therefore, in the future the shape and style of the building could also determine the colour. [15]

The aim of the dissertation is to explore the term biomimicry as a design tool that helps designers build a more sustainable future and redress the balance of past human activity. In the relatively short time humans have been on earth, we have used a large amount of the world's resources without giving any consideration to the impact this has on our environment. "Life on Earth is under tremendous stress," it is now about "time to become conscious and to choose the kind of difference we make."[16] Initially, the thesis explores and details the history of biomimicry and concentrate on the 3 different elements that make up biomimicry. While also detailing and focusing on exciting case studies and developments within the field. Furthermore, the dissertation leads to further examinations within the field of biomimicry to focus on ways to improve the structure of buildings, materials and even the design process. The research journey for this dissertation led to investigations of existing items that demonstrate biomimicry, such as work from architects and designers Frei Otto and Donna Sgro.

15. Biomimicry, film, Janine Benyus, Leonardo DiCaprio Foundation, October 2015.
16. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices,* (U.S.A, Biomimicry 3.8, 2014), pg. 69.

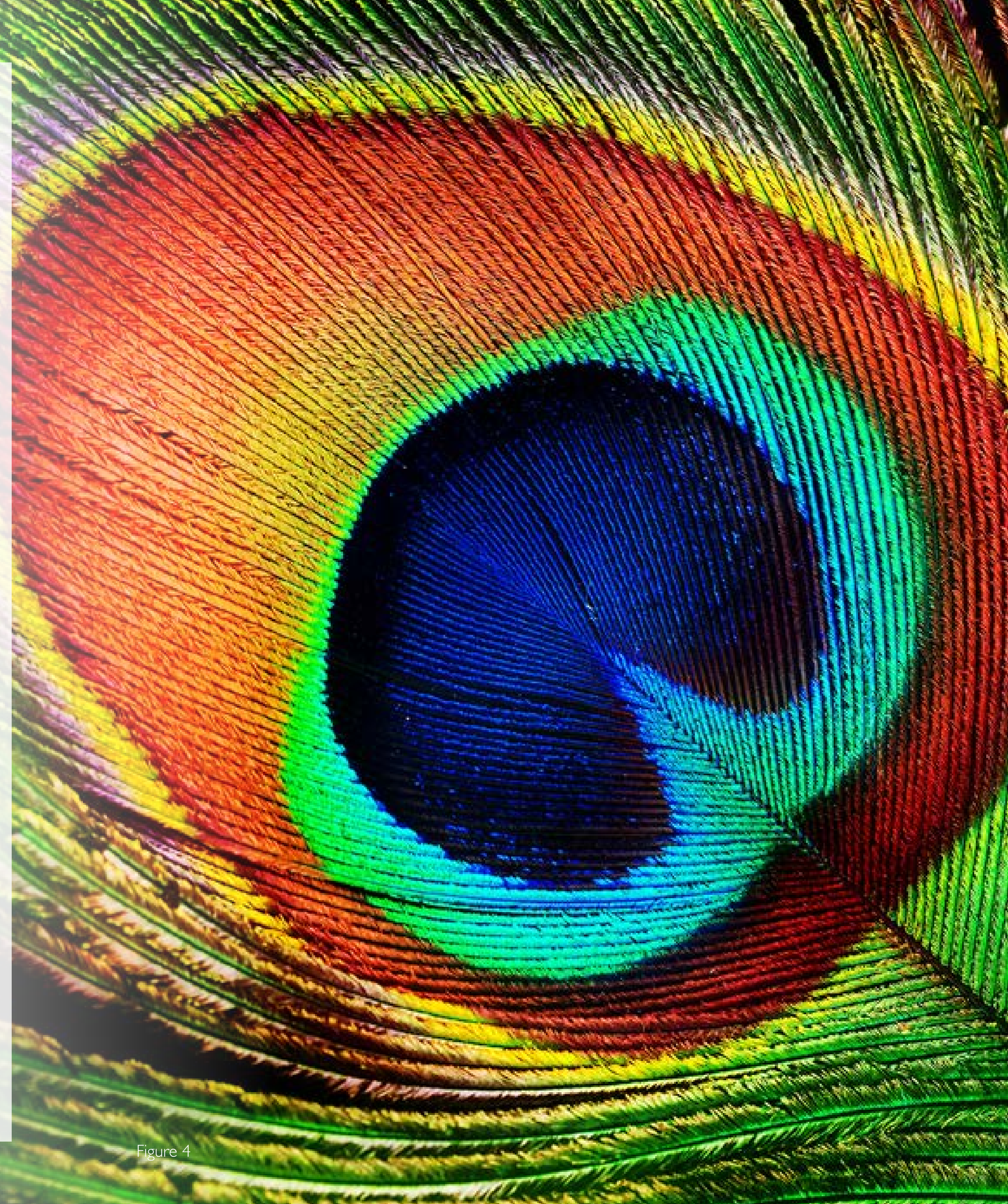

Figure 4

Ethos

(eeth-oss) Noun: the distinctive spirit and attitudes of a people, culture, etc. [Greek][17]

17. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) *English Dictionary*, (Glasgow, HarperCollins Publisher, 2009), pg. 261.

Figure 5

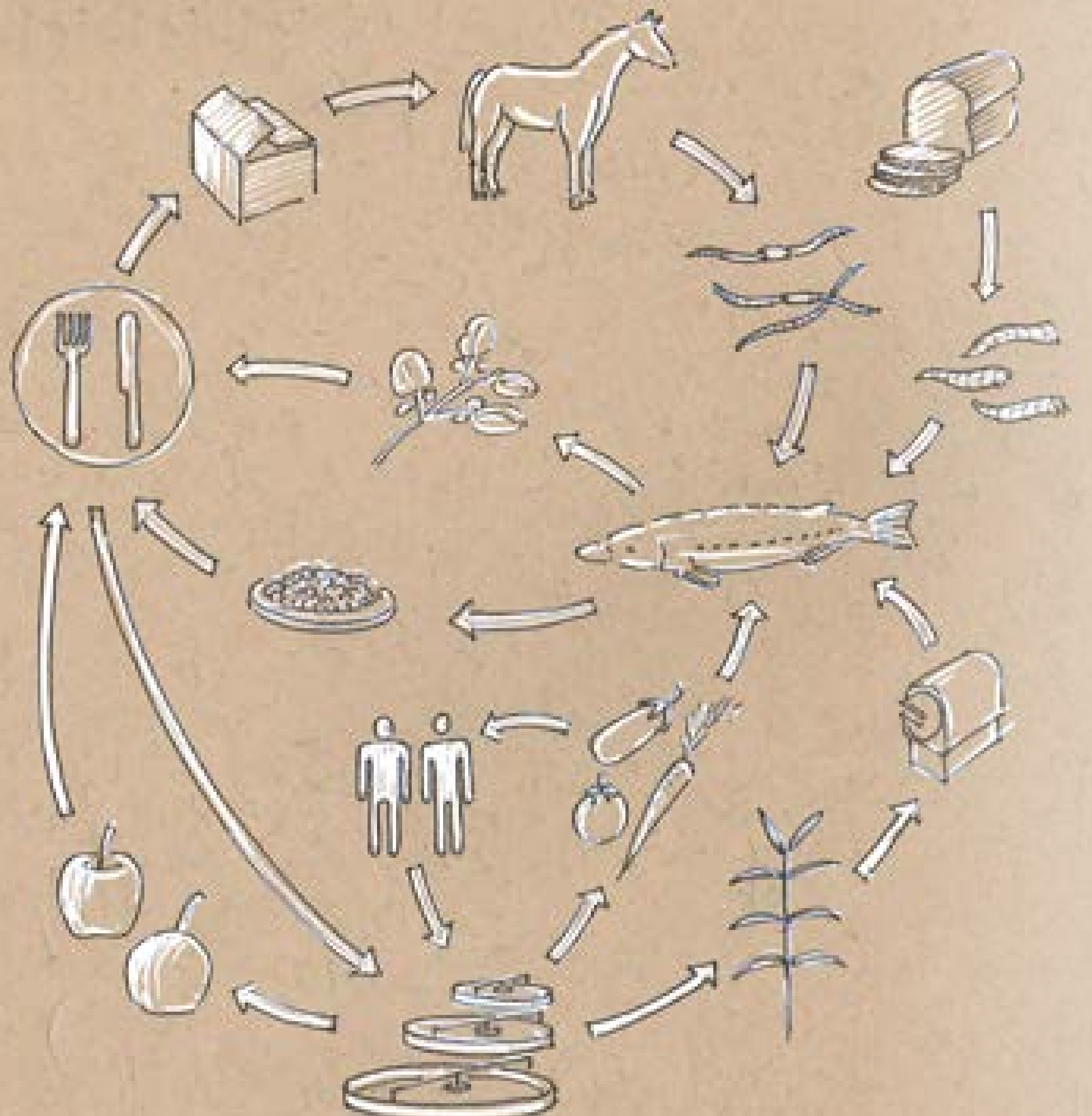

Figure 6

Ethos is a third of the elements of biomimicry, forms the core ethics, intentions and philosophy behind the practice of biomimicry.[18] The philosophy behind Ethos as relating to biomimicry is the belief that humans should be able to live sustainably in their surroundings, amongst the animals and plants on this planet.[19] The idea of biomimicry is to learn from natural organisms that have evolved over the years to become better adapted to their habitats.

The idea is that humans should live in a more closed loop system. To help minimise waste, the Cardboard to caviar project by Graham Wiles is designed to mimic an eco-system, as seen in figure 6. The project collects the waste cardboard from restaurants, shredding and turning it into horse bedding, and the soiled horse bedding is then put it into Wormery composting systems. The worms, in turn, create food for Siberian sturgeon, who produce caviar, which is sold back to the restaurants.[20] Baumesiter explains that biomimicry's ethos is a certain mind-set that designers need to encompass, according to David Orr who is a professor of environmental science and politics at Oberlin College; "The problem is simply how a species pleased to call itself Homo sapiens fits on a planet with a biosphere. This is a design problem and requires a design philosophy. The very idea that we need to build a sustainable civilization needs to be invented or rediscovered, then widely disseminated, and put into practice quickly".[21] However, there is still a debate going on about how different companies view their ethics and whether this matches their philosophy.

Biomimicry is a relatively modern term that has been practiced for the best part of half a century, and which has a completely different view about design and the environment compared to traditional modern design. For example, the British Plastic Federation's ethics are basically the opposite, a linear system heavily focused on making profit and improving export rates. They are trying to be more sustainable, however, with limited success or effort, "all plastic can be recycled but it is not always technically or economically possible."[22] Alternatively, Adidas has the opposite approach with their new running shoe in collaboration with Parley, which "is the space where creators, thinkers and, leaders come together to raise awareness for the beauty and fragility of our oceans and collaborate on projects that can end their destruction."[23] They have come up with a sustainable solution for the wasted plastic found at sea and washed up on beaches. The concept is for a running shoe that is made from illegal deep-sea gillnets and recycled ocean plastic. It was nominee for the Beazley Designs of the Year, in 2016.[24] Another issue to consider is how biomimicry's ethos plays a role with a products aesthetics.

18. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices*, (U.S.A, Biomimicry 3.8, 2014), pg. 63.
19. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices*, (U.S.A, Biomimicry 3.8, 2014), pg. 69-71.
20. Pawlyn, M., *Biomimicry in Architecture*, (Newcastle upon Tyne, RIBA publishing, 2016), pg. 70.
21. Orr, D, W., *The nature of design: Ecology, Culture, and Human Intention*, (Oxford, Oxford university press, 2002).
22. "Sustainability of Plastic" [online], http://www.bpf.co.uk/Sustainability/sustainability-of-plastics.aspx, [15/01/2018].
23. "Parley" [online], http://www.parley.tv/#fortheoceans, [15/01/2018].
24. Mclaughlin, A., "Design Museum reveals shortlist for Beazley Designs of the Year award", Design week (online), 31/08/16.

Figure 7

It is no longer acceptable to just aesthetically "fit in" with the surroundings. Designers are now set the challenge of creating sustainable buildings that work within the landscape, to allow them to blend in seamlessly. A designer that follows biomimicry's ethos will want to apply equal effort into the function and the aesthetics.

Looking at the work from Grimshaw architects is a clear example, especially in collaboration with Michael Pwalyn when designing the Eden Project, that the function of the building along with the aesthesis were of the utmost importance.[25] Multiple aspects of the building drew inspiration from nature; the overall form of the biomes was inspired by soap bubbles to fit with the unusual and changing typography of the site. Furthermore, inspiration for using hexagons and pentagons for structural integrity came from close examinations of carbon molecules and radiolarian though the pollen grain. This technology was first pioneered by Buckminster Fuller with his geodesic domes in the 1940s.[26] From research in to spider's webs that use pliable materials for tension, they decided on Ethylene tetrafluoroethylene (ETFE) instead of glass for the windows.[27] Additionally, the ETFE gives the affect that the building is a living organism that is breathing, which is very symbolic as it is a 'large greenhouse' home to two entire ecosystems. Additionally, the biomes might not conventionally fit in with the surroundings as they are not green or covered in grass. Instead, they interact with the surroundings to create a suitable and sustainable 'home' for the organisms living inside.

However, it is much easier for a building to 'fit in' with the surrounding if it matches the surrounding materials, shapes and colours. This is a common misconception, Treehotel in Sweden designed by Tham & Videgård Arkitekter has cleverly used mirrors to perfectly blend in with the forest. "The exterior reflects the surroundings and the sky, creating a camouflaged refuge."[28] The Treehotel takes the form of a simple cube made from aluminum, that is hung around a tree, the tree acts as a central pole going through the entire building.[29] The cube is cladded in mirrored glass, reflecting the surrounding Boreal forest. To prevent birds from flying straight into the mirrored Treehotel, it has transparent ultraviolet colour laminated into each glass pane. This colour is only visible to the birds. However, apart from the interior being made from plywood and birch, it doesn't fully incorporate the entire biomimicry's ethos as the exterior bliss doesn't translate to the interior. However, the architects managed to suspend a 30-tone tree house from a single tree with a 28-centimeter diameter, but their clever use of adjustable clamps allow the tree to grow over time. "So, as it gets bigger and bigger and bigger, you adjust the bolt and think it's a beautiful balance between clever architectural, design and Mother Nature."[30]

25. Pawlyn, M., *Biomimicry in Architecture*, (Newcastle upon Tyne, RIBA publishing, 2016), pg. 36-43.
26. Pawley, M., *design heroes: BUCHMINSTER FULLER*, (London, Grafton, 1990), pg. 115-145.
27. "Texlon® ETFE system consists of pneumatic cushions restrained in aluminium extrusions and supported by a lightweight structure. The cushions are manufactured from multiple layers of ethylene-tetra-fluoro-ethylene (ETFE), a modified co-polymer." "Eden Project" [online], http://www.vector-foiltec.com/projects/eden-project/, [27/03/2018].
28. Rose Etherington, "Mirrorcube by Tham & Videgård Arkitekter" [online], https://www.dezeen.com/author/rose-etherington/, [27/03/2018].
29. 'Treetop Hideaway', Hospitality Design, Vol. 33, Issue 1, 2011, pg 36.
30. George Clarks amazing spaces, Beehive, Cocktail Bar and Tree Hotel, More4, 2017, 60minutes.

Figure 8

To encompass the essence of Ethos, designers should aim to shift the perspective, from the 'master' to the student.[31] Designers should take a step back and conduct experiments and research to look at how nature problem solves. This is because humans need to learn how to survive better on this planet. Changing the perspective allows humans to study other living organisms that have evolved to survive on this planet; therefore, understanding better what needs changing in order to survive long-term.

This change could be our attitude towards the planet, involving changing core values and beliefs towards design and the planet. As a result, designers need to learn from their 'biological elders'; eventually this will result in conditions conducive to life.[32] Biomimicry 3.8, a bio-inspired consultancy that offers 'intelligence consulting', professional training and inspiration, have come up with a set of six principles to help guide designers towards more sustainable designs through their behaviour and decision making.[33] In this context life's principles are as follows: The ability to evolve to survive, adapt to changing conditions, be locally attuned and responsive, integrate development with growth, be resource efficient (material and energy) and finally, use life-friendly chemistry.[34]

Looking at 'biological elders' is all relative as it depends how their actions/solutions are preserved and interpreted. This is dependent on their individual values and beliefs and what they consider is the most important thing for their business or personal life. A prime example is Michael Pawlyn and Nicholas Grimshaw, they both worked together to create the Eden project, but their design philosophy is different. For example: Michael Pawlyns philosophy is "Innovating and collaborating to address the major challenges of our age."[35] It's all about using biomimicry as a solution to develop new strategies and to help radically rethink new things. Whereas, Nicholas Grimshaw philosophy is more business focused as their work "responds to the needs and resource of the contemporary world. The building we produce come from a detailed understanding of the functions they must fulfil, the conditions they have to provide and the materials from which they are constructed."[36] Therefore, they take into consideration the current climate of Earth but that isn't their main focus, unlike Michael Pwalyn. As a result, their slight differences in philosophy are a perfect match as an architectural team.

31. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices,* (U.S.A, Biomimicry 3.8, 2014), pg. 63-4, 69-71.
32. Biomimicry, film, Janine Benyus, Leonardo DiCaprio Foundation, October 2015.
33. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices,* (U.S.A, Biomimicry 3.8, 2014), pg. 63-4, 69-71.
34. Kennedy, E., Fecheyr- Lippens, D., Bor- Kai, H., Niewiarowski, P, H., Kelodziej, M., "Biomimicry: A path to sustainable innovation," Design issues, Vol. 31, Issue 3, pg 66-73.
35. "Philosophy" [online], http://www.exploration-architecture.com/studio/philosophy, [09/04/2018].
36. "Profile" [online], https://grimshaw.global/practice/, [09/04/2018].

Figure 9

(Re)connect

Verb to link or be linked[37]

Re- prefix (used with many main words to mean) return to a previous condition: renew [Latin][38]

37. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) *English Dictionary*, (Glasgow, HarperCollins Publisher, 2009), pg. 161.
38. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) *English Dictionary*, (Glasgow, HarperCollins Publisher, 2009), pg. 660.

Figure 10

(Re)connect represents the connection humans have with nature through the practice of biomimicry. This could either be the first introduction to nature, forming their first connection or it may be the re-establishing of a former relationship with nature.[39]

It is known that humans have a strong link to nature. Humans are attracted to nature's sights and sounds. Edward O. Wilson a biologist from Harvard claims that humans have an emotional need to connect with the environment, as nature "makes us feel whole".[40] The sense of connection can be used for a range of applications, one of which is education. Earth Education is a learning institute set up in 1974 by Steve Van Matre. Within the education programme they have a set of nine principles and strategies for teaching and learning, known as the 'Interbeing and Deep Ecology Through Art Education'.[41] The fifth principle: Connecting Critical Awareness, Emotion and Actions is all about having a connection with nature that will help children be critically aware. A person's intellect and emotions are vital for their understanding of the nature of their lives and motivation. For example; if a child is not enthused to create and explore, then they will not learn. The argument is in place that children need to experience beauty, power, patterns, smells and connectedness of nature.

There are many 'trends' in education that have proven benefits but much competition for funding and inclusion within the mainstream education system have resulted in limited implementation if any, of Steve Van Matre's Earth Education, similarly the philosophy of both Steiner and Montessori have never really been mainstream.[42] Steiner education is based around the education philosophy of Rudolf Steiner. It places the children's moral, spiritual and creative needs on the same level as their intellect. [43] Montessori education was developed by Dr. Maria Montessori and is a child centred approach. It is based around self-directed activities, hands-on learning and collaborative play.[44]

39. "DesignLens: Essesntial Elements" [online], https://biomimicry.net/the-buzz/resources/designlens-essential-elements/, [29/12/2017].
40. Weil, E., 'Natural High', Vogue, New york, Vol. 204, issue 12, 2014.
41. Anderson, T., Guyas A, S., 'Earth Education, Interbeing and deep ecology', Studies in Art Education; Reston, Vol. 53, Issue 3, 2017, pg. 223-245.
42. Conway, Jacqueline., Face to Face interview, 02/04/2018.
43. Nordlund, C., "Waldorf Education: Breathing creativity", Art Education, Vol. 66, Issue 2, 2013, pg. 13-19.
44. Hambly, B., "What fuels innovation?", Applied arts magazine, Vol. 27, Issue 3, 2012, pg. 16.

Figure 11

Along with the natural bond humans have with nature, there are many physical and emotional advantages from being surrounded by nature. In a survey people were asked to imagine a peaceful place, resulting in 95 percent of people choosing somewhere in nature.

Humans have always had a strong connection to nature and in recent years' studies have been undertaken to explore this further. This has brought on a surge of interest in this area, resulting in household plants within an office space and urban green spaces. There are multiple physical, mental and social health benefits to being surrounded by nature which include: reduced level of stress, improved productiveness, lower sick leave by employees. A pioneering health policy is beginning to recognise nature is a cost-effective device when planning cities to make them healthier. [45] In accordance to these findings the UK ran its first month long nature challenge, it involved people doing "something wild" for 30 days.[46] The study was conducted by University of Derby in conjunction with The Wildlife Trust. Lucy McRobert from the Wildlife Trust found the result "beyond brilliant", as the result illustrated a significant improvement with people's health and happiness. 30% of the participants reported that their health was "excellent" by the end of the trial. "Nature isn't a miracle cure for diseases," says McRobert, "But by interacting with it, spending time in it, experiencing it and appreciating it we can reap the benefits of feeling happier and healthier as a result."[47]

Even though the finding is very positive, it is now a large financial struggle to implement strategies within cities to make them greener, either by planting more trees or adding grass alongside the pavement. Until Pam Warhurst the cofounder of Incredible Edible came along with the idea of turning the unused land in her area into vegetable gardens it was lying derelict and unkept. This has resulted in a surge of tourism because people want to visit the town that has "fruit and veg and herbs sprouting up all over the place."[48] Along with health benefits of being surrounded by plants and greenery everywhere, the locals are able to bask in the financial benefits of the newly created vegetable tourism. Additionally, having home grown vegetable also decreases the towns carbon footprint because less food deliveries are required. Therefore, Pam Warhurst has unknowingly created a happier and healthier town, mentally and physically.

44. Hambly, B., "What fuels innovation?", Applied arts magazine, Vol. 27, Issue 3, 2012, pg. 16.
45. Shanahan, D, F., Lin, B, B., Bush, R., Gaston, K, J., Barber, E., Fuller, R, A., 'Toward Improved Public Health Outcomes from Urban Nature', American Journal of Public Health, Vol. 105, Issue 3, 2015, pg. 470 – 7.
46. Richardson, M., Cormack, A., McRobert, L., Underhill, R., '30 Days Wild: Development and Evaluation of a Large-Scale Nature Engagement Campaign to Improve Well-Being', PLOS one, 2016.
47. Coles, J., "How nature is good for our health and happiness" [online], http://www.bbc.co.uk/earth/story/20160420-how-nature-is-good-for-our health-and-happiness, [28/03/2018].
48. How we can eat our landscapes, TED talk, TEDsalon London, 2012.

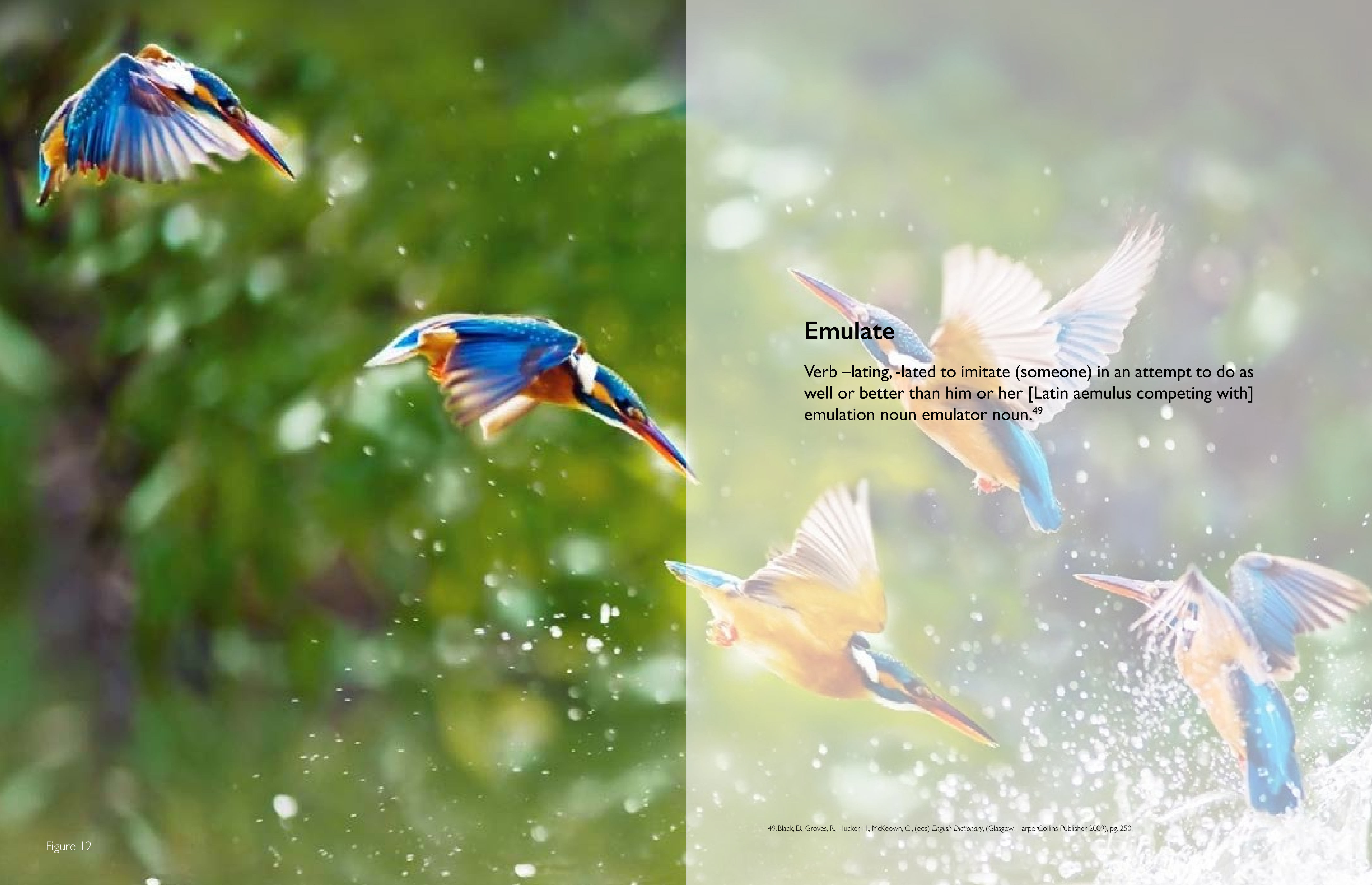

Figure 12

Emulate

Verb –lating, -lated to imitate (someone) in an attempt to do as well or better than him or her [Latin aemulus competing with] emulation noun emulator noun.[49]

49. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) *English Dictionary*, (Glasgow, HarperCollins Publisher, 2009), pg. 250.

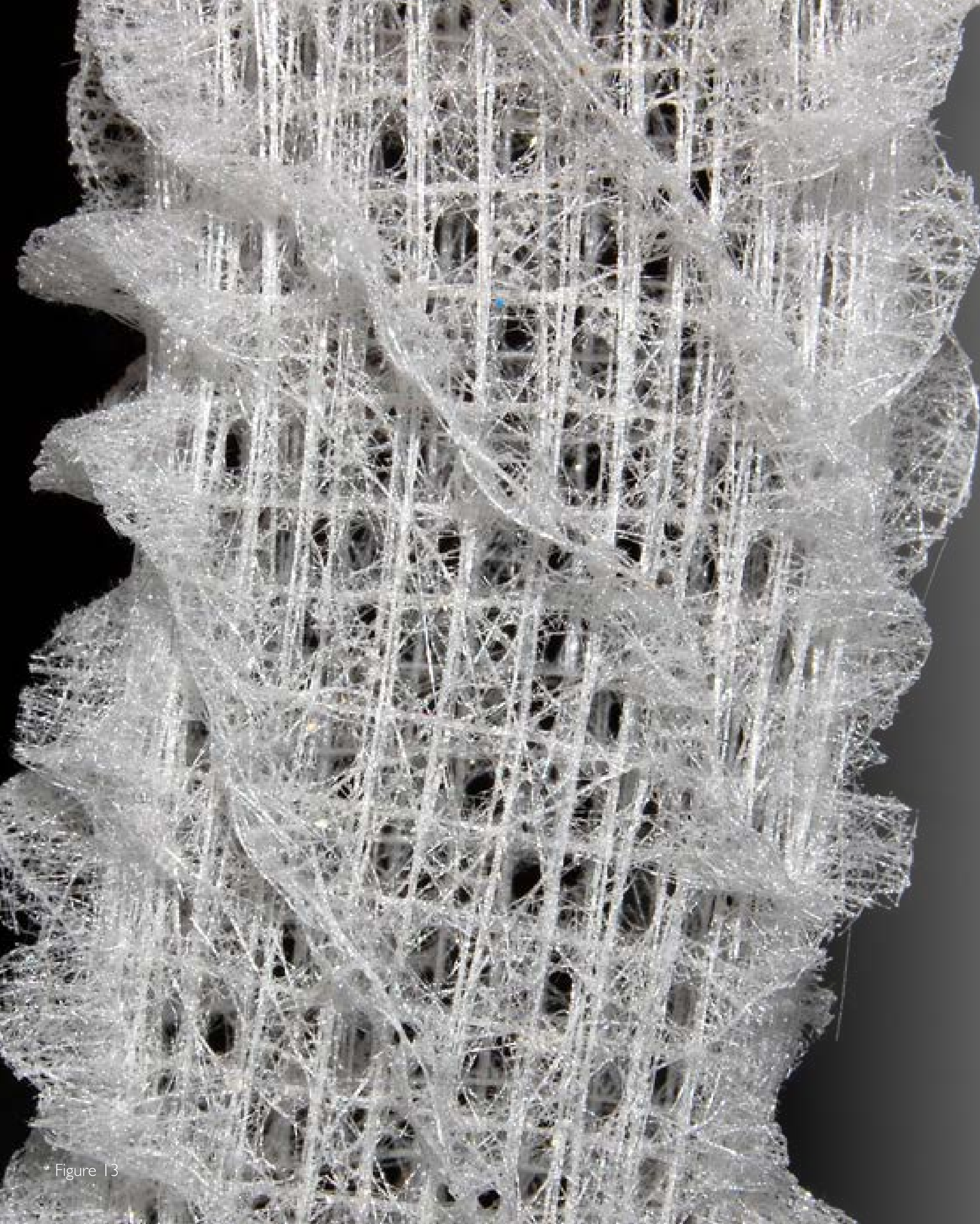

Figure 13

Emulate is the final element of biomimicry and is the most commonly known element and the one people most associate with 'doing biomimicry'. Originally emulate was developed from the perspective of Ethos.[50]

"A well-adapted biological strategy must meet the functional needs of the organism in the context in which it lives in order to contribute to its survival."[51] Emulation is the action of doing biomimicry, this occurs when humans solve problems through bio-inspiration with the ultimate aim to reduce the negative impacts humans have on Earth. This is when bio-inspired design evolves into biomimicry. Some designs do biomimicry by just copying the aesthetics and structure from nature like the Gherkin in London designed by Sir Norman Foster, which takes inspiration from a Venus flower basket sponge.[52] The sponge is structured using a lattice-like exoskeleton. The different levels of fibrous lattice work help to disperse stress; therefore, the Gherkin can disperse weight in various directions. However, the building doesn't give back to the environment or help the function of the building, therefore the building is only meeting one of the three elements of biomimicry: Emulate.

Iridescent fabric is a textile that changes colour dependent on the where the light hits the fabric, therefore the material appears to change colour. This is type of colour creation is found within nature such as: peacocks and butterflies. Shot silk is an iridescent fabric which is made using two or more colours of warp and weft, woven with silk, to produce the iridescent appearance. A purple and yellow shot silk vestment (a garment worn for religious, ceremonial purposes) can be dated back to 698, therefore this technique has existed since at least the seventh century.[53] Which is well before the creation of biomimicry, this illustrates that they were just emulating nature, without following biomimicry's ethos.

50. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices,* (U.S.A, Biomimicry 3.8, 2014), pg. 63-5.
51. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices,* (U.S.A, Biomimicry 3.8, 2014
52. Woodman, E., "Ground Control", Architects' Journal, Vol 239, Issue 15, 2014, pg. 40-47.
53. Dodwell, C, R., Anglo-Saxon Art: A New Perspective, (Manchester, Manchester University Press, 1982) pg. 145-150.

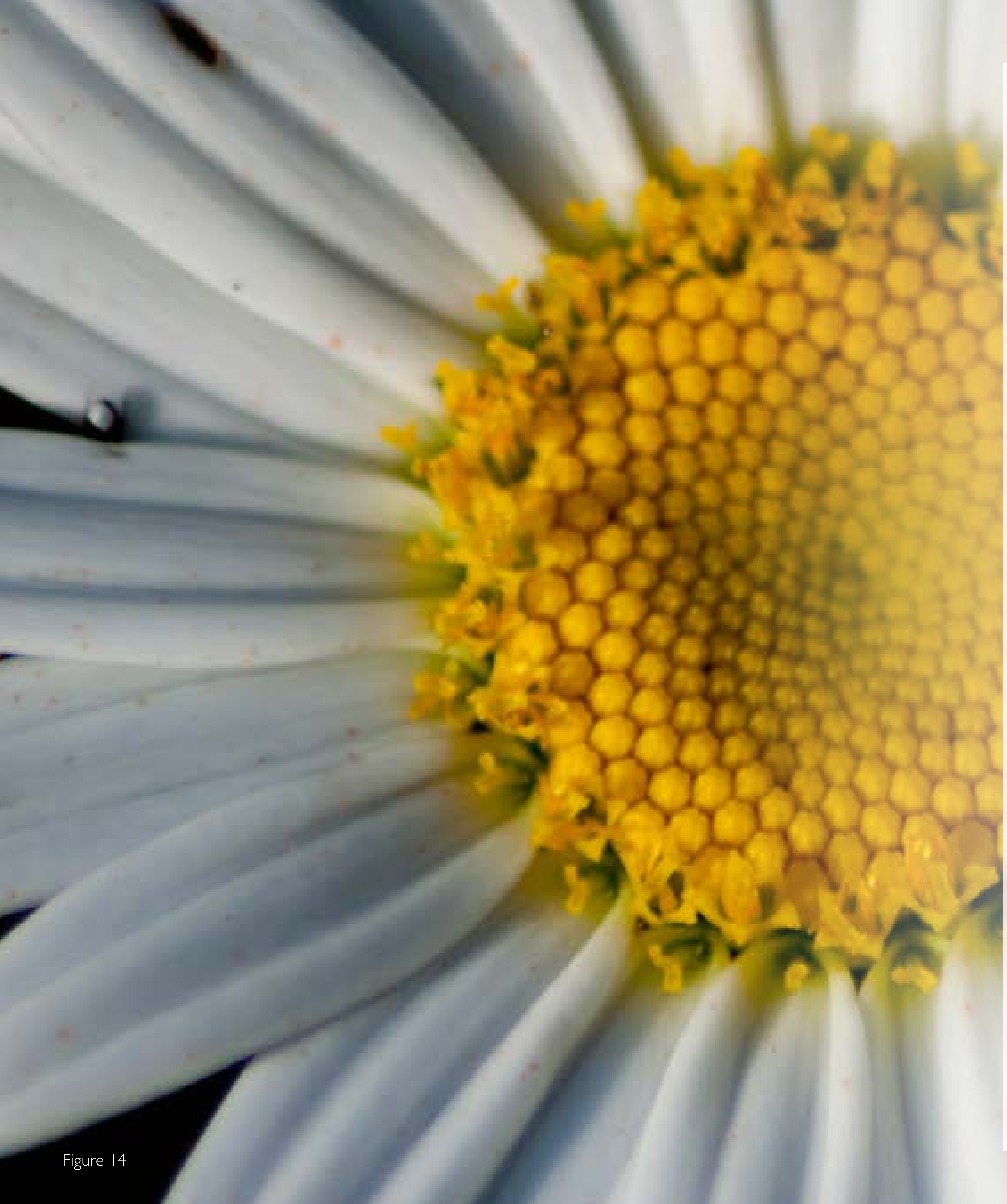

Figure 14

This element looks to nature as a model, mentor and measure, to help humans live accordingly on this planet.All elements tend to cross over as it was mentioned in the previous chapter that designers and architects should become students.

Julian Vincent is a professor of biomimetics and has perceived from his work in the field of biomimetics that "In biology, materials are expensive and shape is cheap."[54] This concept can be seen in Buckmister Fullers geodesic domes. As his first 50 metre diameter, geodesic all-weather dome would be able to survive an earthquake, that its predecessors the St Peter's dome (built around AD 1500) and the Pantheon (built around AD 1) would crumble as a result of an earthquake, even though Buckmister's dome is one - thousandth of their weight. This demonstrates that he was abiding by theory's around biomimicry decades before they were thought of.[55]

Professor of Biology Steven Vogel has observed that 'nature tends towards wet, curved surfaces', whereas 'humans, for example, favour dry, flat surfaces.' He has posed the question "Why are there so many right angles in our technology and civilization?"[56] For examples right angles are found in doors, boxes, book pages, chairs and even some letters. Although, this fascination is not influenced by humans' close relationship with nature, because there is only one right angle commonly seen, this is the right angle observed between a tree trunk and the ground. Vogel believes humans can find a better solution within nature because right angles are structurally weak, as they require cross bracing for rigidity. Whereas, the most structurally sound shape is the triangle because any added force is evenly spread throughout the sides. This is seen within the Fibonacci sequence or the golden ratio, where 'each number is the sum of the preceding two'. These numbers are found within nature, and a prime example can be found in the head of a daisy. Each daisy head is made up of different spiral forms that are comprised of individual 'florets' where they are equal to the Fibonacci sequence.[57]

54. Prof. Menges, A., Reichert, S., Dierichs, K., "Performative Morphology" [online], http://icd.uni-stuttgart.de/?p=4536, [29/03/2018].
55. Pawley, M., *design heroes: BUCHMINSTER FULLER*, (London, Grafton, 1990), pg. 115.
56. Vogel, S., *Life's Devices: The physical world of animals and plants,* (Princeton, Princeton University press, 1988), pg. 58.
57. Campbell, J., 'Dieter Appelt', Border Crossing: Winnipeg, Vol. 24, Issue 2, 2005, pg. 88-89.

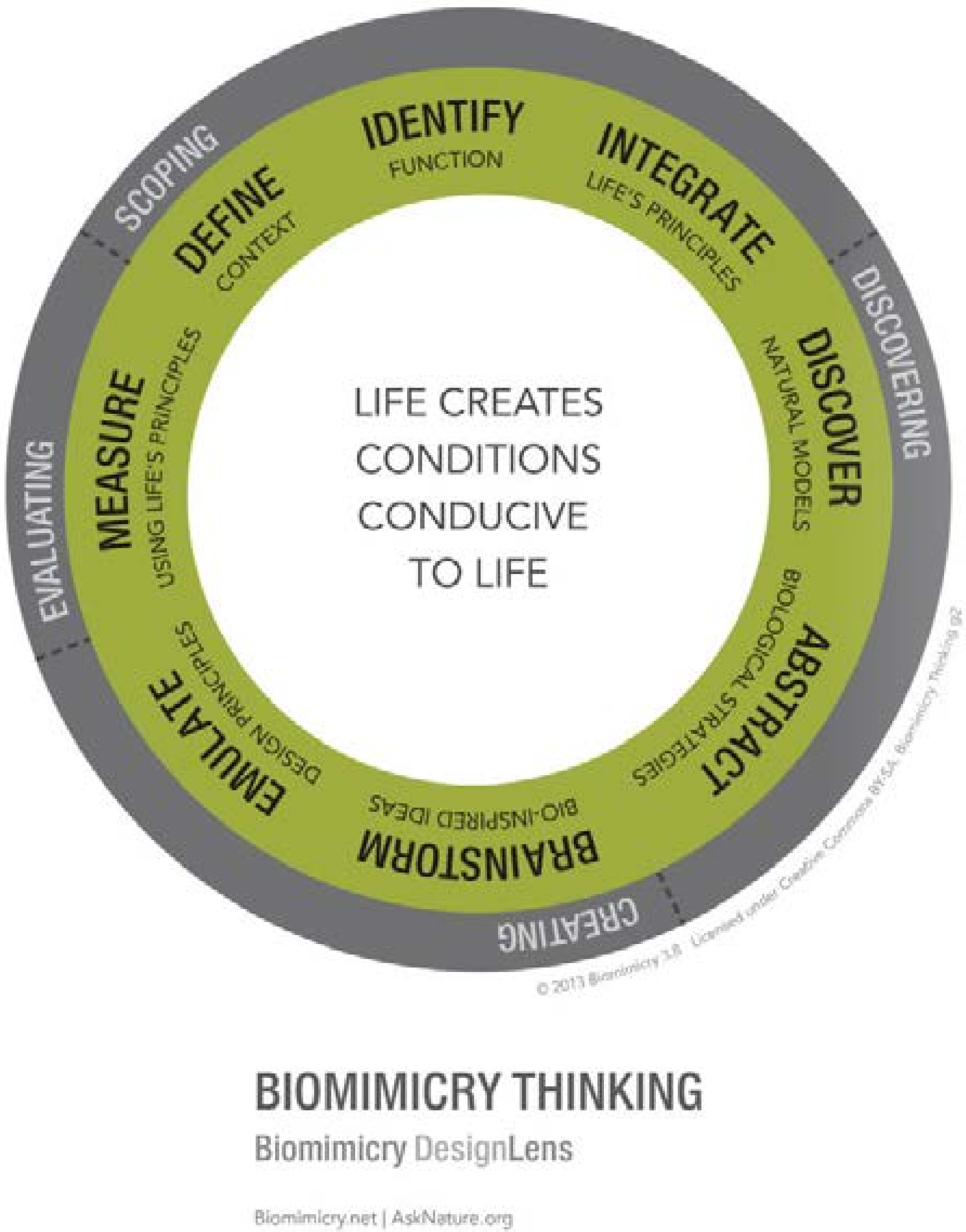

Figure 15

To create a master piece, designers and architects alike go through the design process. However, to create 'conditions conducive to life' they need to include four extra processes to produce biomimicry. These are: Scoping, Discovering, Creating and Evaluating.

Dayna Baumeister and the other members of Biomimicry 3.8 have created a design process for 'doing' biomimicry. It includes Scoping, which is the initial 'leg work' of the project. The aim is to identify the problems and gain more contextual understanding of the issue. There are many benefits to including this with a design process: such as, "articulates a vision in a life-sustaining manner", "Broadens the potential solution space" and "changes mindsets."[58] Next is Discovering, this section often involves a lot of exploratory research as the designers are seeking inspiration for their design. The benefits from this section are: "Discovering a plethora of novel, innovative and life-friendly models, find pre-tested and proven ideas."[59] Followed by Creating, the fun exercise of being creative and generating design solutions to the problems identified within Scoping. The multiple benefits include: "Be inspired by beautiful and elegant ideas, solve vexing challenges and create truly innovative solutions."[60] Finally, the designers need to be Evaluating their work, this involves assessing their work looking at: the nature, quality, ability, extent, or significance of their solution. The multiple benefits of evaluating include: "Identifies missed limits and opportunities, pre-tests for success, works with a more holistic definition of success."[61]

This design process aimed at 'doing' biomimicry can be quite complicated as each section can then be split into smaller sub sections. All with the ambition to create a sustainable solution but, is it good design? According to Dieter Rams good design has ten timeless commands to be followed which include: good design is innovative, good design makes a product useful, good design is aesthetic, good design makes a product understandable, good design is unobtrusive, good design is honest, good design is long lasting, good design is thorough down to the final detail, good design is environmentally friendly and finally good design involves as little design as possible.[62] In the act of 'doing' biomimicry at least five of the principles are fulfilled, potentially more depending on the designer. However, the idea that "good design involves as little design as possible"[63] is all about the simplicity of the product, but there is nothing simple about nature and its unique problem solving methods. Therefore, designers and architecture following biomimicry will struggle to accomplish this design principle.

58. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices,* (U.S.A, Biomimicry 3.8, 2014), pg. 89.
59. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices*, (U.S.A, Biomimicry 3.8, 2014), pg. 89.
60. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices*, (U.S.A, Biomimicry 3.8, 2014), pg. 89.
61. Baumeister, D (Ph.D)., *The Biomimicry Resource Handbook: A Seedbank of Best Practices*, (U.S.A, Biomimicry 3.8, 2014), pg. 89.
62. Hecht, S., "On Good Design", Architecture design, Vol. 37, Issue 4, 2017, pg. 164.
63. Domingo, M., "Dieter Rams: 10 Timeless commands for Good Design" [online], https://www.interaction-design.org/literature/article/dieterrams-10-timeless-commandments-for-good-design, [10/04/2018].

Figure 16

Butterflies

Noun, plural –flies an insect with a slender body and brightly coloured wings.[64]

64. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) *English Dictionary,* (Glasgow, HarperCollins Publisher, 2009), pg. 100.

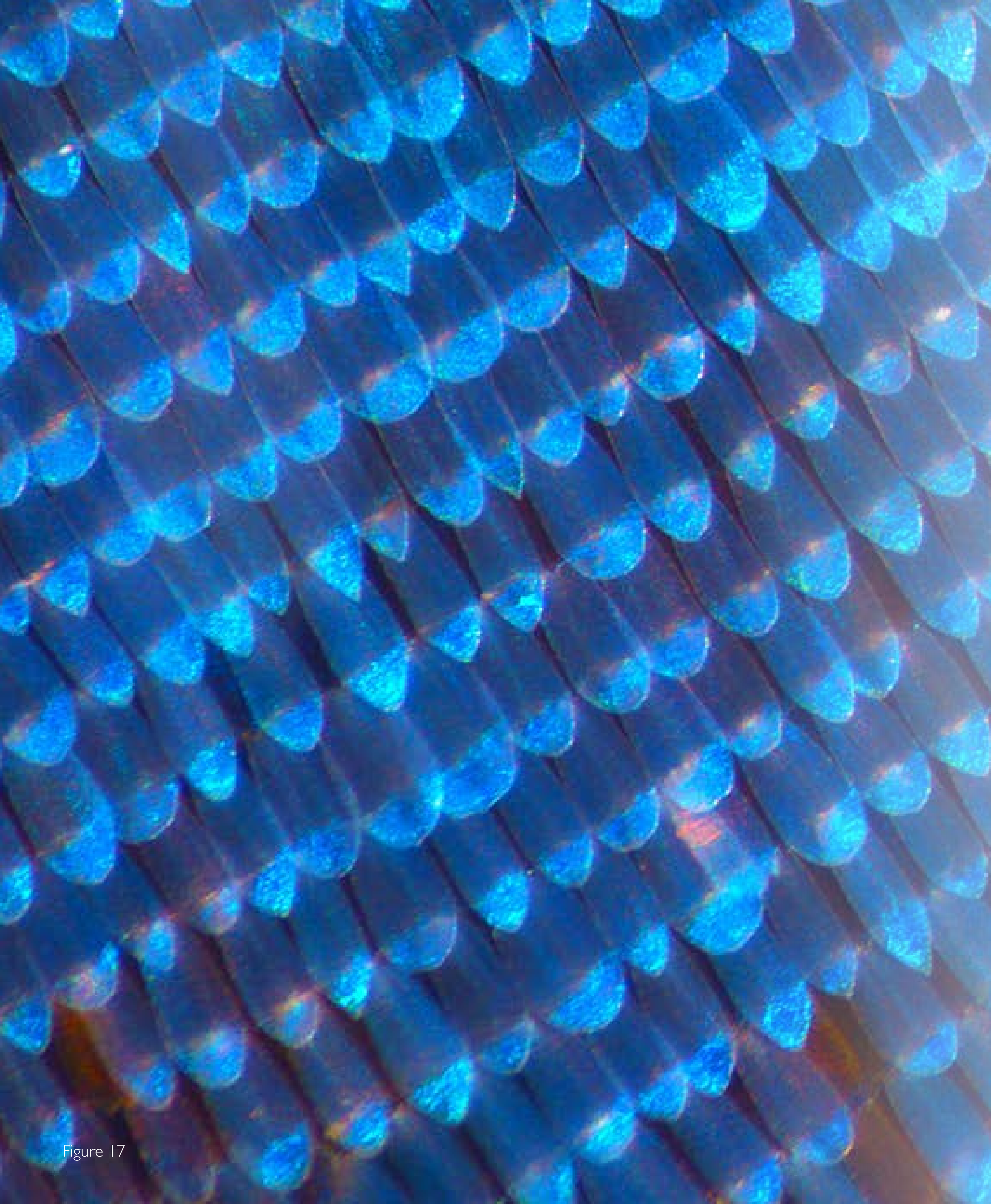

Figure 17

Butterflies are remarkable, yet fragile creatures that, depending on their species can last for a matter of weeks, like the Monarch butterfly that lives from anywhere between two to six weeks; compared to the South American blue Morpho butterfly that can live for up to 4 months and the Vanessa Cardui that has a life span of a year.[65] However, the most intriguing feature of butterflies that has caught the attention of designers and biologists is the alternative way they create colour, additionally, their ability to glide has interested Professor of Biology Steven Vogel. He is has studied how butterflies and similar sized insects like locusts are able to glide, due to their lift to drag ratio.[66] The Blue morpho butterfly, has caught the eye of multiple scientists because of its vibrant iridescent blue wings, the colour is created through the microstructure of the wing and how it refracts and scatters light. [67]

The way butterflies create their magical colours is unique to the natural world, otherwise known as 'structural colouration', which is common amongst insects and animals. This is created by harnessing the physics of light at a Nano scale. The colour of the wings is created by a 'variety of Photonic (light) mechanisms', instead of using tiny light-absorbing particles, the colour comes from the microstructure of its scales, shells or feathers interfaces, these do not just reflect light,[68] but, the microscale, transparent, chitin-and-air layered structures cause light to hit the surface and diffract and interfere. The cross ribs that protrude out from the sides of the ridges of the wing scales diffract the incoming light waves, resulting in the waves being spread throughout the spaces between the structures.[69] Certain colour wavelengths are cancelled out because the diffracted light waves interfere with each other (destructive interference). Whereas other light waves are intensified and reflected (constructive interference). The variety of the scales heights affect the interference of light waves so that the colours are uniform from a wide range of angles. The specific colour is decided by the shape of the structures and the distance between them. As a result of butterflies being able to manipulate light it means they are able to camouflage, thermoregulate and use signaling.

65. "Identify a butterfly" [online], https://butterfly-conservation.org/50/identify-a-butterfly.html, [02/04/2018].
66. Vogel, S., *Comparative Biomechanics*, (Princeton, Princeton University Press, 2003) pg. 261.
67. Pawlyn, M., *Biomimicry in Architecture,* (Newcastle upon Tyne, RIBA publishing, 2016), pg. 58.
68. Kapsali, V., *Biomimetics for Designers*, (U.K., Thames &Hudson, 2016), pg. 66.
69. Vukusic, P., "Structural colour in Lepidoptera", Current Biology, Vol. 16, Issue 16, 2006.

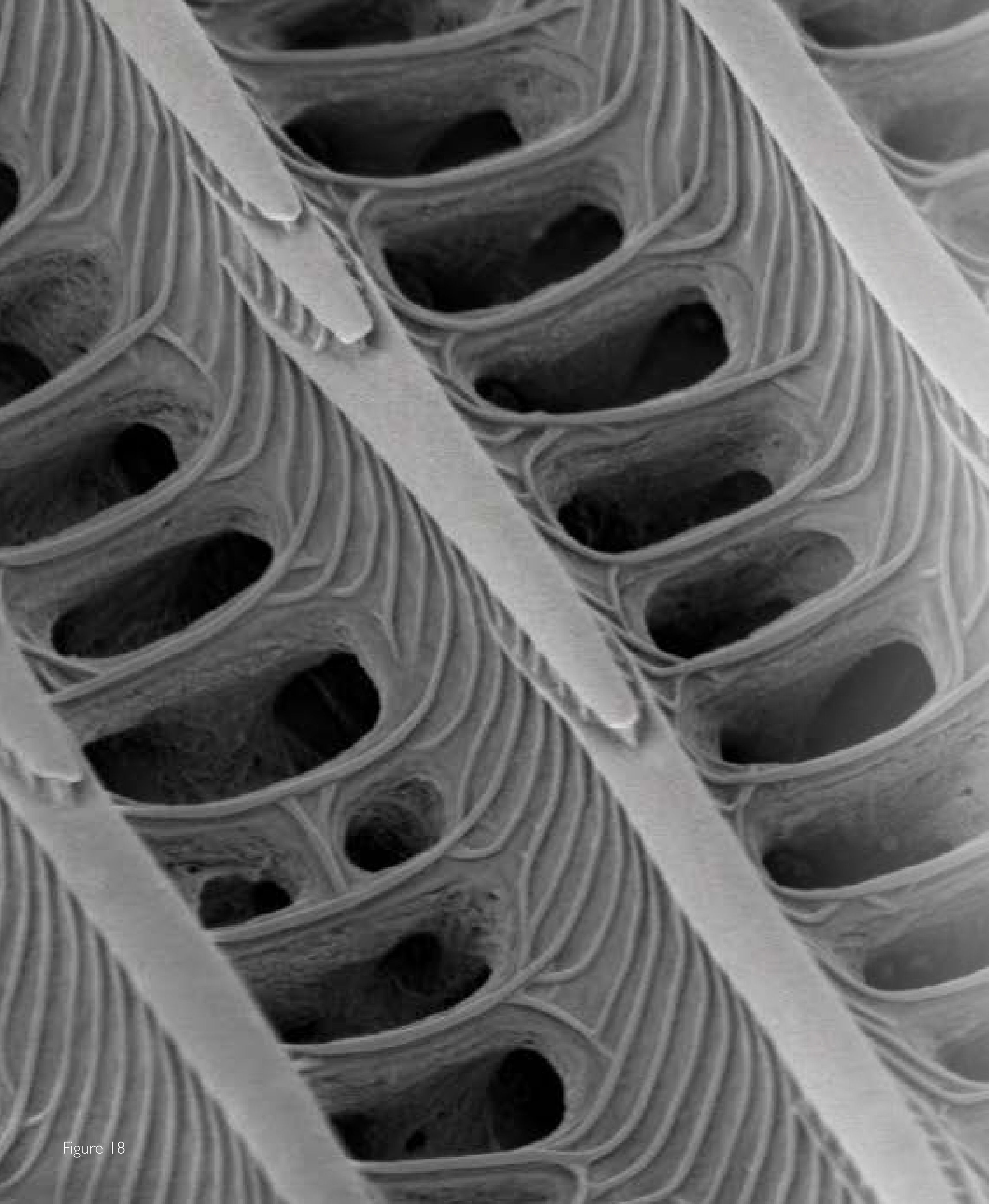

Figure 18

The South American blue morhpo butterfly is well know because of its iridescent blue wings, but the 'structural colourations' doesn't extend to the exterior side of the wings as the yellows, browns and black colours featured are crafted from biological pigments, known as biochromes.[70] The preserved blue wings are covered with minuscule scales of chitin ("is a large, structural polysaccharide made from chains of modified glucose"[71]), the microscopic ridges and cross ribs that resemble rows of trees. The surface texture plays with the light waves to reflect and disperses it in multiple directions. The microscopic distances between the rows of chitin scales determines the colour, as a result the human eye can see the iridescent blue colour.[72]

'Structural colouration' is a more sustainable and environmentally friendly method of creating colour as it does not use any toxic chemicals, commonly used in creating colour in the man-made world. At the moment, the most common way to generate colour is from using pigments. Pigments are small partials of materials that alter the of colour of transmitted or reflected light as a result of absorbing particular wavelengths. Initially, pigments were extracted from natural resources such as plants and minerals, then mixed with either liquids or into a paste to create dyes, paints etc. Evidence of humans using pigments to introduce colour has been found within textiles that date back more than 5,000 years.[73] For example, the pigments created and used by the Egyptians were the largest and most diverse pigments palette from the ancient world.[74] Unfortunately, in recent years the industry has taken a step backwards as the pigments created are highly toxic paints, resulting in an unsustainable practice. This is due to the developments in chemistry which have produced a large array of acritical counterparts that are compatible with new synthetic materials. All created for a more aesthetically pleasing product.[75]

Butterflies' structural colour can be found within a variety of other animals, for example: it can be found with a peacock, especially their feathers because, when looking at a peacock feather it can be seen as an array of beautiful blues, turquoises and greens. However, this is actually the eyes being deceived because a peacock's feathers only use the colour brown. This effect is generated by the way light interacts with each strand and their distance apart from each other. Imagine if it was possible to emulate this in buildings, public realm spaces or even everyday products. It would cut down on a lot of toxic chemicals being sprayed into the air to colour items. As a result, things could potentially change colour depending on the time of day and how much light is in the room. The shape and style of the building would also determine the colour.[76]

70. What Gives the Morpho Butterfly Its Magnificent Blue?, video, Deep Look, 2014.
71. The tough substance forming the outer layer of their bodies of arthropods and a polysaccharide is a large molecule made of many smaller monosaccharides. "Chitin Definition" [online], https://biologydictionary.net/chitin/, [30/03/2018].
72. Yoshioka, S., Kinoshita, S., 'Wavelength-selective and anisotropic light-diffusing scale on the wings of the Morpho butterfly', Proceedings of the Royal Society B: Biological Science, Vol 271, Issue 1539, 2004.
73. Kapsali, V., *Biomimetics for Designers,* (U.K., Thames &Hudson, 2016), pg. 66.
74. Scott, A, D., 'A review of ancient Egyptian pigments and cosmetics', Studies in Conservation, Vol. 61 Issue 4, 2016, Pg. 185-202.
75. Pawlyn, M., *Biomimicry in Architecture,* (Newcastle upon Tyne, RIBA publishing, 2016), pg. 58.
76. Biomimicry, film, Janine Benyus, Leonardo DiCaprio Foundation, October 2015.

Figure 19

Architect and designer Neri Oxman has been working with a group of her students from MIT media lab. She has lead experiments to create objects from one material with 'no seams', this is how nature makes things, for example a silk worm creates it's dome from one single silk thread. She often asks herself "What would design be like if objects were made of a single part? Would we return to a better state of creation?"[77] The research leads them to chitin which is found within butterflies to make their microscopic scales. Around 100 million tons of chitin is made every year from organisms such as: shrimps, crabs, butterflies etc. They believed they could manipulate its properties to produce multifunctional structures from a single piece. From the chitosan paste, they were able to vary the chemical concentrations resulting in a wide range of properties "from dark, stiff and opaque, to light, soft and transparent."[78] Additionally, she uses biomimicry when creating the robot arm to print the structure, because the robot arm has multiple nozzles, similar to spinnerets found within a spider. The work expanded to collaborate with Harvard and other members of MIT, to embed bacteria (that has been engineered to convert carbon from the atmosphere into sugar) with the chitin paste.[79] This alters the materials' characteristics allowing them to create on a larger scale, plus effortlessly transform beams to mesh. Additionally, the material is 100 percent recyclable because when placed in the sea it will nourish the marine life, and will help trees grow if placed in soil.

By looking at natures solutions to creating colour, designers can now create colour without all the toxic chemicals. This has inspired companies such as Japanese company named Teijin Fibers limited, whose design philosophy is to "enhance the quality of life through a deep insight into human nature and needs, together with the application of our creative abilities."[80] As a result, they have developed Morphotex™, which is inspired by the surface structure of the South American blue Morpho butterfly wings. It is the first fibre technology to use structure to create colour rather than pigments and dyes. Morphotex™ is a "fibre with a special structure based on nano-technology mimicking the colour development mechanism found in the wings of the morpho buttefly."[81] Additionally, it is an environmentally friendly material because it uses less energy during the manufacture compared to similar products in the market, plus it does not use any water or energy usually consumed in the dying process.

77. Design at the intersection of technology and biology, TED talk, Neri Oxman, TED, 2015.
78. To create the chitosan paste they need to grind up a bunch of shrimp shell. Which goes against the idea of creating something for nature as it involves killing innocent creatures for their cause. Design at the intersection of technology and biology, TED talk, Neri Oxman, TED, 2015
79. Oxman, N., "Templating Design for Biology and Biology for Design", Architectural Design, Vol. 85, Issue 5, 2015, pg. 100-107.
80. "Corporate Philosophy and Brand Statement" [online], https://www.teijin.com/about/philosophy/, [07/04/2018].
81. "2005 The Teijin Group CSR report" [online], https://www.teijin.com/csr/report/pdf/csr_05_en_all.pdf, [07/04/2018].

Figure 20

The researchers and development team at Teijin designed the fibre made from sixty-one alternative nylon and polyester layers. Each one of these layers resemble rows of trees as seen is the Morpho butterfly wing.[82] The fibre enables colour development by interfering with light waves. As a result, it is able to produce basic colours such as, blue, red and green just by altering the distance between the ridges. No pigments are used anywhere. This technology has opened doors for designers and offers an alternative technology, that is a less hazardous technique of introducing colour to textiles. At the moment Morphotex™ is primarily used in high-apparel, cosmetics and paints because the technology is equally sensitive to humanity and the environment.[83]

Donna Sgro is a fashion designer from Australia, who is most well known for her work with Morphotex™ as she was the first designer to create a structural-coloured garment. She took up the opportunity to work with Morphotex™ when she created a dress for the first Japan's Shinma Creators project back in 2009. Despite her best effort and appearances around the world, including the stint in SXSW Austin as part of the 'Fashionware'. The dress is now part of the London Science Museum and Biomimicry Europa collections.[84] This is because Morphotex™ is not commercially viable at the moment, there is a low market demand for the fibre, as a result preventing the production of sustainable volumes.

82. Kapsali, V., *Biomimetics for Designers*, (U.K., Thames &Hudson, 2016), pg. 68.
83. "2006 Teijin Group CSR report" [online], https://www.teijin.com/csr/report/pdf/csr_06_en_all.pdf, [07/04/2018].
84. "Donna Sgro" [online] http://www.donnasgro.com/Donna-Sgro, [07/04/2018].

Figure 21

Apart from structural colour butterflies are also able to self-medicate. Biologist Jacobus De Roode has been studying monarch butterflies for over ten years, he is fascinated in the fact that they get sick just like humans however, they have a clever way of fixing their illness.[85] The illness monarch butterflies contract in called ophryocystis elektroscirrha, this produces millions of spores on the outside of the butterfly. They cause real damage to the butterflies and it can reduce their life span and limit their ability to fly. The experiments included placing the butterflies (mothers) in a controlled environment, where one side was full of medicinal plants and the other side full of non-medicinal plants. The results were collated and he found out that the monarch butterflies much preferred to lay their eggs on the medicinal plants, around 68 percent of the eggs were laid on medicinal plants. This demonstrates that even though they can't cure themselves, they can help all their future off spring to live a healthier life. Jaap De Rhoode believes that due to this "discovery that these animals can also use medication opens up completely new avenues, and I think that maybe one day, we will be treating human diseases with drugs that were first discovered by butterflies, and I think that is an amazing opportunity worth pursuing."[86]

Furthermore, 'Structural colouration' has multiple applications from fashion to security to large scale construction. Glasgow university are developing a "Nano-structure printing process could thwart bank-note fakers."[87] The technology has possibilities for being used as anti-counterfeiting software, as they are able to create high-resolution images over 100,000 dpi. The bank note surfaces can be embedded with this technology making it ridiculously difficult to forge as the image would shine different colours depending on the angle. However due to the price of manufacturing, research and development it is not common place within design. Plus, dyes and pigments are readily available at an affordable price, even if they are not good for the environment.

85. How butterflies self-medicate, TED talk, Jacobus de Roode, TEDYouth, 2014
86. How butterflies self-medicate, TED talk, Jacobus de Roode, TEDYouth, 2014
87. "Nano-structure printing process could thwart bank-note fakers" [online], https://www.theengineer.co.uk/nano-structure-printing-process/, [09/04/2018].

Figure 22

Spiders

Noun a small eight-legged creature, many species of which weave webs in which to trap insects for food [old English spithra] spidery adjective[88]

88. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) *English Dictionary*, (Glasgow, HarperCollins Publisher, 2009), pg. 774.

Figure 23

Spiders are magnificent creatures; they are truly global citizens because they can be found in nearly every terrestrial habitat apart from Antarctica. There are over 50,000 described species on Earth, ranking them seventh in the world for their population.[89] Unfortunately, because they live in such diverse habitats the number is difficult to identify precisely. Spiders can be traced back 380 million years, whereas the first human on Earth only seven million years ago.[90] Spiders' silk is one of life's greatest creations that scientists have not been able to recreate, even with all the modern technology available today. The silk comes from the abdominal area of a spider and is used to create webs, spiders silk is considered to be the "strongest material in the world."[91]

Silk is essential for the spiders to survive and for their reproduction. According to research carried out by Christopher Viney a professor at the school of engineering (UC Merced), working with a golden orb weaver spider; the spiders are able to use their silk for many purposes, from wrapping eggs for reproduction, to protection, foraging and trailing safety draglines.[92] Hayashi is a biologist who has dedicated her research to spiders and their silk. Her research has helped with the understanding of spiders and how they create silk. Her findings illustrate how remarkable spinnerets are, as they are still able to create silk even once the spider has been fossilized.[93] It is shown on close examination of figure23 of the impression of the spinneret. Multiple fibres come from the spinnerets, because each individual spinneret has many spigots. The silk fibres then exit from the spigots where all of the spigots connect to their own silk gland, which look like a sac full of silk protein. For example, within an orb spider (chosen by Hayashi for it's incredible capabilities to produce seven different types of silk, when in total there are only eleven types throughout) "you would find is a bounty of beautiful, translucent silk glands."[94] There are seven different categories of silk glands within an orb web weaving spider: Tubuliform (Outer silk of egg sac), Aggragate (Sticky droplets), Flagelliform (Fibre of capture spiral), Pyriform (Attachment cement), Aciniform (Prey wrapping, inner lining of egg sac), Minor (temporary spiral) and Major (frame threads dragline).[95]

89. "Spiders facts and information" [online], http://www.spidersworlds.com/, [01/03/2018].
90. The magnificence of spider silk, TED talk, Cheryl Hayashi, TED, 2010.
91. "Spiders facts and information" [online], http://www.spidersworlds.com/, [01/03/2018].
92. Benyus, M, J., *Biomimicry: Innovation Inspired* by Nature, (U.S.A., William Morrow, 1997), pg. 129.
93. The magnificence of spider silk, TED talk, Cheryl Hayashi, TED, 2010.
94. The magnificence of spider silk, TED talk, Cheryl Hayashi, TED, 2010.
95. The magnificence of spider silk, TED talk, Cheryl Hayashi, TED, 2010.

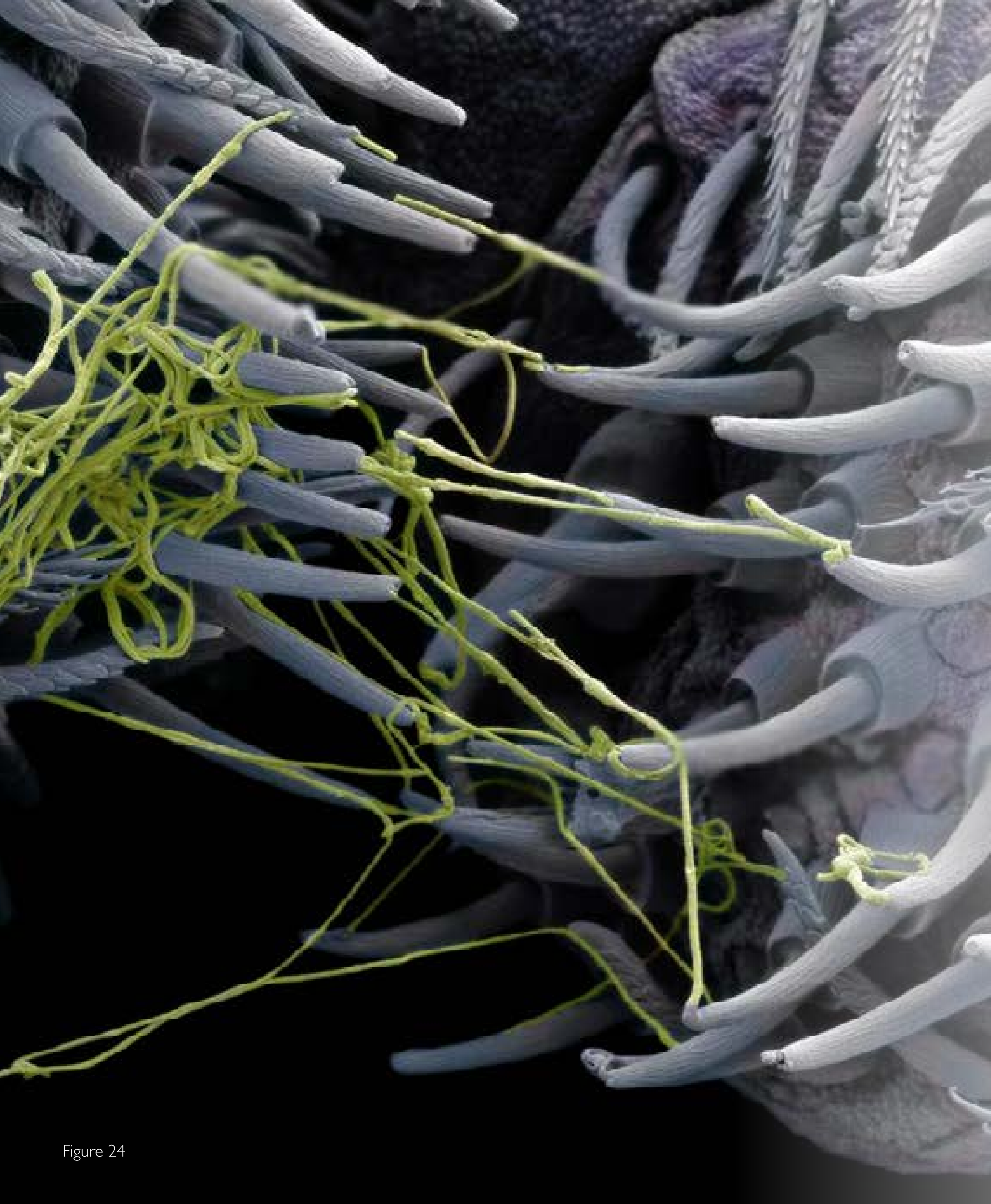

Figure 24

Spiders silk is one of the most highly performative materials known to man. According to Christopher Viney, "None of our metals or high-strength fibres can come even close to this combination of strength and energy-absorbing elasticity."[96] In Kraig Biocraft Laboratories they are preforming tests and experiments on spiders' silk to question this theory and find an alternative man made solution. They believe that "The Future is Made in the Laboratory"[97] The main tests have involved comparing the strength and capabilities of Kevlar and steel to spiders' silk. They conducted two studies to find out the material toughness and the tensile strength of each material. "Compared ounce for ounce with steel, dragline silk is five times stronger, and compared to Kevlar (found in bulletproof vests), it's much tougher and able to absorb five times the impact force without breaking"[98]

Tensile strength is "a measure of the ability of a material to withstand lengthwise stress, expressed as the greatest stress that the material can stand without breaking."[99] Spiders' silk is far superior to steel a man-made material as it has a high tensile strength by over 1,000 (measurement here is in millions of pascals) and these tests were completed using steel that weighted over six grams per cubic centimeter more than spider silk. Dragline spider silk has a material toughness between 120,000-160,000 J/kg (Joules per Kilogram), Whereas, steel is a maximum of 6,00 J/kg.[100] These results demonstrate spiders' silk is far tougher than steel, by over 150,000 J/kg.[101] Furthermore, Christopher Viney discovered that spiders' silk can stretch up to 40% further than its original length and bounce back, this is something steel could never do.[102]

Kevlar is the only aramid fiber (a fiber having resistance to high temperatures and great strength) that has qualities that come close to spiders' silk.[103] Dragline spider silk has a material toughness between 120,000-160,000 J/kg Whereas, Kevlar's material toughness is a maximum of 50,00 J/kg.[104] Therefore, spiders' silk is far tougher than Kevlar by over 100,000 J/kg. However, Kevlar has slightly higher tensile strength than spiders' silks, but these tests were completed using Kevlar that weighted over more than 0.10 grams per cubic centimeter.[105]

96. Lipkin, R., Science News, in January 21, 1995.
97. "Introduction to spider silk, the product" [online], http://www.kraiglabs.com/spider-silk/#anchor, [22/02/2018].
98. Benyus, M, J., *Biomimicry: Innovation Inspired by Nature*, (U.S.A., William Morrow, 1997), pg. 132.
99. Black, D., Groves, R., Hucker, H., McKeown, C., (eds) English Dictionary, (Glasgow, HarperCollins Publisher, 2009), pg. 833.
100. "Introduction to spider silk, the product" [online], http://www.kraiglabs.com/spider-silk/#anchor, [01/03/2018].
101. 102. "Introduction to spider silk, the product" [online], http://www.kraiglabs.com/spider-silk/#anchor, [01/03/2018].
102. Benyus, M, J., *Biomimicry: Innovation Inspired by Nature*, (U.S.A., William Morrow, 1997), pg. 132.
103. Benyus, M, J., *Biomimicry: Innovation Inspired by Nature*, (U.S.A. William Morrow, 1997), pg. 132.
104. "Introduction to spider silk, the product" [online], http://www.kraiglabs.com/spider-silk/#anchor, [05/03/2018].
105. "Introduction to spider silk, the product" [online], http://www.kraiglabs.com/spider-silk/#anchor, [05/03/2018].

Figure 25

The dragline silk is the most interesting and important silk out of the possible eleven different types. Each dragline silk is mixed within the spider's glands, then extruded through their spinnerets, also enriched with individual chemicals and physical properties, which are required for the spider's survival. [106] Dragline silk is used to construct the outer frame work of the spiders' web, as well as for pulling themselves along the web.[107] This makes the web incredibly tough, plus before the web fails it will soak up a large amount of energy. 'The energy absorbency of a spider web could stop a car travelling at full speed with a strand of fiber as thick as a pin'. The dragline silk from Golden Orb-Weaving spider is studied the most by scientists, they are described of having 'a web of golden threads' because they build large webs out of yellow silk that glistens in the sun light. Their dragline silk is their strongest kind of silk because it is vital that it can support the spider's weight, and acts as a safety line as well as a non-sticky spoke of a web.[108] In the next three years there could be a polymer that is as good as spiders' silk at dissipating energy and have similar elastic properties.[109]

For centuries spiders' silk has been the most diversely used silk known to man. Ancient Greeks used to stop bleeding with cobwebs, and Australian Aborigines used spiders' silk to catch small fish.[110] Yet in more recent years, Dave Kaplan of the U.S Army, in their research, development and engineering center, has a particular interest in 'the quest to synthesize a gene for silk like protein'.[111] Even though Kevlar is highly effective, the army have started to look towards nature for a solution. Spiders' silk has the potential to be used as a more lightweight and flexible body and equipment armour. This means the body armour is tougher than Kevlar but as soft as cotton. This has been made achievable by Canadian scientist from the Biotech firm Nexia, from their experiment with their Spider-Goat. The Spider-Goat can produce silk milk (this is milk that contains spiders silk), it was created by embedding DNA from a spider into a goat.[112] Additionally, there is the potential for spiders' silk to be used for anti-ballistic capabilities, that can detect, intercept or destroy ballistic missiles. However, one underpinning principle of biomimicry is ethos, which is the ethical approach and outcome of the final product in relation to saving the planet. If these designs are used to potentially harm or destroy the planet (as in war) this creates an ethical dilemma for the designer.

106. Benyus, M, J., *Biomimicry: Innovation Inspired by Nature*, (U.S.A., William Morrow, 1997), pg. 129.
107. Losonczi, A., 'Solution: Material world', Building Design, Tunbridge, 18/03/2005, pg. 22.
108. "Spider silk: Chemical structure" [online], http://www.chm.bris.ac.uk/motm/spider/page3.htm, [30/02/2018].
109. Losonczi, A., 'Solution: Material world', Building Design, Tunbridge, 18/03/2005, pg. 22.
110. David Attenborough's Natural Curiosities, documentary, Hilary Jenkins, 2016.
111. Benyus, M, J., *Biomimicry: Innovation Inspired by Nature*, (U.S.A., William Morrow, 1997), pg. 136.
112. 113.'In brief', Report/Newsmagazine (Alberta Edition), Vol. 29, Issue 15, 22/07/2002, pg. 58.

Figure 26

Frei Otto is a German architect known for his pioneering lightweight structures that are still relevant over 60 years later.[113] He was awarded the Pritzker prize shortly after he died in 2015. He was awarded the prize due to his highly-innovative idea, talent and "contributions to humanity and the built environment through the art of architecture."[114] He encompasses the meaning of ethos into his work, because he began to look into lightweight and tensile structures that use minimal geometry and minimal material consumption. As a result, he was able to become closer to achieving his goal of structural efficiency. His most famous structures that demonstrate his work in lightweight, tensile structures are the Olympic stadium for the 1972 Munich Olympic Games and the German pavilion at the Montreal World Expo in 1967. He is arguably the greatest champion of tension structures, he was a pioneer for cable-net buildings, and has consequently published a large amount of literature on 'structural design principles from nature'.[115]

There is a vast variety of spider web designs within nature that differ in complexity, from the common place web created by household spiders, all the way to the remarkably engineered tensile structure created by the grass spider (Genus Agelenopsis). To the uniquely shaped architecture from the female bauble spider (Achaearanea globispira) and bowl and doily spider (Frontinella communis).[116] Comparing cable-net structures and spider webs, illustrates that they have a lot of similarities, but it also exposes the gap been biological manufacture and human engineering.[117] Michael Pawlyn has noticed the connection between Frei Otto's work and the work of a spider. However, there is still more work to be done as the main problem is the large sizing of the cables and their visible connections. Nonetheless, designers such as Frei Otto are slowly narrowing this gap, with continuous development humans should be able to get close to the more elegant structures created by spiders.

113. Evan Rawn, "Spotlight: Frei Otto" [online], https://www.archdaily.com/511689/happy-birthday-frei-otto, [15/01/2018].
114. Martha Thorne, "The Pritzker Architecture Prize" [Online], https://www.pritzkerprize.com/about/purpose, [22/01/2018].
115. Otto. F., Institute for light weight structures, volume IL 1 to IL 32, dated from 1971.
116. Pawlyn, M., *Biomimicry in Architecture*, (Newcastle upon Tyne, RIBA publishing, 2016), pg. 30.
117. Pawlyn, M., *Biomimicry in Architecture*, (Newcastle upon Tyne, RIBA publishing, 2016), pg. 31.

Figure 27

Frei Otto has aimed to answer the age-old question 'How to achieve more with less, that is, less material and effort.'[118] He was able to demonstrate the advantages of tensile structure through his larger scale projects. The German pavilion at the World Expo in 1967 in Montreal, is a prime example of how he has used large scale cable net structures to stun the world. The pavilion is one of his most famous pieces of work noted for its grace and originality because it was prefabricated in Germany, then shipped over to Montreal where it was assembled in a relatively short amount of time on site.

Another distinguished structure that defied the odds as many critics said it "could not be achieved" is the Olympic stadia in Munich for the 1972 games, following a similar style as the pavilion combining lightness and strength to provide an architectural landscape. Unfortunately, the large scales of the building affect the sculptural quality, as it was essential to minimize the wind pressure, this results in more low-curved forms. [119] The structure was designed based around the formation of soap bubbles. From his initial experimentation with soap bubbles in the 1950s looking for extreme lightweight structures, this was where his passion was born. He had a very hands on approach to design as he was always experimenting in 3D forms, especially using soap bubbles.[120] Similarly, to soap film and fabric membrane a cable-net structure can support a heavy weight as along as it is not concentrated on to one point, but can transfer the weight via a sufficient transfer length.[121] These experiments resulted in him inevitably becoming the closest to emulating the structure of a spider's web because his structures are both lightweight and strong.

118. Mark, L., "Pritzer Prize recognizes 'visinary architect' Frei Otto", The Architects Journal, London, (online), 11/03/2015.
119. Glaesser, L., *The Work of Frei Otto,* (U.S.A. The Museum of Modern Art, 1972).
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121. Bach, K. Burthardt, B. Otto, F., *Forming Bubbles*, (Stuttgart, Institute for lightweight structures, 1988), pg. 142.

Figure 28

Scientists have been experimenting with the capabilities with spiders' silk for a while now, to find a range of applications for this spectacular material, but Luca Alessandrini a recent graduate from the Royal College of Art, created the first violin made from silk and spiders silk. During his studies at the RCA he spent his time exploring the field of biomaterials within the field of acoustics.[122] Alessandrini admits to having an interest in spiders' silk because of two particular characteristics: elasticity and strength. "The amazing properties of spider's silk means that it serves many purposes. It is a home, a net for catching food and a means of communicating - via vibrations - when prey is ready to be pounced on and devoured,"[123] He developed a violin made of a 'composite material made from worm silk and a binding agent instead of traditionally-used wood, impregnating the violin's top side with three strands of golden silk spun by an Australian golden orb spider.'[124] The most effective place to put the 35cm long strand of spider's silk is under the bridge of the violin, as it uses only a small amount of material. Unfortunately, his approach is expensive, compared to traditional violin making techniques.

In the past, people have used spiders silk as string to create bows for instruments. Whereas, from Alessandrini work with spiders' silk he has been able to uncover a wide range of applications within the acoustic field. As a result of his experiments with the prototype fibres and how mixing the different fibres can create new sounds, his findings illustrate the ability to customize the acoustics depending on the required sound. As a result, there are a range of future applications such as: headphones, speakers and amplifiers.[125]

In addition to the wide range of possibilities spiders' silk brings to the design either in defense, architecture, music or many more; scientists have been looking at spiders' silk and its benefits within the biomedical field, to create artificial tendons and ligaments, they can serve as guides to help regrow the nerves and become like scaffolding for tissue growth. This is due to the tensile strength of dragline silk.[126] This sudden interest comes from the fact that spiders silk does not evoke an immune response.

122. RCA, "Luca Alessandrini", [Online] https://www.rca.ac.uk/students/luca-alessandrini/, [29/02/2018].
123. Mclaughlin, A., 'Design student makes a prototype violin using spider silk', Design Week (Online), London, 30/06/2016.
124. Mclaughlin, A., 'Design student makes a prototype violin using spider silk', Design Week (Online), London, 30/06/2016.
125. Mclaughlin, A., 'Design student makes a prototype violin using spider silk', Design Week (Online), London, 30/06/2016.
126. Chamberlain, G., 'Spider silk could replace torn ligaments', Design news (Online), Vol. 51, Issue 11, pg. 15.

Figure 29

"I think the biggest innovation of the 21st century will be the intersection of biology and technology. A new era is Beginning"[127] – Steve Jobs

127. "Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies" [online], https://challenge.biomimicry.org/en/page/what-is-biomimicry-en, [13/04/2018].

Even though the term biomimicry is modern the concept of it has been around for centuries because around five hundred years ago Leonardo da Vinci warned: "Those who take for their standards anyone but nature – the mistress of all masters – weary themselves in vain."[128] This philosophy has only just started to resonate with people, along with Dr Dayna Baumesiter's theory around biomimicry's three elements. It has become increasingly easy to follow and be part of the movement. One of the elements is biomimicry's Ethos which is used to describe the core ethics, intentions and underlying philosophy of a designer. To examine this concept, I look at examples like the cardboard to caviar project or the Adidas running shoe made from recycled ocean plastic. Unfortunately, this shoe never came in to production, therefore is only a small step in the right direction.

(Re)connect is another element of biomimicry and is used to define a person refining their understanding of nature or new connection with nature. I investigated how we have an emotional and physical connection with nature and the additional benefits. I looked into the education system in more detail by focussing on the benefits of the Steve Van Matre's Earth Education compared to main stream Education. Additionally, I thought it was inspirational to see Pam Warhurst initiating the Incredible Edible Initiative as there are endless benefits to being surrounded by nature and eating home grown foods.

The Final element of biomimicry that I investigated was Emulate which is used to illustrate 'doing biomimicry' as in reacting to and in coordination with nature. 'Doing biomimicry' should do more than just copy the aesthetics of structure observed in nature. Such as the Gherkin in London that takes inspiration from the Venus flower basket sponge. For the process to be properly fulfilled there are many considerations which need to be included, such as scoping, discovering, creating and evaluating.

The initial case study explored was centred around butterflies and their ability to create colour through 'structural colouration' especially seen within the blue Morpho butterfly. 'Structural colouration' is commonly found in nature and is an environmentally friendly way of creating colour, using the way light reacts and is reflected from the nano-scale structure found on a butterfly wing. The case study dived deep into an array of applications that have been influenced by butterflies from medication to security and objects being made from a single material (chitin). It was very enlightening to see the work being produced by Teijin Fibers limited and Donna Sgro it gives hope of a more sustainable future when creating colour, as no dyes or pigments are required to create colour using this method.

128. Da Vinci, L., *The Notebooks of Leonardo Da Vinci*, (New Delhi, General Press, 2016).

The second case study explored was based on spiders and their incredible silk that has a higher tensile strength than steel. It highlights the complexity of spiders' silk and how spiders are able to create the silk using their multiple spinnerets. The investigation found out that there are possible applications within medicine and within the music industry, as the silk can be manufactured into instruments and even amplifiers. Additionally, focusing on Frei Otto's work demonstrated that we are narrowing the gap with spiders' silk when it comes to creating structure and forms using a similar technique. Frei Otto's work used new experimental techniques to make strides within the field that to this day have still not been beaten.

Having carried out in-depth research into the details and traits of biomimicry and its potential for creating a more sustainable future, I was able to find inspirational work using biomimicry that has been around for centuries, as well as the new developments occurring currently. Looking at people and companies at the forefront of development in this field gave more realistic rather than idealistic examples of biomimicry in action, such as Janine Benyus, Michael Pawlyn from Exploration and Dr Dayna Baumesiter. With the aim of answering the question I explored details of the history, as well as the three different elements that make up biomimicry. A thorough in-depth study of the chosen case studies highlighted the potential and the limitations surrounding the use of biomimicry within design.

For the purposes of this dissertation and word limit, only a small section of biomimicry has been covered. Recommended further reading are a case study by Veronika Kapasali explaining how lotus leaf has the ability to capture water and self clean and how this can be used to assist human technology.[129] Due to the limit on words I was not able to cover everything I wanted, as I also planned to look into another case study, either the lotus leaf and its ability to capture water and self-clean or polar bear fur and the potential for solar textiles. I find the subject of biomimicry fascinating and keep learning new and exciting things. Additionally, if I had more time I would have liked to have experimented with some of the ideas that I focused on within the dissertation. For example: experimenting with structural colour, to see if I could try and replicate it or potentially visit a lab that is experimenting within this field. Furthermore, I feel it would have been beneficial to have visited and interviewed professionals within their specialist subjects, this could have been done by visiting the butterfly house within Bristol Zoological Gardens and speaking to the zoologist. Or I could have visited one of the places I have spoken about within the dissertation such as the Olympic stadium in Munich.

129. Kapsali, V., *Biomimetics for Designers*, (U.K., Thames &Hudson, 2016), pg.62.

Figure 30

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