Bionic principles applied to MAV design

Introduction

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The micro air vehicle (MAV) business has boomed in recent years, making them available to a wide range of persons and purposes such as surveillance, delivery of goods, mapping, and many more. Our business realized the potential of MAVs and intends to provide a multirole surveillance drone capable of effortlessly transitioning between air and water by exploiting bionic principles.

Over the last few years there has been a huge boom in the micro air vehicle (MAV) market, making them accessible for a wide range of people and purposes like surveillance, delivery of goods, photographing and many more. Our company has recognized the potential of MAVs and revolutionizes it by transforming a micro air vehicle to a micro autonomous amphibious air vehicle. Which means it has three times as many functions in a single system. //TODO: (Aufgabenstellung als Quellenangabe)

Problem

Bionic engineering principles are difficult to integrate in the construction of a micro air vehicle (MAV). In order to enhance the performance of technological systems, bionic engineering incorporates biological principles and materials. This can be a complex and subtle procedure, requiring an in-depth knowledge of both the biological systems being replicated and the technological requirements of the MAV.

Multiple variables contribute to the difficulties of incorporating bionic engineering principles into the design of an MAV. The necessity to balance the opposing demands of performance, functionality, and durability is one of the key obstacles. Due of the fragility and environmental sensitivity of bionic materials and systems, it might be challenging to fit them into an MAV's tough and high-performance design. In addition, the integration of bionic systems into an MAV necessitates a high level of technical skill and complex production procedures, which can be time-consuming and costly.

Implementing bionic engineering principles in the design of an MAV necessitates a cautious and nuanced approach, and it is a substantial task that calls for a combination of technical expertise, ingenuity, and resourcefulness.

Scoping

For the Scoping of the project we referred to the biomimicry modeling wheel (Fig.1). It allowed us to structure our scoping into three distinctive categories:

- Context definition
- Function identification
- Life's principle integration

{:.image-caption}
The caption for my image

Context definition

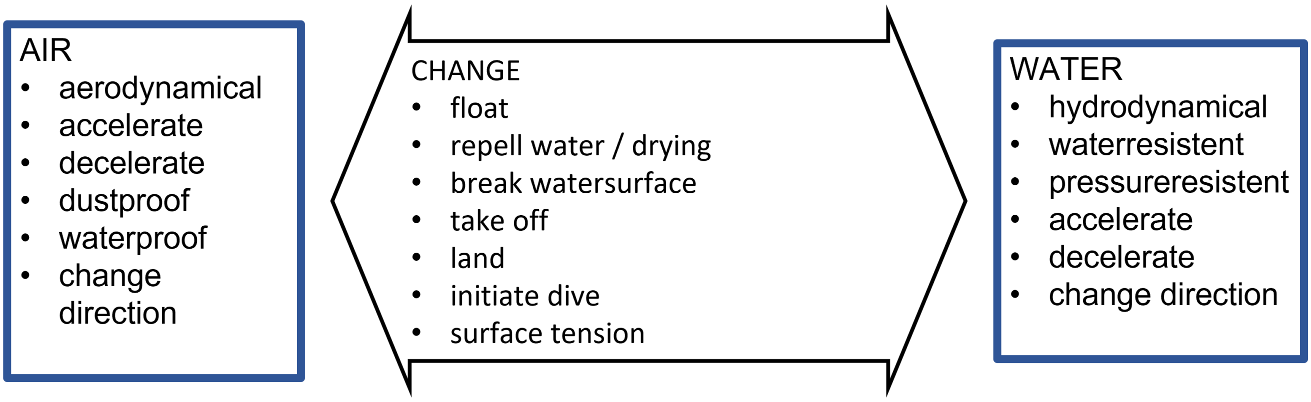
We identified two main contextual areas for our project, and several sub-context, while also considering a transitional context.

The following table summarizes our work in this regard.

AIR	TRANSITION	WATER
WEATHER SUNLIGHT TEMPERATURE HUMIDITY RAIN WIND ICE&SNOW	**DENSITY**	**CONDITIONS** water current waves
HAZARDS animals/insects moving objects abrasives people	**SURFACE TENSION**	**HAZARDS** animals moving objects
TOPOLOGY mountains forests glaciers buildings		**TOPOLOGY** lake/river depth stones/rocks plants

Function's identification

To have a better grasp on what the MAV will have to be able to perform, it's functions had to be placed within their contexts (Fig.2).



Life's principle integration

When looking at how to integrate/use natural engineering solution, we identified the following Life's principle that we wanted to integrate into the project:

1. adapt to changing conditions
2. Change between air and water
3. Temperature change
4. Altitude change
5. be resource efficient
6. Navigation for over and underwater

Discovering

The discovering phase is all about understanding the technical solutions that the natural world has to offer after millions of years of natural evolution.
The objective was to find applicable biological models or answers to the issues and functions that the MAV would have to overcome/perform. Therefore we took the terms of our scoping part and started searching for inspirations in nature. For some of the tasks found in scoping, we did a keyword search on asknature. Other parts we were able to take from experience. In the following section only the few choosen mechanisms which made it to the final prototype are listed.

Function Lense

In this approach we were searching different sources for functionallities our problem has to fullfill. Therefore the questions/functions had to be **Biologized**. [1]

https://asknature.org/strategy/body-protected-from-diving-impact/

How would nature transition from air to water?

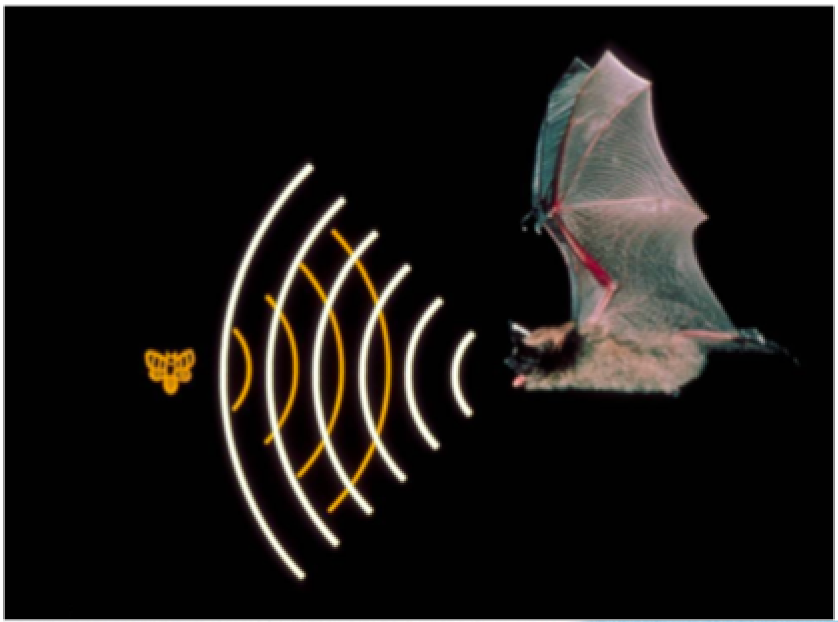
One of the most important and critical functionalities that the MAV must master to perfection is the transition between air/flight and water/diving.
The difficulty here is surface tension, which increases at higher speeds, causing the water to feel like concrete. This has already been evolved over many years by various bird species. One of them are the **Kingfisher**. They fly ~30 meters above the water and dive into the water at a speed of about 97km/h. Not only can they go up to depths of 25 meters with diving, they are also able to pursue fish as deep as 90 meters. In order to break the water tension optimally, they fold their wings just before the impact and the structure of the beak helps them to do so (Figure 1).

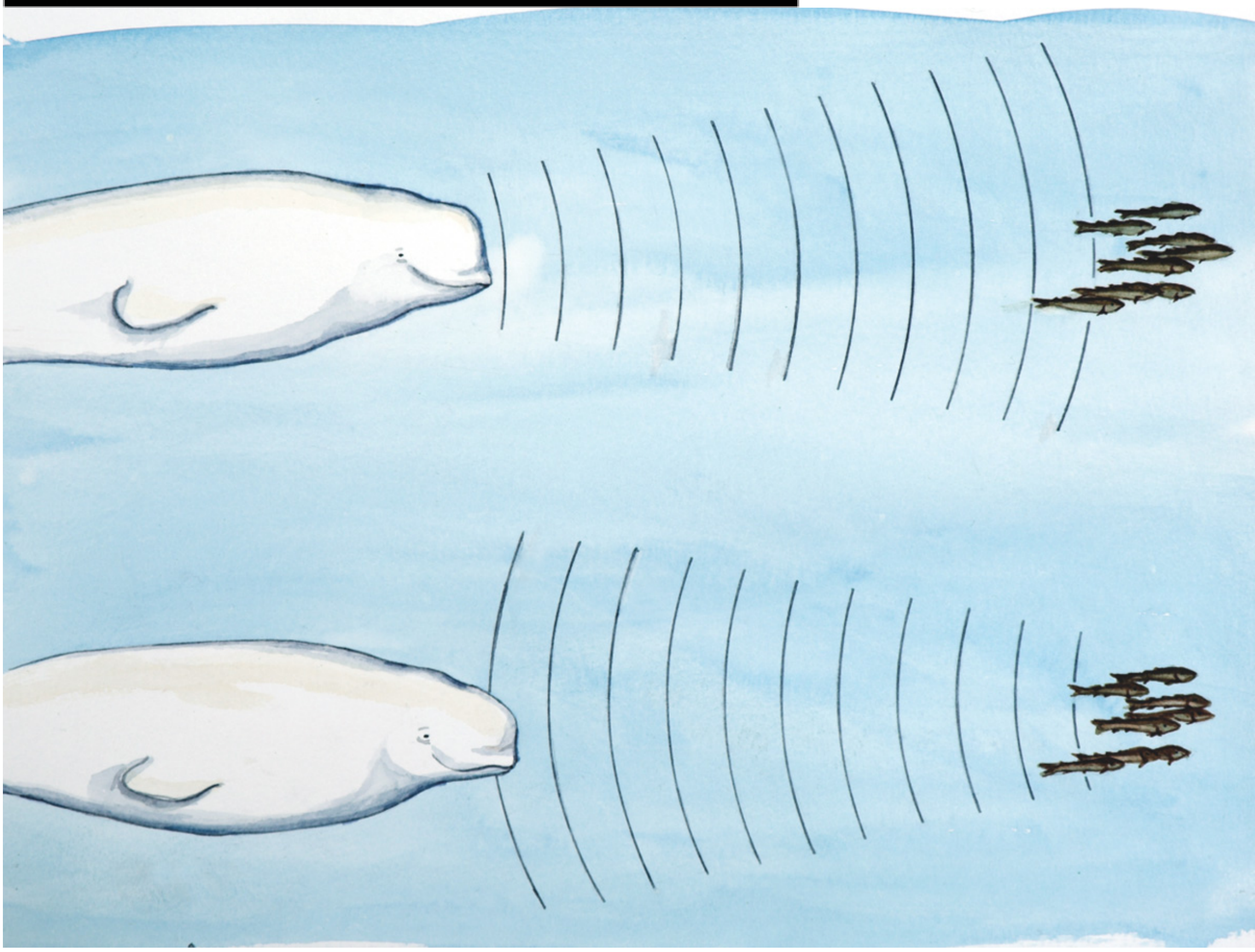
https://www.pnas.org/doi/10.1073/pnas.1608628113
https://www.10000birds.com/well-adapted-for-a-plunge-diving-lifestyle.htm
https://eartheclipse.com/animals/birds/water-diving-birds.html

How would nature navigate under water? (sonar)

//TODO: eine zweite navigation "Discovern"
https://asknature.org/strategy/spiders-surf-on-electric-fields/

Without navigation, the MAV would be useless. the difficulty is to find a navigation underwater and have a fallback scenario. A well-known variation of this is the echosounder, which is used by various animals such as tenrec, bats or wales. This works by emitting very high-pitched sounds that bounce off objects and return to the animal. From the time of bounce and the incoming waves, you can tell the distance, direction, speed, density and even the size of an object. [2]





https://www.zmescience.com/mrf4u/statics/i/ps/cdn.zmescience.com/wp-content/uploads/2013/09/echolocation-sonar-.jpg?width=1200&enable=upscale

How would nature communicate under water and in the air?

Fortunately, or thanks to clever evolution, the echosounder is also used by animals to communicate. This works with the same principle as described above.
https://blog.scienceandmediamuseum.org.uk/the-sophisticated-use-of-sound-in-the-animal-kingdom/

How does nature move underwater and in the air?

MAV's have long mastered the concept of flying. That's why we asked how nature **moves** in the air to find more efficient or suitable approaches.

Spiders can be found multiple kilometers in the air and over a thousand kilometers out to sea. Spiders can detect electronically charged atmospheres. Taking their senses and environment for advantage they crawl on a negatively charged edge from where they shoot out a couple strands of silk. The strands pick up the negative charges of the edge surface and repel from the like charged surface, which let's them travel through air. [3]

Because our mav is breaking into the water at speed, the focus on moving underwater was to change directions and move short distances.

//TODO flagella

Operating Conditions

Operating Conditions are very important for the MAV to consider. Lots of different areas of applications have to be considered, especially with the diverse topology of switzerland in mind.

Resistance to high temperature changes

A good insulator is very important so that the MAV can be used at all temperatures. Many animals but also plants have tricks that we can analyze to protect themselves from the temperature.

A role model are animals with fur like the beaver. Fur always consists of two different types of hair. The longer ones are called guard hairs and form a protective cover for the underhairs, which are denser (1 guard hair protects on average 3 underhairs). The beaver and other aquatic mammals have scales on the outer layer of their underhair. This makes the hairs interlock with each other and prevents the penetration of cold water and traps air bubbles. Air bubbles form a good insulating layer. [4]

Multicellular organisms such as the Pompeii worm (Alvinella pompejana) are also specialized in adapting to extreme temperature fluctuations. Measurements showed that they can survive despite a difference of 60°C in two parts of the body. It achieves this by building protective tubes that create a mosaic of microenvironments with which he can determine the thermal and chemical gradients. [5] [6]

Structural integrity

Good structural integrity has always been proven to bring with it a certain degree of isolation. Nevertheless, it is important that durability is considered as a specific criterion, as the MAV should be able to withstand water pressure, water impact and possible collision. Nature is once again a wonderful source of inspiration for structural integrity with many completely different techniques to meet the criteria.

By hammering the tree, the woodpecker must stop forces to prevent brain injury. This is achieved by the unique structure of its skull. The skull bone has a layered, plate-like structure that resembles a sponge. They function as shock absorbers, deflecting the forces of impact in different directions. [7]

Diatoms have another unique strategy to ensure stability. They create a shell of silicona. Through a characteristic structure such as circular or star-shaped and a pore pattern, they manage to create a particularly good structural integrity. Not only diatoms. Not only diatoms but also the Venus' flower basket sea sponge uses a unique structure for itself. Like the diatoms, the sea sponge is also made of silica (in fact, glass).
A layering of 50 to 200nm small silica spheres and organic compounds can prevent the propagation of cracks. The relatively

stiff inorganic spheres and the energy-absorbing organic compounds are arranged in a square lattice that is rolled up into a tube. This is the main form of the glass sponge and is so tough that even the shrimp living in its woven glass basket cannot break out. [8] [9]

Naturalist Lens

After a functional analysis and the elaboration of operating conditions, the tables should be turned and nature should be used as an inspiration. For this purpose, sites such as asknature can be used to look for exciting ideas. [10]

Buoyancy

To create neutral or positive buoyancy, fish use a simple but very solid strategy. They have a swim bladder, which is located in the body cavity. This bubble is filled with gas, which can give good buoyancy due to its low density. [11] [12] [13]

Swarm behaviour

In order for several MA[^3]V to work together on a mission, they must be able to act in a "swarm".

One feature that would be beneficial in a swarm is collision detection. Locusts migrate in a huge swarm without colliding. Like humans, their movements are converted into electrical signals by the eye and finally read by the brain. the exciting thing is that locusts only detect those movements that interfere with their flight path. this happens because the electrical signal increases when an object moves directly towards them. this signal is then filtered according to strength so that only those objects which are on a direct flight path are detected. [14]

Another useful feature would be the collaboration between the different individuals of the swarm. Honey bees can share their knowledge through two different channels. On the one hand, they communicate through movement by performing a so-called "waggle dance", which indicates to other bees where, for example, the food source is. On the other hand, they can communicate through pheromones. When a worker bee stings, it produces pheromones that alerts the other bees of danger.

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Defense

//TODO: defense schreiben
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6646469/#:~:text=For%20self%2Ddefense%2C%20electric%20eels,nociceptors%20to%20deter%20their%20target.
https://asknature.org/strategy/deployable-web-distracts-predators/
https://www.birdwatchingdaily.com/news/science/secrets-of-the-worlds-poisonous-birds/

Hydrophobicity

//TODO fertig stellen
https://asknature.org/strategy/surface-allows-self-cleaning/

Idea Creation

After the discovering phase, we were able to move on to the next phase with a lot of interesting strategies of nature. This chapter explains which ideas are combined into a prototype, how they interact and which biomimicry approaches could not be used.

//TODO: Image of Prototype handdrawn

1. To make transitoining from air to water as easy as possible, two different traits inspired by kingfisher will be adopted. On the one hand, attention will be paid to a slender hydrodinamic design, which helps to break into the water at high speed, and on the other hand, the wings and propellers will be collapsible to further optimise the hydrodynamics.
2. For vision, we are integrating the bee's functions by incorporating compound vision cameras that can perceive as many aspects of the environment as possible. Not only the vision but also the swarm behaviour should work as well as the bees. This will be made possible with emergent behaviour AI, which mimics the behaviour of bees so that several MAVs can collaborate with each other.
3. As a denfense mechanism, the prototype is to be coated with a non-lethal toxin so that enemies in the environment as well as human opponents can be kept at a distance.
4. To navigate underwater and in poor conditions, echolocation technology is used for maximum performance in all conditions.

Inspired by whales and bats, ultrasound is also used to communicate and transfer research data underwater.
5. To create a hydrophobic effect, the surface of the fabric is coated with a water-repellent coating, which also increases bacterial resistance.
6. The drone's frame is modeled like marine organisms like Sponges and Diatomea. Topological optimization, a novel technique, guarantees a lightweight but sturdy construction with insulation capabilities that shield delicate gear from impacts.
7. Similar to the Anacondas in the Amazonian Basin or certain microorganisms with their flagellum, while underwater the drone should be propelled by its tail.
   Thus it can push itself and travel in 3D underwater space when agitated.
8. To control the buoyancy, a bladder similar to the fish should be used. This bladder should be filled with gas and be controllable to stabilize the drone in the water.

Of course, many exciting technologies did not qualify for the final prototype.

- Surfing on electric fields" was not feasible as a means of transport because the weight of the MAV is too great.
- Although the Pompeii worm is insanely resistant to temperature differences, its protective tube building strategy did not translate well into a micro air vehicle.
- Fur as insulation has long been discussed as it can also be water repellent and hydrophobic. However, it was decided against, as a coating and a smooth surface is more practical and easier to produce.

In the discussion, the possibility of moving forward under water for short distances was also often discussed, as the anwnendugsfall was only intended for a fast, deep dive. It was decided to incorporate a biomimic aspect for a controlled forward movement under water. Therefore, the discovery process had to be gone through again and the flagella was found.

Evaluation

//TODO: Kapitel beschreibung fertig machen
//TODO: insert image icons per life principle

In this chapter, the selected functions are evaluated on the basis of the life's principle, which we set out to achieve in chapter XY.

Evolve to Survive

Continually incorporate and embody information to ensure enduring performance. //TODO: quoting style

Replicate Strategies that work

functioning micro air vehicles have already implemented many strategies. therefore, some components such as the propeller structure and RF communication will be adopted in the new design. In addition, various strategies from nature mentioned in the Idea Creation chapter are reused and adapted to the MAV context.

Be Resource (Material and Engergy) Efficient

Skillfully and conservatively take advantage of resources and opportunities //TODO: quoting style

Use Multi-functional Design

Some multifunctional designs have been integrated. One of these is the flagella, which serves as a means of transport in water and as an antenna for RF signals in the air. Another such design is the echo sounder, which can be used not only for navigation but also for communication. A final and most exciting multifunctional design is the topologically optimized surface that combines maximum lightness, insulation and resistance.

Recycle all Materials

This topic is discussed in more detail in the chapter on Cradle to Cradle. From the beginning, however, care was taken to make all materials as recyclable as possible. As an example, a biodegradable plastic called BiomeHTX is used. To give the non-recyclable components a new life in other applications was another very important aim.

Fit form to function

The shape of the prototype was worked out as minimalistic as possible and as efficient as possible, so that the MAV can fulfill all functional criteria as lean as possible.

Adapt to changing conditions

Appropriately respond to dynamic contexts. //TODO: quoting style

Incorporate Diversity

For some key components, such as navigation and communication, a strong focus was placed on diversification. For navigation, cameras and echolot were used to take into account failures, changing visibility qualities and partly unpredictable environments. Communication does not work in the same way in the water as it does on the surface, so two different technologies (RF and echolot) are used.

Use Life-friendly Chemistry

Use chemistry that supports life processes. //TODO: quoting style

This life principle was the most difficult to fulfill, as the hydrophobic and non lethal toxic coating is a chemical product that needs to be inspected more closely. There are already several solutions, but whether they are safe in all the designated areas of application must be tested in more detail in a study to be absolutely sure.

Prototype

Concept

Extension Possibilities

Cradle to Cradle

Innovation through biomimicry, applied lifes principles, and all other techniques are incomplete without attempting zero waste production and developing a cradle-to-cradle product.

- The hull, propeller, and topologically optimized structure will be made from a 3D-printable biodegradable material, BiomeHTX.
- The components will be modular so that they can be replaced in the event of problems and fed into a new lifecycle.
- The electronics will be supplied protected so that they can be recycled back into the technical cycle.

Discussion

Thanks to a cradle to cradle and biomimicry approach, the problem was approached in a completely different way and viewed from a completely new angle. this led to the functionalities being rethought from scratch and not only the question of what? but repeatedly also the question of why? was in focus.
Starting with scoping, it was not yet clear how exactly the end product could look, and everything that could be relevant was simply questioned and described. In the process, for example, it emerged that the transition from the surface into the water plays a central role. In the discovering part, many exciting and new techniques appeared, which could (not always) be used, but even if they were not used, they have remained in the back of the mind for the next project (e.g. sending data like water strides).
When it finally came to the prototype, a lot of preliminary work had been done and only the compatibility and technological requirements had to be checked. This was not always easy, but thanks to the good groundwork, a lot of time could be saved.

Conclusion

References

The following links are relevant:

https://asknature.org/strategy/beak-protects-during-dives/

https://asknature.org/strategy/deep-divers-manage-temperature/

https://asknature.org/strategy/leg-position-initiates-dive/

https://asknature.org/strategy/spinning-makes-safe-dive/

https://asknature.org/strategy/beak-provides-streamlining/

https://asknature.org/strategy/body-protected-from-diving-impact/

https://asknature.org/strategy/legs-reversibly-stick-to-surfaces-underwater/

https://asknature.org/strategy/olfactory-cues-aid-in-prey-detection/

https://asknature.org/strategy/moths-alter-flight-to-deal-with-winds/

https://asknature.org/strategy/sonar-adjusts-to-surroundings/

https://asknature.org/strategy/navigation-underwater/

https://asknature.org/strategy/eyes-see-magnetic-fields/

https://asknature.org/strategy/spiders-surf-on-electric-fields/

https://asknature.org/strategy/how-flies-survive-freezing/

https://asknature.org/strategy/legs-detect-small-vibrations-for-communication/

https://asknature.org/strategy/body-designed-for-fast-efficient-swimming/

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1. https://moodle.zhaw.ch/pluginfile.php/477890/mod_resource/content/2/04%20Biomimicry%20-%20Discovering_11102022.pdf ↩
2. https://www.discoverwildlife.com/animal-facts/what-is-echolocation/ ↩
3. https://asknature.org/strategy/spiders-surf-on-electric-fields/ ↩
4. https://asknature.org/strategy/fur-keeps-heat-in-and-cold-water-out/ ↩
5. https://www.cambridge.org/core/journals/international-journal-of-astrobiology/article/adaptations-to-environmental-extremes-by-multicellular-organisms/788142428590F0D32F24F139CA20B9B4 ↩
6. https://asknature.org/strategy/worm-tolerates-temperature-gradient-of-140-deg-f/ ↩
7. https://asknature.org/strategy/spongey-cranium-absorbs-impact/ ↩
8. https://asknature.org/strategy/diatoms-build-glass-houses-that-are-stable-and-strong/ ↩
9. https://asknature.org/strategy/glass-skeleton-is-tough-yet-flexible/ ↩
10. https://moodle.zhaw.ch/pluginfile.php/477890/mod_resource/content/2/04%20Biomimicry%20-%20Discovering_11102022.pdf ↩
11. https://asknature.org/strategy/swim-bladder-helps-maintain-buoyancy/ ↩
12. https://www.scientificamerican.com/article/floating-with-a-swim-bladder/ ↩
13. https://www.britannica.com/science/swim-bladder ↩
14. https://asknature.org/strategy/collision-detection-in-a-swarm/ ↩
15. https://www.thoughtco.com/how-honey-bees-communicate-1968098 ↩

16. https://asknature.org/strategy/collaborating-for-group-decisions/ ↩