WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Colour changing 3D prints

BIOMIMICRY DESIGN	Description
Step 2 – Biologioe	**2.a Ask yourself how nature can solve this.** How are animals capable of rapid colour change in critical situations with less energy consumption? **Context** In nature, the chameleon changes colour by using specialised cells called chromatophores, which rapidly adjust pigment and reflect different wavelengths of light. External stimuli control this process and do not require a large amount of energy. **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do. • **Dynamic colour changing:** Chameleons change colour for camouflage and communication. • **Material efficiency:** Chameleon's skin adjusts pigment without waste. • **High precision:** Chromatophores in chameleon skin control hues. **2.c Flip the question. Consider opposite functions.** How do organisms in nature manage to change colours to adapt to their environment rapidly?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Rapid colour change for camouflage and communication. **Natural models** • **Cephalopod:** Using a complex system of pigment cells for instant adaptations.

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	• **Butterflies:** Change colour depending on viewing angle, improving mate attraction and protection. • **Spiders:** Use pigmentation and texture to blend into their habitat. **3.b Identify experts & connect to communities of biologists and naturalists.** • Universities and research institutions (Harvard University, Smithsonian Institution) • Professional communities (International Society of Biology, Ecology Society) • Online forums and groups (ResearchGate) • Local organisations and events
Step 4 – Abstract	**4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Core functions** • **Colour change:** Chameleons change colours for camouflage, communication, and temperature regulation. • **Pigment and structural colours:** Chameleons use both pigments and structural colours to achieve their colour changes. • **Chromatophores:** Chameleons have colour-bearing cells that contain pigments which are responsible for their colour change. • **Iridophores:** Chameleons have iridophore cells that produce structural colours through nano-sized crystals that reflect light. **Keywords** Adaptability, camouflage, communicativeness, instantaneity, control, and reflection.  https://asknature.org/innovation/colourful-3d-printing-inspired-by-chameleons/

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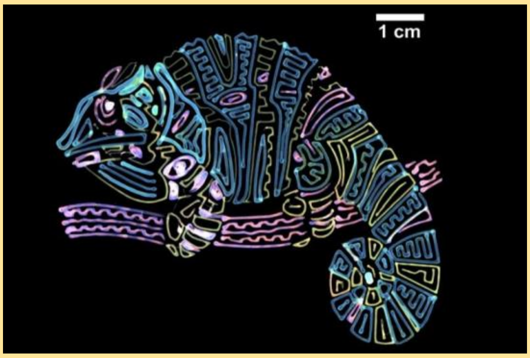
4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

- **Dynamic colour adaptation:** Create the printer to allow immediate colour changes based on user preferences or environmental cues.
- **Efficient use of materials:** Optimise the printing process to use a single type of material while achieving a wide range of colours and effects.
- **Precision and detail:** Incorporate advanced control mechanisms to ensure accurate and detailed colour application during printing.
- **User-centric interface:** Develop an intuitive interface that allows users to easily select and customise colours and patterns.



https://news.illinois.edu/view/6367/809468

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Step 5 – Emulate

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5.a List your key information and explore as many ideas as possible.

Features

Dynamic colour adaptation.

Ideas

Customised jewellery, adaptive clothing, dynamic art, phone cases, car exteriors or interiors, interactive toys, wearable health monitors, prosthetics, product packaging

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Features

- Change colour based on lighting or user preference.
- Adjust colour to match different outfits or environments.
- Change colour for aesthetic or functional purposes.

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	• Change colour for personalization or safety. • Change colour to attract attention or convey different messages. **Context** Industry applications, education, military settings, and healthcare. **Constraints** • Complexity of integrating real-time colour mixing. • Challenges in maintaining print quality during colour transitions. • Initial investment in technology and materials. • Balancing affordability with advanced features. • Ensuring the interface is intuitive for non-technical users. • Providing support and resources for diverse user backgrounds. **Idea selected** Adaptive clothing which adjust their colour to match different outfits or environments.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model**. The design concepts for the colour-changing 3D printer largely align with the criteria of the design challenge, particularly in terms of innovation and sustainability. However, challenges in technical implementation and cost management must be addressed. The business model appears feasible, particularly if supported by strategic partnerships and a focus on sustainability, which aligns with current market trends and consumer preferences. Overall, with careful planning and execution, the project has the potential for success. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** By revisiting and refining each step, the proposed solution for a colour-changing 3D printer can be made more viable. Focusing on simplified technology, sustainable materials, user-centric design, and a robust business model will enhance the chances of success while ensuring alignment with environmental goals and market demands. Regular feedback and collaboration will be key to adapting the solution as it evolves.

Additional resources:

https://biomimicry.org

https://asknature.org/innovation/colourful-3d-printing-inspired-by-chameleons

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: The natural white pigment of Cyphochilus beetle

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can certain organisms reflect light effectively to improve their camouflage? **Context** Some organisms reflect light efficiently through specialised structures, such as microscopic scales or nanostructures, that manipulate light at a wavelength level. These adaptations allow them to blend seamlessly into their environment, reflecting the colours and patterns around them. By mimicking the surrounding light conditions, they improve their camouflage, making it difficult for predators or prey to spot them. This efficient reflection of light often requires minimal energy, allowing these organisms to conserve resources while maximising their survival. **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do. • **Light reflection:** Organisms that use microscopic structures to camouflage themselves, such as the Cyphochilus beetle. • **Non-toxic composition:** Plants and microorganisms that produce natural pigments such as chlorophyll. • **Durability and stability:** Pigments in butterfly wings that resist UV and weather conditions. **2.c Flip the question. Consider opposite functions.** How do animals camouflage their colours to adapt to different habitat environments?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Light reflection. **Natural models**

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	• **Butterfly wings:** Butterflies have microscopic structures on their wings that interact with light, generating iridescent effects. This allows them to camouflage themselves in their natural environment and attract mates. • **Chameleon skin:** Chameleons have special cells called chromatophores that allow them to quickly change colour depending on their environment or emotional state, helping them hide from predators or communicate with other chameleons. • **Corals:** Corals develop natural pigments that protect their tissues from damage caused by ultraviolet radiation, while also having vibrant colours that contribute to the diversity of corals in reefs. • **Spiders:** Certain spiders develop webs with patterns and colours that match their natural background, protecting themselves from predators and helping them attract prey. **3.b Identify experts & connect to communities of biologists and naturalists.** • Local universities. • Research institutions. • Entomological Society of America. • Society for integrative and comparative biology. • Online communities and forums. • Conferences and workshops.
Step 4 – Abstract	**4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions:** • **Light scattering:** The primary function of the microstructures in the Cyphochilus beetle's exoskeleton is to scatter light, resulting in a brilliant white appearance. • **Colour production:** In nature, microstructures can produce colours through the interference and scattering of lightwaves. This is different from chemical pigments, as the colour is generated by the physical structure rather than a chemical compound. • **Optimistion of light interaction:** The nonuniform scales on the Cyphochilus beetle's exoskeleton are optimized to interact with light in a way that enhances its visibility. This optimization ensures that the beetle's white colouration is highly effective in its natural environment.

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	Keywords Microstructures, lightwaves, light scattering, exoskeleton, nonuniform scales, irregularly spaced filaments.  https://asknature.org/innovation/super-white-material-inspired-by-the-cyphochilus-beetle/ **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • **Bright and reflective surfaces:** Develop surfaces that effectively bounce light, creating a bright and appealing appearance. • **Safe and eco-friendly materials:** Use materials that are naturally derived and environmentally friendly, ensuring they do not pose health risks to individuals or harm the planet. • **Long-lasting performance:** Develop products that are resilient to various environmental factors, ensuring they maintain their quality and appearance over time. • **Versatile colour options:** Develop products that can adapt to different settings or personal preferences, allowing for changes in colour or appearance as needed.  https://www.jacksonsart.com/blog/2021/09/10/pigment-colour-index-white-pigments/
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Bright and reflective surfaces, safe and eco-friendly materials, long-lasting performance, versatile colour options

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	Ideas Healthy and functional food, shelf-stable Ingredients, eco-friendly paints, coatings for buildings, cosmetics, packaging, textiles, outdoor and indoor decor, toys **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • **Bright and reflective surfaces:** eco-friendly paints, reflective and water-resistant coatings for buildings, cosmetic products. • **Safe and eco-friendly materials:** biodegradable packaging, non-toxic materials, fashion and textiles, healthy and functional food, shelf-stable Ingredients. • **Long-lasting performance:** outdoor gear, durable home décor. • **Versatile colour options:** fashion and textiles, toys and educational Products, customisable colour palettes. **Context** Consumer goods, home and living, outdoor applications, education and community engagement. **Constraints** • **Material limitations:** Need to source sustainable, non-toxic materials that are both effective and aesthetically pleasing. • **Cost considerations:** Products should be affordable to encourage widespread adoption while maintaining quality. • **Durability requirements:** Items must withstand environmental factors without degrading quickly. • **Regulatory compliance:** Ensure products meet safety standards and comply with relevant environmental regulations. **Idea selected** Shelf-stable Ingredients: Develop food products with ingredients that have a long shelf life without the need for artificial preservatives, ensuring they remain fresh and safe to consume
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The design concepts inspired by the Cyphochilus beetle align well with the criteria of the design challenge and demonstrate compatibility with Earth's systems through sustainable practices. Advancements in biochemistry support the technical feasibility of sourcing and producing a

	natural white pigment, while the business model is strengthened by market trends favouring eco-friendly products. Addressing constraints and investing in research and development will be critical to successfully bringing these concepts to market. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** By revisiting and refining the previous steps in the design process, we can create a robust plan for developing a natural, non-toxic white pigment inspired by the Cyphochilus beetle. Focusing on product refinement, overcoming challenges, and executing a comprehensive implementation plan will enhance the viability of this solution in the marketplace. This approach will not only cater to consumer demands for sustainable products but also promote a healthier relationship with our environment.

Additional resources:

https://biomimicry.org

https://asknature.org/innovation/super-white-material-inspired-by-the-cyphochilus-beetle

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LET'S MIMIC SOLUTIONS

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Solution: The termite mounds' tunnels

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologize</td><td>
2.a Ask yourself how nature can solve this.
What is nature's strategy for creating natural ventilation systems to regulate temperature and airflow without the need for external energy?
Context
The termite mounds are designed with a network of tunnels that draw in cool air from the base and expel warm air from the top, utilizing convection currents. Termite mounds harness the natural flow of air, using temperature differences to create circulation. Even in extreme heat, termite mounds maintain a stable internal environment. The mound structure provides cooling and airflow with zero energy input, relying solely on the design and natural airflow dynamics.
2.b Ask yourself what your design wants to do.
Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish.

Enhance energy efficiency: Termite mounds use natural ventilation and thermal mass to regulate internal temperatures with minimal energy input.
Maintain thermal comfort: The construction materials of termite mounds, such as soil and clay, have high thermal capacity. This allows the mound to absorb and store heat during the day and release it during the cooler night, helping to stabilize internal temperatures.
Humidity regulation: Termites maintain a moist environment within the mound, which helps regulate temperature and humidity. The moisture in the soil and the termites' activities contribute to a stable microclimate.
Adaptive architecture: The architecture of termite mounds can vary depending on the external environment. In cooler habitats, mounds are designed to minimise heat loss, while in warmer areas, they are structured to enhance ventilation and cooling

2.c Flip the question. Consider opposite functions.
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	What is nature's strategy for creating natural humidity control systems to maintain optimal moisture levels?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Functions** • **Thermal regulation:** passive cooling and temperature regulation. • **Natural ventilation:** minimal energy usage. **Natural models** • **Termite mounds (Macrotermes michaelseni):** Termite mounds in Africa maintain stable internal temperatures despite extreme external conditions. They achieve this through complex ventilation systems, thermal mass, and insulating materials. • **Fish gills and their lungs:** Gills in fish and lungs in air-breathing animals are highly efficient at gas exchange, enabling optimal respiratory function with minimal energy. • **Beehives:** Bees regulate the temperature inside their hives through fanning their wings to create airflow and clustering to generate heat. This natural ventilation system helps maintain a stable environment for the hive • **Cactus spines:** Cacti in arid environments use their spines to collect and direct water droplets from fog. The spines also provide shade and reduce air movement around the cactus, minimizing water loss and helping to regulate temperature • **Ant nests:** Some ant species build nests with intricate tunnel systems that promote airflow and regulate temperature. These tunnels allow for passive ventilation, helping to keep the nest cool in hot climates • **Leaf structures:** Many plants have leaves with structures that promote natural ventilation and cooling. For example, the stomata on leaves open and close to regulate gas exchange and water loss, helping to maintain optimal internal conditions • **Penguin huddles:** Emperor penguins huddle together to conserve heat and protect themselves from the cold. This collective behaviour reduces heat loss and helps maintain a stable temperature within the huddle **3.b Identify experts & connect to communities of biologists and naturalists.** • University departments and research institutes. • Research institutes. • Biomimicry Institute.

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	• Ecology societies (e.g Ecological Society of America (ESA)). • Natural history museums. • Scientific journals and conferences.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Core functions** • **Thermal regulation:** The mounds are constructed based on soil and clay, which have high thermal capacity. This allows the mound to absorb and store heat during the day and release it during the cooler night, stabilising internal temperatures. • **Natural ventilation:** Termite mounds have a network of tunnels and chimneys that facilitate natural airflow. Warm air rises and exits through the chimneys, creating a convection current that draws in cooler air from the base.  Generated with AI tool. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • **Thermal regulation:** Create buildings with well-designed ventilation systems and thermal mass elements. Incorporate features like thick walls or insulating materials that keep the interior temperature stable without relying on mechanical heating or cooling. Ensure that the building's layout promotes natural airflow to maintain comfort in varying weather conditions. • **Natural ventilation:** Incorporate strategically placed vents and openings to promote natural airflow throughout the building. Use design elements such as high ceilings, cross-ventilation openings, and adjustable vents to enhance air circulation and maintain good indoor air quality.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.**

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Features

Stable indoor temperatures with minimal energy use, improve air quality and reduce reliance on mechanical systems.

Ideas

Stack ventilation, wind catchers, high thermal capacity materials, phase change materials, green roofs, living walls, operable windows and louvres, dynamic facades, night purge ventilation, shading devices, building orientation, courtyards and atriums

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Features

- **Thermal regulation (stable indoor temperatures with minimal energy use):** high thermal capacity materials, phase change materials (PCMs), green roofs, living walls, dynamic facades, building orientation.
- **Natural ventilation (improves air quality and reduces reliance on mechanical systems): stack ventilation, wind catchers, operable windows, ventilation louvres, night purge ventilation, shading devices, courtyards,** and atriums.

Context

- Climates with significant temperature variations.
- Climates where natural ventilation can significantly improve indoor air quality.
- New constructions or major renovations where thermal management can be integrated early in the design process.
- New buildings and renovations where airflow can be optimised.

Constraints

- Higher initial costs and potential complexity in installation.
- Additional structural support may be required, and maintenance can be intensive.
- Limited flexibility for existing structures and retrofits.
- May require significant structural modifications.
- Potential for mechanical failure and maintenance.

Idea selected

- **High thermal capacity materials:** Just like termite mounds use soil and clay to absorb and store heat, using materials with high

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	thermal mass in buildings can help stabilize indoor temperatures by storing heat during the day and releasing it at night.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** **High thermal capacity materials** have the ability to absorb, store, and release significant amounts of heat. In buildings, using materials with high thermal mass can help stabilize indoor temperatures by moderating temperature fluctuations. **Constraints** • **Climate suitability:** Thermal mass materials are most effective in climates with significant temperature variations between day and night. In regions with consistently mild or extreme temperatures, their benefits may be limited. • **Initial construction costs:** Incorporating high thermal mass materials like concrete, brick, or rammed earth can increase initial construction costs due to the need for specialised materials and construction techniques. • **Structural considerations:** The weight of thermal mass materials requires strong structural support, which can complicate the design and increase costs. • **Design integration:** Effective use of thermal mass requires careful design and placement within the building to maximize heat absorption and release. Poor integration can lead to suboptimal performance. • **Insulation requirements:** Adequate insulation is necessary to ensure that the stored heat is retained and not lost to the external environment. **Compatibility with the Earth's systems** • Reduce energy consumption. • Promote sustainability. • Enhance indoor air quality. **Technical feasibility** • **Material availability:** High thermal mass materials like concrete, brick, and rammed earth are widely available and can be sourced locally, making them technically feasible for most construction projects.

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	• **Design flexibility:** These materials can be integrated into various building designs, from traditional to modern, allowing for flexibility in architectural styles. • **Performance:** When properly designed and integrated, thermal mass materials can significantly enhance the thermal performance of buildings, reducing energy consumption and improving occupant comfort. **Business model feasibility** • **Cost savings:** While initial construction costs may be higher, the long-term savings in energy costs can make thermal mass materials economically viable. Reduced reliance on mechanical systems translates to lower operational costs. • **Market demand:** There is growing demand for energy-efficient and sustainable building solutions, making thermal mass materials an attractive option for developers and investors. • **Regulatory support:** Increasingly stringent building codes and regulations promoting energy efficiency and sustainability support the adoption of thermal mass materials. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To generate a viable solution for maintaining stable indoor temperatures with minimal energy use, improving air quality, and reducing reliance on mechanical systems, the proposed design should look into: climate suitability, design integration, evaluation of structural support and balancing initial costs with long-term savings.

Additional resources:

https://biomimicry.org

https://asknature.org/innovation/passively-cooled-building-inspired-by-termite-mounds

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Solution: Aerodynamics of Sycamore tree seeds

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.

How can nature solve the challenge with less power to create a substantial airflow?

Context

In nature, the shape of the sycamore seed's wings allows it to glide through the air, creating a spiral motion.

2.b Ask yourself what your design wants to do.

Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish.

Summary of key functions and nature's contexts

<table>
<tr><th>Design Function</th><th>Nature's Context (Adaptation)</th></tr>
<tr><td>Efficient air circulation</td><td>Fish fins, whale flippers</td></tr>
<tr><td>Silent operation</td><td>Owl wings, shark skin</td></tr>
<tr><td>Durability and lightweight design</td><td>Spider silk, bird bone structure</td></tr>
<tr><td>Heat regulation</td><td>Termite mounds, elephant ears</td></tr>
<tr><td>Adaptability and flexibility</td><td>Plant leaves (tropism), penguin thermoregulation</td></tr>
<tr><td>Sustainability and eco-friendly materials</td><td>Bamboo, mollusk shells</td></tr>
<tr><td>Dispersed, uniform airflow</td><td>Schooling fish, beehive airflow regulation</td></tr>
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2.c Flip the question. Consider opposite functions

How can nature look into restricting or blocking airflow?</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution.

Functions</td></tr>
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- **Efficient air circulation:** Moving air efficiently with minimal energy.
- **Silent operation:** Operating quietly with minimal noise.
- **Sycamore seed (maple seed):** The seed's wing-like structure allows it to spin and glide through the air efficiently, using aerodynamic principles to cover large distances with minimal energy.

Natural models

- **Dragonfly wings:** Dragonflies have highly efficient wings that create lift and propulsion with minimal energy, allowing for rapid and agile flight.
- **Bat wings:** Bats use a flexible wing membrane that adapts its shape for efficient, controlled flight, optimizing airflow around their wings for maneuverability.
- **Owl wings:** Owls have specialized wing feathers with serrated edges that reduce turbulence and noise, enabling nearly silent flight.
- **Beetle wings:** Some beetles, like the titan beetle, have wing structures that reduce noise during flight through their unique wing texture.
- **Hummingbird feathers:** Hummingbirds use specialized feathers to minimize noise while hovering and rapidly moving.

3.b Identify experts & connect to communities of biologists and naturalists.

- University and Research Institutions (University of California, Berkeley, Harvard University)
- Specific Experts (Janine Benyus, Daniel Pauly, Mark Miodownik)
- Biomimicry Institute
- American Society of Mechanical Engineers (ASME)
- Society for Conservation Biology.
- Specialised Journals and Publications.
- Online Forums and Social Media.
- Conferences and Workshops (Biomimicry Global Design Challenge, International Conference on Biomimetic and Biohybrid Systems, Ecological Society of America (ESA) Annual Meeting).
- International Society for Bioclimatic Architecture (ISBA).
- American Institute of Architects (AIA).

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	• Local Nature Centres and Botanical Gardens. • Audubon Society Chapters. • Academia.edu.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** • **Efficient air circulation:** Achieves smooth and efficient air movement with minimal energy and less noise • **Autorotation:** Enables the seedpod to stay in the air for longer and travel greater distances. • **Curved shape:** Facilitates the autorotation of the seedpod. • **Weight and wing length balance:** Ensures smooth autorotation during free fall.  Copyright @Adobe Stock **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • **Efficient air circulation:** Design the fan blades to create smooth, effortless airflow. The blades should be shaped to move air effectively while using minimal energy, ensuring a high-performance cooling effect. • **Ensure quiet operation:** Incorporate features that minimise noise during operation. Design the fan blades and motor to reduce vibrations and sound, creating a quiet and pleasant environment. • **Weight and wing length balance:** Use materials that are both strong and lightweight. This ensures the fan is durable and easy to handle, yet sturdy enough to withstand regular use.

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Regulate temperature efficiently: Integrate design elements that help manage and maintain a comfortable temperature. This might involve optimising airflow patterns to enhance cooling and improve overall temperature control.

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<td>Step 5 – Emulate</td>
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5.a List your key information and explore as many ideas as possible.
Features
Maximise airflow with minimal energy, noise reduction, material optimisation, and sustainable materials
Ideas
Curved blades, aerodynamic blades, fewer blades, and balanced blades in terms of weight and length.
5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
Features

Blade design: Wing-like blades modelled after sycamore seeds and dragonfly wings to enhance airflow efficiency.
Variable speed mechanism: Adjustable blade angles or speeds to optimise airflow based on room size and conditions.

Context

Residential use: The fan should be suitable for various home environments, including living rooms, bedrooms, and offices.

Constraints

Budget: Cost considerations for materials and production processes need to be balanced with the desired features and functionality.

</td>
</tr>
<tr>
<td>Step 6 – Evaluate</td>
<td>6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility</td>
</tr>
</table>

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	with Earth's systems. Assess the feasibility of both the technical and business models. The design concepts for the sycamore seed-inspired ceiling fan align well with the challenge's criteria, offering efficient air movement, quiet operation, strength, adaptability, and environmental sustainability. They are compatible with Earth's systems by promoting energy efficiency and reducing waste. The technical and business models are feasible, although considerations for cost and market education will be necessary for successful implementation—the innovative features and eco-friendly design position the fan favourably in a growing market for sustainable home products. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** By revising and refining each design concept, the ceiling fan can be better aligned with the design challenge criteria, ensuring efficient air movement, silent operation, and adaptability while leveraging eco-friendly materials. The revised approach addresses technical and business feasibility, with a focus on sustainability and consumer demand. The final design will incorporate advanced features and environmentally conscious practices, positioning it as a competitive and innovative product in the market.

Additional resources:

https://biomimicry.org/

https://asknature.org/innovation/aerodynamic-ceiling-fan-inspired-by-sycamore-seedpods

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Portable toilets and waterless

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.
How does nature solve natural filtration?
Context
Nature provides several solutions to sanitation challenges through efficient waste management and resource recycling. For instance, wetlands filter pollutants from water through the action of plant roots and microbial activity. This principle can be applied to sanitation systems that treat waste and recycle water, ensuring cleanliness and ecological balance.
2.b What do I want my design to do?
Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish.
Key functions of the design
• Waste containment.
• Natural decomposition.
• Odour control.
• Water conservation.
• Ease of transport.
• User-friendly operation.
Natural models
• Wetland ecosystems.
• Composting systems.
• Plant water storage.
• Forest canopies.
• Insect habitats.
2.c Flip the question. Consider opposite functions.
How can nature look into restricting or blocking natural filtration?</td></tr>
</table>

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Step 3 – Discover	3.a Search for natural models that match the same functions and context as your design solution.
	Wetland plants (e.g., cattails and reeds). • **Function:** Waste containment and natural filtration • **Model:** Wetland plants thrive in waterlogged environments and help filter pollutants from water through their root systems. They contain and manage nutrients, making them effective at maintaining ecosystem health. **Termite mounds** • **Function:** Natural decomposition and odour control. • **Model:** Termite mounds maintain a stable internal environment that promotes the breakdown of organic materials. The mounds have ventilation systems that regulate temperature and humidity, helping to control odours and facilitate decomposition. **Composting worms (e.g., red wigglers).** • **Function:** Waste breakdown and nutrient cycling. • **Model:** These worms play a crucial role in composting by breaking down organic waste into nutrient-rich soil. Their burrowing behaviour aerates the compost, promoting decomposition and improving soil quality. **Succulent plants (e.g., aloe vera).** • **Function:** Water conservation and storage • **Model:** Succulents store water in their leaves, allowing them to survive in arid conditions. This adaptive strategy can inspire designs that minimize water use and effectively manage waste without requiring large amounts of water. **Nutrient cycling in forest ecosystems.** • **Function:** Decomposition and soil enrichment. • **Model:** The natural process in forest ecosystems, where dead plant material decomposes and enriches the soil, can inform composting toilet designs that recycle waste into usable compost to enrich the soil. **3.b Identify experts & connect to communities of biologists and naturalists.** • Universities with environmental science or biology departments. • Research centers. • Ecological Society of America (ESA). • Society for Conservation Biology. • The Nature Conservancy.

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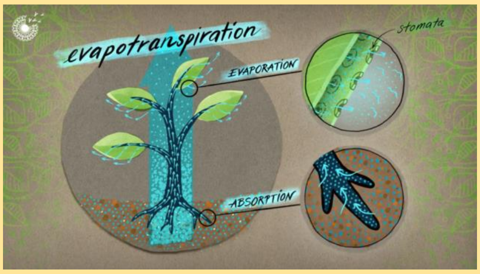
	• ResearchGate. • Ecological conferences. • Local nature workshops
Step 4 – Abstract	**4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core Functions** • **Water transport:** Evapotranspiration involves the movement of water from the soil through the plant and out through the stomata in the leaves. This process helps transport essential nutrients from the soil to various parts of the plant. • **Cooling mechanism:** As water evaporates from the stomata, it cools the plant, similar to how sweating cools the human body. This helps maintain optimal temperatures for metabolic processes. • **Nutrient uptake:** The upward movement of water through the plant aids in the uptake and distribution of nutrients dissolved in the water. This is crucial for the plant's growth and development. • **Water cycle contribution:** Evapotranspiration contributes to the water cycle by returning water vapor to the atmosphere. This process is essential for maintaining the balance of water in the environment.  https://thekidshouldseethis.com/post/how-did-trees-inspire-the-sustainable-superstar-of-toilets **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Design strategies inspired by nature** • **Waste containment:** Create a robust structure that securely holds waste to prevent leaks and odours, ensuring safety and hygiene. • **Natural breakdown:** Implement a system that encourages the breakdown of waste into harmless materials, using processes that are simple and effective. • **Odor management:** Design a ventilation system that allows fresh air to circulate while effectively controlling unpleasant smells.

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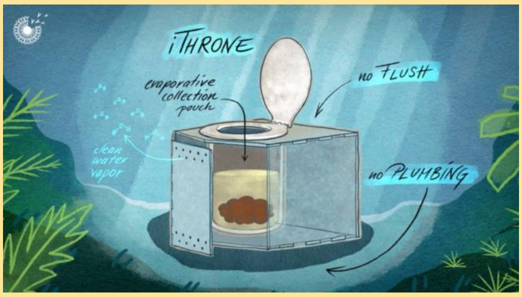
	• **Water efficiency:** Use minimal or no water for operation, maximizing efficiency and reducing reliance on water resources. • **Portability:** Make the toilet lightweight and easy to transport, allowing for quick setup in various locations, whether for events, rural areas, or emergency situations.  https://thekidshouldseethis.com/post/how-did-trees-inspire-the-sustainable-superstar-of-toilets
Step 5 – Emulate	**"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs."** https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **Features** Preventing leaks and odours, secure storage of human waste, safely decomposing waste, Use of microbial processes or composting techniques, adequate ventilation and odour control, comfort and hygiene, minimising water usage, dry or minimal-flush options, easy transport and quick setup **Ideas** Modular design, biodegradable materials, integration of a composting feature, and fan- or passive airflow systems. **5.b Organize your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • **Waste containment:** Secure storage to prevent leaks and odours. • **Natural breakdown:** Composting mechanism for nutrient recycling., Biodegradable materials to enhance sustainability. • **Odor management:** Effective ventilation system (passive or active). • **Water efficiency:** Dry or minimal-flush options. • **Portability:** Lightweight, modular design for easy transport.

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	• **Smart features:** Sensors for monitoring waste levels. **Context** Rural areas with limited infrastructure, Outdoor events (festivals, concerts), Disaster relief zones, and developing urban areas. **Constraints** • **Cost:** Initial investment limits, especially for low-income communities. • **Maintenance:** Need for user education and ongoing maintenance. • **Regulatory Compliance:** Navigating local health and safety regulations. • **Environmental Impact:** Ensuring that materials and processes do not harm local ecosystems. **Idea selected** • **Modular composting toilet:** Combines secure waste storage with a composting feature. Lightweight and portable, it can be easily set up in various locations.

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Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** **Alignment with design challenge criteria:** ● **Waste management:** Effectively contains and decomposes waste, promoting sustainability. ● **Water efficiency:** Requires minimal to no water, aligning with conservation goals. ● **Portability:** Designed for easy transport and setup in various locations. **Compatibility with Earth's Systems:** ● **Nutrient recycling:** Converts waste into compost, enriching soil and supporting local ecosystems. ● **Resource conservation:** Minimizes water use and leverages natural processes for decomposition. **Feasibility:** ● **Technical**: Requires research into materials and design for effective composting and odor control. Potential challenges include ensuring effective decomposition in diverse climates. ● **Business model:** Can target both individual consumers and organizations (e.g., events, NGOs), but initial costs may limit accessibility in low-income areas. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Integrated modular composting toilet with ventilation ● **Modular components:** Allow for customization based on user needs and environmental conditions (e.g., additional composting units, different sizes). ● **Natural ventilation system:** Incorporate features like vents or chimneys to promote airflow and control odors without mechanical components. ● **Biodegradable materials:** Use materials that break down over time, aligning with sustainability goals. ● **User-Friendly access:** Ensure easy access for maintenance, education materials, and waste management.

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Additional resources:

https://biomimicry.org/

https://asknature.org/innovation/low-cost-portable-toilet-inspired-by-evapotranspiration-in-plants

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: V formation of migrating birds

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do birds fly more efficiently and safely to reach their destination? **Context** As we look up into the sky, we can notice a flock of birds flying toward the south, arranged in a V-shaped formation. It's an unmistakable sight in the fall, reminding us that colder and darker days lie ahead. There's actually quite an interesting science behind why certain species of large birds organise themselves in this manner, and it has everything to do with efficiency, especially for the long-haul flights of migration. This flying pattern helps all the birds preserve energy. It turns out that when large birds flap their wings, circulations of air are generated, called vortices, which have both rising and sinking segments, pockets of swirling air. **2.b Ask yourself: What do I want my design to do?** • Reduce the amount of CO_2 emissions. • Reduce the amount of fuel consumption. • Ensure the safety of the aircraft and the people in it. **2.c Flip the question. Consider opposite functions.** How do birds use less energy?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution. Read scientific literature.** • **Natural models** • **Bats:** Bats are known for their agile flight and ability to navigate through complex environments. They utilise echolocation to avoid obstacles and locate prey, enabling them to fly efficiently even in complete darkness. • **Insects:** Many insects, such as bees and dragonflies, have highly efficient flight mechanisms. Bees, for example, use a combination of rapid wing beats and body movements to hover and manoeuvre precisely. Dragonflies can change the angle of their wings to maximise lift and minimise drag. • **Gliding mammals**: Animals like flying squirrels and sugar gliders use a different approach to efficient travel. They glide from tree

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	to tree by utilising a membrane stretched between their limbs, which enables them to cover large distances with minimal energy expenditure. • **Fish**: Some fish, like the flying fish, can leap out of the water and glide over the surface to escape predators. They use their pectoral fins to catch the air and glide efficiently. **3.b Identify experts & connect to communities of biologists and naturalists.** • Cornell Lab of Ornithology. • Royal Society for the Protection of Birds (RSPB). • Partners in Flight (PIF). • Max Planck Institute for Ornithology.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** • Biological strategies applied by migration birds: • Aerodynamic flight patterns. • Gliding and soaring. • Wing shape and flexibility (high aspect ratio wings, flexible wing usage. • Metabolic adaptations (efficient musculature, fat reserves). • Wingbeat optimization (intermittent flapping (flap-gliding or flap-bounding), efficient wingbeat frequency). • Body streamlining (aerodynamic body shape). • Environmental exploitation (tailwinds and updrafts, ridge lift and thermals). • Behavioural adaptations (energy-conserving routes, group coordination). 

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	https://en.wikipedia.org/wiki/V_formation **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** ● Both aircraft must be headed in the same direction. ● Since it is easier to make the V formation mid-flight, the airplanes do not have to take-off or land at the same time. ● From there, pilots activate a coupling beacon. ● Once synced, the software determines where the secondary airplane should be to capitalize on the swirling air generated by the first aircraft. ● Autopilot may be used from there to maintain proper distance.  https://en.wikipedia.org/wiki/V_formation
Step 5 – Emulate	**“Emulation is an exploratory process that strives to capture a “recipe” or “blueprint” in nature’s example that can be modelled in our own designs.”** **https://toolbox.biomimicry.org/methods/emulate/** **5.a List your key information and explore as many ideas as possible.** ● **Energy efficiency:** Birds flying in a V formation benefit from reduced air resistance. The lead bird creates a vortex that provides lift to the birds behind, allowing them to expend less energy. This principle has been applied to military aircraft to improve fuel efficiency and extend flight range. ● **Fuel savings:** In military aviation, the "V" or "Vic" formation is a standard practice. It was first used during World War I and has been shown to improve fuel efficiency by reducing drag. This formation allows aircraft to fly longer distances without refuelling.

- **Coordination and safety:** Flying in a V formation requires precise coordination among the birds, which translates to improved safety and communication in aviation. Military pilots use this formation to maintain visual contact and ensure synchronised manoeuvres.

- **Research and simulation**: While less common, the principles of V formation are occasionally applied in commercial aviation, particularly in research and experimental flights. Studies have shown potential fuel savings and reduced emissions when commercial aircraft fly in formation, though practical implementation is still in the experimental stages.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

	Context	Features	Constraints
Energy efficiency	military aviation commercial aviation	improve fuel efficiency extend flight range	**Technological Barriers:** requires significant investment in research and development **Operational Changes:** new flight procedures and optimizing routes for fuel efficiency require changes in pilot training and air traffic management **Environmental Factors:** Weather conditions, air traffic congestion, and other environmental factors can impact the effectiveness of fuel-saving measures
Fuel saving		improve fuel efficiency by reducing drag fly longer distances without refueling	
Coordination and safety		improved safety and communication synchronized maneuvers maintain formation integrity	
Research and simulation		fuel savings emissions reduction flight Planning route Optimization technological innovation	

Step 6 – Evaluate

6.a Evaluate the design concept(s) about their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Design criteria

- **Aerodynamics:** The aircraft must have an optimised shape to reduce drag. This includes features like blended wing bodies, winglets, and laminar flow control.

- **Weight reduction:** Using lightweight materials such as carbon fiber composites to reduce the overall weight of the aircraft.

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- **Efficient engines:** Developing more efficient engines, such as turbofans with higher bypass ratios or hybrid-electric propulsion systems.
- **Energy sources:** Exploring alternative energy sources like biofuels, hydrogen, or fully electric powertrains.
- **Operational efficiency:** Implementing advanced flight management systems for optimal route planning and fuel-efficient flight profiles.

Constraints

- **Technological feasibility:** The technology must be sufficiently mature to be implemented safely and reliably in both commercial and military aircraft.
- **Regulatory compliance:** The design must meet stringent aviation safety and environmental regulations.
- **Economic viability:** The aircraft must be cost-effective to produce and operate, ensuring it is financially viable for airlines and military operators.
- **Infrastructure compatibility:** The design must be compatible with existing airport infrastructure and maintenance facilities.

Compatibility with the Earth's Systems

- **Environmental impact:** The aircraft should minimize emissions and noise pollution, contributing to global sustainability goals.
- **Resource use:** Efficient use of materials and energy sources to reduce the environmental footprint during manufacturing and operation.
- **Lifecycle management:** Considering the entire lifecycle of the aircraft, from production to disposal, to ensure minimal environmental impact.

Technical feasibility

- **Current technologies:** Many of the required technologies, such as advanced composites and efficient engines, are already in use or under development. However, fully electric or hydrogen-powered aircraft are still in the experimental stages.
- **Research and development:** Significant investment in R&D is needed to bring emerging technologies to market readiness.

Business model feasibility

- **Cost savings:** Fuel-efficient aircraft can offer substantial cost savings over their operational life, making them attractive to airlines despite higher initial costs.

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	• **Market demand:** There is growing demand for sustainable aviation solutions from both consumers and regulatory bodies, which supports the business case for fuel-efficient aircraft. • **Investment and incentives:** Government incentives and investments in green technologies can help offset development costs and encourage adoption. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** By addressing the criteria and constraints identified in the previous steps, we can develop a viable solution for a more fuel-efficient aircraft. More focus should be on integrating advanced technologies, optimising operational efficiency, and ensuring economic and environmental sustainability. Collaboration across the aviation industry, regulatory bodies, and research institutions could be the key to achieving these goals.

Additional resources:

https://biomimicry.org/

https://www.airlinepilotcentral.com/articles/news/should-airplanes-follow-bird-flight-formation.html

https://www.theweathernetwork.com/en/news/nature/animals/the-science-behind-migratory-birds-v-shaped-formations

https://birdsconnectsea.org/2023/09/21/its-a-bird-its-a-plane-aviation-designs-inspired-by-birds-earthcare-northwest/

https://www.flyajetfighter.com/why-fighter-planes-fly-in-formation/

https://edition.cnn.com/travel/article/airbus-formation-flight/index.html

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Swift and precise flight of a hummingbird

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do hummingbirds have such a high-precision flight? **Context** Is evolution the best inventor? With hundreds of millions of years of work and the natural world as its canvas, it would seem so. The swift and precise flight of a hummingbird has inspired scientists, researchers and the drone industry to develop flying devices that are also capable of intricate manoeuvres. Hummingbirds are among the smallest birds in the world, and they occupy a unique place in nature: they fly like insects but possess the musculoskeletal system of birds. They possess small, lightweight torsos with relatively large wings that allow them to fly remarkably fast with incredible precision. **2.b Ask yourself, "What do I want my design to do?"** • Help the military and other law enforcement organisations to conduct surveillance, reconnaissance, security or covert missions in sensitive or hostile areas with high precision and without being detected by the enemy forces. • Provide a quieter alternative to the existing drones and find a quicker way of delivering different goods. • Provide a more precise and silent way of collecting wildlife data, without disturbing the studied wildlife • Create a more precise and safer way for rescue workers to come to the aid of people in disaster-affected areas. • Become an important tool in precision agriculture by pollinating crops, monitoring both plant health and fields without disturbing livestock or creating noise pollution, and thus solving one of the problems that farmers are facing today - the decline of natural pollinators like bees. **2.c Flip the question. Consider opposite functions.** What are the challenges faced by hummingbirds during turbulent weather conditions, and how do they adapt their flight?

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Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution. e.g. Read scientific literature.** ● **Owls:** Owls achieve silent flight through specialized feathers that reduce noise. Their serrated feather edges break up turbulence, and soft plumage absorbs sound, inspiring quieter drone designs. Owls' excellent night vision and acute hearing enable precise hunting in low light, suggesting advanced sensors and vision systems for drones to operate in various lighting conditions. ● **Bats:** Bats use echolocation to navigate and hunt in darkness, inspiring drones with advanced sonar or lidar for low-visibility navigation and obstacle detection. Their flexible wing membranes allow agile flight, suggesting drones with flexible or morphing wings for similar adaptability and precision. ● **Dragonflies:** Dragonflies can fly in multiple directions, hover, and make sharp turns with precision, inspiring drones with enhanced agility and control. Their large compound eyes provide a wide field of view and excellent motion detection, suggesting advanced visual systems for improved situational awareness and navigation in drones. ● **Falcons:** Falcons' high-speed dives and precise hunting skills inspire drone designs for high-speed, precise operation. Their streamlined bodies reduce air resistance, suggesting aerodynamic designs for faster, more efficient drones. **3.b Identify experts & connect to communities of biologists and naturalists.** ● Purdue University . ● U.S. Defense Advanced Research Projects Agency (DARPA). ● American Society of Naturalists (ASN). ● Ecological Society of America (ESA). ● Society for Conservation Biology (SCB).
Step 4 – Abstract	**4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** ● **Wing structure and mechanics:** Hummingbirds' wings rotate at the shoulder, allowing for a wide range of motion, enabling them to hover, fly backward, and make sharp turns with precision. Their wings beat up to 80 times per second, generating the lift and stability needed for precise flight. ● **Muscle adaptations:** Hummingbirds have large pectoral muscles that provide the necessary power for sustained hovering and agile manoeuvres. These muscles make up a significant portion of their body weight.

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- **Energy management:** Hummingbirds have one of the highest metabolic rates among animals, which supports the energy demands of their rapid wing beats and agile flight. They consume large amounts of nectar to fuel their activities.
- **Vision and navigation:** Hummingbirds have sharp vision and can see a broad spectrum of colours, including ultraviolet light, aiding in precise navigation and locating food. Their quick visual processing allows rapid flight adjustments to avoid obstacles and capture prey.
- **Aerodynamics:** Their bodies are streamlined to reduce air resistance, enhancing their ability to move swiftly and precisely through the air. The shape of their wings is optimized for both lift and manoeuvrability, allowing them to perform complex aerial manoeuvres.
- **Sensory integration:** Hummingbirds have excellent coordination between their visual and motor systems, enabling them to execute precise movements and maintain stability during flight.

Image copyright: https://watchingthebirds.com/how-hummingbirds-fly-the-structure-of-a-flight/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

The core functions identified from studying Hummingbirds, can be translated into a human-centric context, focusing on:

Structural design and mechanics

- **Flexible components:** The drone should have highly flexible parts for a wide range of motion, enabling it to hover, move backward, and make sharp turns with precision.
- **Rapid movement:** The drone's components must move at high speeds to provide the lift and stability needed for precise manoeuvres.

Power and efficiency

- **Powerful motors:** Equip the drone with powerful motors for sustained hovering and agile movements.

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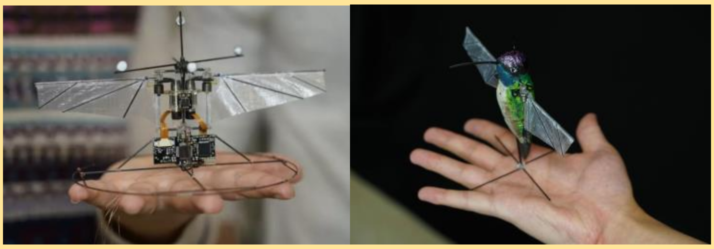
	• **Energy management:** Design an efficient energy management system to support rapid movements and maintain activities. **Vision and navigation** • **Advanced vision systems:** Use high-resolution cameras and sensors for precise navigation and target location. • **Quick data processing:** Enable rapid visual information processing for quick flight adjustments and obstacle avoidance. **Aerodynamics** • **Streamlined design:** Design a streamlined body to reduce air resistance and enhance swift, precise movement. • **Optimized wing shape:** Shape the wings for both lift and manoeuvrability to perform complex aerial manoeuvres. **Sensory integration** • **Coordination systems:** Ensure excellent coordination between visual and motor systems for precise movements and flight stability.  Images copyright https://www.purdue.edu/newsroom/archive/releases/2019/Q2/hummingbird-robot-uses-ai-to-soon-go-where-drones-cant.html
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Agile manoeuvrability like flexible wing design and rapid wing beats. • Advanced navigation system which can include AI or Machine learning and provides a tactile feedback . • Sensory integration such as high resolution cameras or multi sensor fusion. • Design centred on energy efficiency by using lightweight material. • Autonomous navigation system and real time decision making tools integrated. • Fail-safe mechanism and redundant system.

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- Application of specific features which can be adapted to different environmental challenges.

5.b Organize your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

	Context	**Features**	**Constraints**
Agile maneuverability	Enables precise control and agile maneuvers in tight and complex environments	flexible wing design rapid wing beats	• Requires advanced materials and engineering to achieve the necessary flexibility and speed without compromising durability
Advanced navigation system	Enhances navigation and obstacle avoidance, especially in low-visibility or cluttered environments	AI Machine learning Tactile feedback	• High computational power needed for real-time processing • Potential challenges in training AI models for diverse environments
Sensory integration	Provides comprehensive situational awareness and precise navigation capabilities	High resolution camera Multi-sensor fusion Thermal imaging cameras	• Integration of multiple sensors can increase weight and power consumption. • Ensuring seamless data fusion from different sensors.
Energy efficiency	Reduces energy consumption, allowing for longer flight times and improved performance	Efficient Power Management Lightweight Materials	• Balancing lightweight design with structural integrity and durability
Autonomous capabilities	Enables drones to operate independently in complex environments, adapting to changing	Autonomous Navigation Real time data processing and decision-making systems	• Ensuring reliability and safety of autonomous systems. • High

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	conditions		computational requirements for real-time processing.
Safety and redundancy	Enhances reliability and safety, ensuring continued operation in case of failures.	Return-to-home functions emergency landing protocols Redundancy design of critical components to ensure continued operation in case of a failure	• Additional weight and complexity from redundant systems. • Designing effective fail-safe protocols.
Application of specific features	Tailors drone capabilities to specific use cases, improving effectiveness and efficiency.	Thermal imaging cameras or other sensors Environmental Monitoring such as: air quality and vegetation health Urban Logistics	• Customization for different applications may require modular designs. • Balancing versatility with specialized performance.

Idea selected

Advanced navigation system.

Step 6 – Evaluate

6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Alignment with challenge criteria

1. High-precision flight

- **AI and machine learning:** These technologies enhance the drone's ability to navigate with high precision by learning from its environment and making real-time adjustments. This directly addresses the need for precise control in complex environments.
- **Tactile feedback:** Provides additional sensory input, allowing the drone to navigate even in low-visibility conditions, further improving precision.

2. Stealth

- **Optimized flight paths:** AI can optimize flight paths to minimize noise and visibility, making the drone stealthier. This is crucial for applications like surveillance and reconnaissance.
- **Adaptive navigation:** The ability to adapt to changing conditions reduces the likelihood of detection and enhances stealth capabilities.

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3. Versatility in complex environments

- **Obstacle avoidance:** Advanced navigation systems improve the drone's ability to avoid obstacles, making it suitable for diverse environments such as urban areas, forests, and disaster zones.
- **Real-time decision making:** Enables the drone to respond dynamically to environmental changes, ensuring effective operation in various scenarios.

Constraints

- High computational power
- Training and adaptation
- Integration of multiple sensors

Compatibility with the Earth's systems

1. Environmental impact:

- **Energy efficiency:** By using lightweight materials and optimizing energy consumption, the drone can minimize its environmental footprint.
- **Sustainable materials:** Incorporate sustainable and recyclable materials in the drone's construction to reduce environmental impact.

2. Adaptability to various conditions:

- **Weather resistance:** Design the drone to withstand different weather conditions, such as rain, wind, and temperature fluctuations, ensuring reliable operation in diverse environments.
- **Robust design:** Ensure the drone's structure can handle environmental stressors, enhancing durability and longevity.

3. Regulatory compliance:

- **Safety standards:** Ensure the drone meets safety and regulatory standards for operation in public spaces, addressing concerns about privacy and airspace management.
- **Ethical considerations:** Implement ethical guidelines for the use of AI and data collection to protect privacy and ensure responsible use.

Technical feasibility for implementing an **Advanced Navigation System**

Features	***Current state***	***Feasibility***
AI and Machine Learning Integration	*AI and machine learning technologies are well-developed and increasingly*	***High*** *The integration of AI for navigation and obstacle*

	used in various applications, including autonomous vehicles and robotics	*avoidance is technically feasible with existing technology. Continuous advancements in AI will further enhance capabilities.*
Tactile Feedback Systems	*Tactile sensors are used in robotics for touch-based navigation and mapping*	***Moderate to High*** *While tactile feedback systems are less common in drones, they are technically feasible and can be developed with current sensor technology*

Business model feasibility

1. Market demand

- **Current trends:** There is a growing demand for advanced drones in various sectors, including logistics, surveillance, environmental monitoring, and emergency response.
- **Feasibility:** High. The market demand for high-precision, stealthy drones is strong and expected to grow.

2. Cost and pricing

- **Development costs:** Initial development costs may be high due to the integration of advanced technologies.
- **Pricing strategy:** Premium pricing can be justified by the advanced capabilities and specialized applications of the drones.
- **Feasibility:** Moderate to High. While development costs are significant, the potential for high returns in specialized markets supports the business model.

3. Competitive landscape

- **Current competitors:** The drone market is competitive, with several established players.
- **Differentiation:** The unique features of high-precision and stealth capabilities provide a competitive edge.
- **Feasibility:** High. Differentiation through advanced features and specialized applications can position the product favourably in the market.

4. Regulatory compliance

- **Current regulations:** Drones must comply with aviation regulations, which vary by region.
- **Compliance strategy:** Ensuring compliance with safety and privacy regulations is essential.

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- **Feasibility:** Moderate to High. While regulatory compliance can be challenging, it is manageable with proper planning and adherence to guidelines.

5. Scalability

- **Production and distribution:** Scaling production and establishing distribution channels are critical for business growth.
- **Feasibility:** High. With a well-planned production and distribution strategy, scaling the business is feasible.

6.b Revise and revisit previous steps as necessary to generate a viable solution.

Key features to follow

- Adaptive algorithms.
- Obstacle detection and avoidance.
- Path optimization.
- Environmental adaptation.
- Touch-based navigation.
- Environmental mapping.
- Collision avoidance.
- Redundancy for visual systems.

Integration into drone design

- Sensor fusion.
- Lightweight and efficient design.
- Modular architecture.

Implementation plan

- **Prototype development:** Create a prototype incorporating the key features and test in controlled environments.
- **Testing and validation:** Conduct extensive testing in various scenarios to validate performance and reliability.
- **Optimisation:** Refine the design based on test results, focusing on improving energy efficiency and reducing weight.
- **Regulatory compliance:** Ensure the design meets all safety and regulatory standards.
- **Production and scaling:** Develop a scalable production plan and establish distribution channels.

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Additional resources:

https://royalsocietypublishing.org/doi/10.1098/rsfs.2016.0078

https://www.audubon.org/news/hummingbirds-inspire-drone-design

https://pubmed.ncbi.nlm.nih.gov/28675148/

https://biomimicryuniverse.com/concept/hummingbird-drones

https://newsroom.carleton.ca/story/hummingbirds-wings-inspire-technology/

https://www.psu.edu/news/engineering/story/hummingbird-flight-could-provide-insights-biomimicry-aerial-vehicles

https://spectrum.ieee.org/aerovironments-nano-hummingbird-surveillance-bot-would-probably-fool-you

https://www.purdue.edu/newsroom/archive/releases/2019/Q2/hummingbird-robot-uses-ai-to-soon-go-where-drones-cant.html

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- WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: The kingfisher, the owl and the penguin

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do owls fly so silently? How do Adelie penguins reduce air resistance? How do kingfishers dive into the water without a splash? **Context** • **Owls:** Owls are silent hunters, relying on their unique feather structures to reduce noise during flight. Their large wings generate lift, but flapping them could create turbulence and noise. However, owls have evolved serrated feathers at the front and fringe-like structures at the back, which break up turbulence and disperse it, minimizing noise. Additionally, their concave faces and downy bodies absorb sound, making their flight nearly silent. • **Adeline penguins:** Adelie penguins are exceptional swimmers, spending about 75% of their time in the water. Their wings have evolved into powerful flippers, allowing them to swim long distances and at lower depths, resembling flying underwater. Their torpedo-shaped bodies and rear-placed legs minimize drag, enabling speeds of up to 25 mph. They reduce drag further by fluffing their feathers and releasing bubbles, tripling their speed. Using a technique called porpoising, they swim just below the surface, leaping in and out of the water to breathe without slowing down. They are also excellent divers, holding their breath for about 6 minutes and diving to depths of 9 to 18 meters. Additionally, they swallow small stones to aid digestion and help them dive deeper. • **Kingfisher:** The Kingfisher's head and beak shape allow it to glide through the air and dive into water efficiently, transitioning from air to water seamlessly. Flying at speeds up to 25 mph, their sharp, long beaks slice through water silently, enabling stealthy dives to catch fish. Despite the beak's length being a challenge in dark nests, Kingfisher chicks have white-tipped beaks and parents have white facial flashes, providing visual cues for feeding. **2.b Ask yourself What do I want my design to do?**

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	• **High-speed, safer transportation:** Facilitates economic growth, regional development, and social integration by linking major cities, improving business travel, commuting, and tourism. • **Reduce congestion:** Offers a high-capacity rail service to ease road and air traffic and relieve pressure on other rail systems. • **Environmentally friendly:** Emits significantly less CO2 per passenger-kilometre compared to cars or aeroplanes, supporting goals to reduce greenhouse gas emissions and promote sustainable transport. **2.c Flip the question. Consider opposite functions.** How do birds improve their flight or swimming efficiency in their environment conditions?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution. e.g. Read scientific literature.** • **Sharks:** Their skin texture reduces drag and prevents biofouling, inspiring efficient ship and aircraft surfaces. • **Dolphins:** Streamlined bodies and powerful tails enable high-speed swimming and acrobatics. They use echolocation for efficient navigation and hunting. • **Birds of prey:** Wing shapes and flight mechanics of falcons and eagles influence aircraft wing design for better lift and manoeuvrability. • **Hummingbirds:** Agile and fast, they hover, fly backwards, and change direction rapidly due to their unique wing structure and high metabolism. • **Albatrosses:** Masters of gliding flight, they travel vast distances with minimal energy using long, narrow wings for dynamic soaring. • **Bats:** Only mammals capable of sustained flight, they possess flexible wings that enable precise control. They use echolocation to navigate and hunt efficiently in the dark. **3.b Identify experts & connect to communities of biologists and naturalists.** • National Geographic. • Journal of Ornithology. • University Research Departments. • iNaturalist. • American Society of Naturalists. • AskNature.

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Step 4 – Abstract

4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.

Owls

- **Core functions:** Silent flight, noise reduction.
- **Keywords:** Silent hunters, feather structures, serrated feathers, fringe-like structures, turbulence, concave faces, downy bodies.

Adelie penguins

- **Core functions:** Efficient swimming, drag reduction, deep diving.
- **Keywords:** Exceptional swimmers, powerful flippers, torpedo-shaped bodies, rear-placed legs, drag reduction, fluffing feathers, releasing bubbles, porpoising, diving, swallowing stones.

Kingfisher

- **Core functions:** Efficient diving, stealthy hunting.
- **Keywords:** Head and beak shape, glide, dive, transition, sharp beaks, silent dives, visual cues, white-tipped beaks, white facial flashes.

  

https://medium.com/@StammBio/what-is-biomimicry-the-train-and-the-kingfisher-1a459ef21af0

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4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

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https://medium.com/@StammBio/what-is-biomimicry-the-train-and-the-kingfisher-1a459ef21af0

In 1987, Japan faced a noise issue with its Shinkansen bullet trains, which created a loud "tunnel boom" when passing through tunnels at high speeds. Eiji Nakatsu, inspired by the kingfisher's beak, redesigned the train's front to reduce noise and improve efficiency. This new design allowed the train to travel 10% faster, use 15% less electricity, and eliminate the tunnel boom. The streamlined body, influenced by the Adelie penguin, further reduced air resistance. This biomimicry not only solved the noise problem but also highlighted the potential for sustainable innovation in various industries.

Key design strategies

1. Noise reduction and efficiency

- **Problem:** The trains created disruptive noise when exiting the tunnels.
- **Solution:** Redesign the train's front to minimise noise and enhance efficiency.
- **Outcome:** The new design enabled the train to travel 10% faster, use 15% less electricity, and eliminate the need for the tunnel boom.

2. Aerodynamic optimization

- **Problem:** High-speed travel caused significant air resistance.
- **Solution:** Streamline the train's body to reduce air resistance.
- **Outcome:** The streamlined design further reduced air resistance, contributing to the train's improved performance.

Context and human perspective

- **Function:** The primary goal is to create a quieter, more efficient high-speed train.
- **Human impact:** The redesign not only solved the noise problem, making the environment more pleasant for nearby residents, but also improved the train's speed and energy efficiency. This innovation demonstrated the potential for sustainable solutions in transportation and other industries, highlighting how design

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	inspired by natural principles can lead to significant advancements in technology and efficiency.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Noise reduction** • Mimic natural shapes to reduce aerodynamic noise. • Implement serrations or other noise-dampening features on critical components. • Use materials that absorb or deflect sound. **Efficiency improvement** • Streamline designs to reduce air resistance. • Optimise energy consumption through design changes. • Incorporate features that enhance speed without increasing energy use. **Sustainable innovation** Apply biomimicry principles to other transportation modes. • Explore natural solutions for common engineering problems. • Promote designs that balance performance with environmental impact. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • **Redesigned front end:** Mimics kingfisher's beak to reduce noise. • **Serrations on the pantograph:** Reduce aerodynamic noise. • **Streamlined body:** Influenced by the Adelie penguin to reduce air resistance. **Context** • **High-speed travel:** Trains travelling at 200+ mph. • **Noise pollution:** The tunnel boom is disturbing residents. • **Energy efficiency:** Need to reduce electricity consumption. **Constraints** • **Decibel limit:** Must meet noise regulations (70 dB). • **Aerodynamic challenges:** High speeds increase noise and resistance. • **Design integration:** Changes must fit within the existing train infrastructure.

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	Selected idea **Streamlined body** - design inspired by Adelie penguin. • **Function:** Reduce air resistance and improve efficiency. • **Context:** High-speed, energy-efficient travel.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** **Alignment with design challenge's criteria and constraints** **1. Noise reduction** • **Criteria:** The design must reduce noise pollution, particularly the "tunnel boom.". • **Evaluation:** The streamlined body inspired by the Adelie penguin reduces air resistance, which indirectly contributes to noise reduction by minimizing turbulence and aerodynamic noise. **2. Energy efficiency** • **Criteria:** The design should improve energy efficiency. • **Evaluation:** The streamlined design reduces drag, allowing the train to travel faster while using less energy. This aligns with the goal of reducing electricity consumption by 15%. **3. High-speed travel** • **Criteria:** The design must support high-speed travel (200+ mph). • **Evaluation:** The streamlined body is optimized for high-speed travel, reducing air resistance and enabling the train to maintain high speeds more efficiently. **4. Regulatory compliance** • **Criteria:** The design must meet noise regulations (70 dB limit). • **Evaluation:** By reducing aerodynamic noise, the streamlined design helps the train comply with noise regulations. **Compatibility with the Earth's systems** • **Environmental impact:** The streamlined design reduces energy consumption, leading to lower greenhouse gas emissions. This supports sustainable transportation goals and minimizes the environmental footprint. • **Resource efficiency:** The design leverages natural principles to achieve efficiency, reducing the need for additional resources or complex technologies. **Feasibility of technical and business model**

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- **Technical feasibility:** The streamlined design is technically feasible, as it involves modifying the train's exterior shape. This can be achieved with current engineering capabilities and materials.
- **Business model feasibility:** The design offers cost savings through reduced energy consumption and maintenance costs. The improved efficiency and compliance with noise regulations can enhance the train's marketability and operational viability.

6.b Revise and revisit previous steps as necessary to generate a viable solution.

Revisit design integration

- Ensure the streamlined body design is compatible with existing train infrastructure and does not require extensive modifications.
- Conduct further testing to optimise the shape for maximum noise reduction and energy efficiency.

Enhance noise reduction features

Combine the streamlined body with additional noise-dampening technologies, such as sound-absorbing materials or advanced pantograph designs.

Sustainability focus

Explore the use of eco-friendly materials in the construction of the streamlined body.

Implement energy recovery systems to enhance efficiency further.

Final viable solution

The streamlined body design inspired by the Adelie penguin effectively addresses the design challenge by reducing air resistance, improving energy efficiency, and minimizing noise pollution. By integrating this design with additional noise reduction features and focusing on sustainability, the solution aligns with the criteria and constraints, ensuring technical and business model feasibility. This approach not only solves the immediate problem but also promotes sustainable innovation in high-speed rail transportation.

Additional resources:

https://biomimicry.org/

https://www.japanfs.org/en/news/archives/news_id027795.html

https://asknature.org/innovation/high-speed-train-inspired-by-the-kingfisher/

https://medium.com/@StammBio/what-is-biomimicry-the-train-and-the-kingfisher-1a459ef21af0

https://labs.blogs.com/its_alive_in_the_lab/2019/04/bbc-the-unexpected-inspiration-behind-japans-bullet-train.html

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

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https://pastcontest.diproinduca.com/how-nature-inspired-japans-shinkansen/

https://xshore.com/us/news/penguins-swim-underwater-at-up-to-25-miles-per-hour

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Adaptive behaviour of slime moulds

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.

How can slime mould connect different sources of food?

Context

Physarum polycephalum is a greenish-yellow slime mould that can convert to multiple forms. Despite lacking a brain, it displays complex behaviour, forming a tubular network to transfer nutrients efficiently. It thrives on rotting vegetable matter in cool, humid, dark environments like forest leaf litter.

Slime moulds forage broadly, then optimise their network for nutrient transport. In labs, they can grow over 30 cm in diameter. They use past experiences to adjust behaviour, though the mechanisms are unknown. Their network resembles animal brain synapses, with interconnected tubes and oscillations creating wave patterns. Slime moulds solve complex problems, like finding the shortest path in a maze or balancing nutrient levels. Their ability to navigate and form networks has intrigued researchers in fields like artificial intelligence.

2.b Ask yourself "What do I want my design to do?"
Design a more efficient, adaptable, and resilient transportation network by mimicking slime moulds' natural behavior in finding optimal pathways. This network should use fewer resources, consume less energy, and have a lower environmental impact. .
Create a subway system that is resilient to disruptions like breakdowns, construction, or natural disasters, and can adapt to urban growth and changing population patterns. Address urban transportation complexities, such as congestion, by optimizing for multiple factors.
2.c Flip the question. Consider opposite functions.

How can slime mould efficiently transport nutrients throughout its body?</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution. e.g. Read scientific literature.</td></tr>
</table>

	• Fungal networks: Mycelium forms underground networks that transport nutrients and reorganise to optimise resource distribution. • Vascular systems in plants: Xylem and phloem transport water, nutrients, and sugars, adapting to environmental changes for efficient distribution. • Ant trails: Ant colonies create optimised trails through pheromone signalling to find the shortest paths to food. • Animal circulatory systems: Animal circulatory systems efficiently transport blood, oxygen, and nutrients, adapting to changes in demand. • Microbial colonies: Bacterial colonies form networks to optimise nutrient uptake and waste removal, reorganising in response to environmental changes. **3.b Identify experts & connect to communities of biologists and naturalists.** • Institute of Experimental Design and Media Cultures (IXDM). • Physarum Network. • Slime Mould Time Mould.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Key elements of the biological strategy** • Exploration and detection: Slime moulds extend their network of protoplasmic tubes in various directions to explore their environment and detect food sources. • Signal response: Upon finding food, chemical signals are released, attracting more protoplasm to the area and causing the tubes to thicken. • Selective reinforcement: Tubes that efficiently transport nutrients are reinforced, while less efficient or redundant tubes are reabsorbed. • Dynamic adjustment: The network continuously adjusts based on the availability of food and environmental conditions. • Memory and efficiency: The slime mould retains a "memory" of previous food locations by maintaining thicker tubes in those areas, allowing quick reconnection if the food becomes available again. **Core functions**

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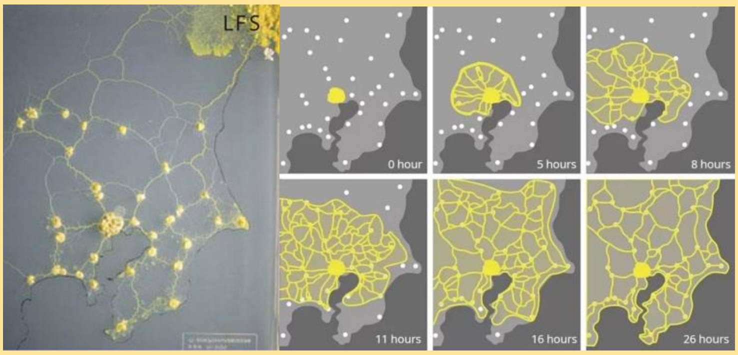
- Nutrient transport: Efficiently transporting nutrients throughout the organism.
- Adaptability: Adjusting the network in response to changes in the environment.
- Optimization: Maintaining an optimal network structure for resource distribution.
- Problem-solving: Demonstrating the ability to solve complex problems, such as finding the shortest path through a maze.

Keywords: Protoplasmic tubes; Chemical signalling; Network reinforcement; Dynamic reorganisation; Nutrient transport; Environmental adaptation; Optimization; Problem-Solving



[Slime Mold Network Engineering: Science Fiction in the News]

[How Japan Used Oats And Mold To Make Its Subway System More Efficient]

A graphical representation of a slime mould that spreads and establishes connective networks around different points marked with oat flakes.

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Researchers in Japan used the behaviour of a simple organism to redesign Tokyo's subway system. In a 2010 study, they placed the organism in a dish with food scraps arranged to mimic major sites in Tokyo. The organism's network formation closely mirrored the actual subway system, showcasing an efficient and resilient design.

This experiment demonstrated that natural strategies could inspire urban infrastructure design. The organism's network was efficient in connecting key points and robust against disruptions, highlighting the potential for creating more efficient, adaptable, and resilient transportation networks.

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<table>
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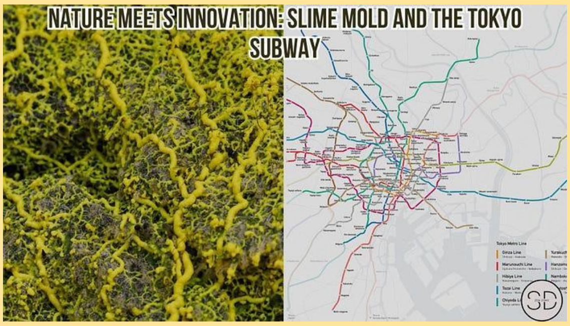
Application context

Urban planning: Optimise traffic flow and public transportation routes to reduce congestion and improve commute times.
Supply chain management: Enhance logistics networks to ensure timely delivery of goods and reduce transportation costs.
Telecommunications: Improve data routing in communication networks to enhance connectivity and reduce latency.
Energy distribution: Optimise power grids to balance supply and demand, reducing energy waste and improving reliability.



https://saugatadastider.medium.com/nature-as-an-innovator-lessons-from-slime-mold-to-tokyos-subway-265cdb1904ff
</td>
</tr>
<tr>
<td>Step 5 – Emulate</td>
<td>
5.a List your key information and explore as many ideas as possible.
Key principles

Dynamic adaptation.
Resource efficiency.
Resilience.
Scalability.
Decentralised control.

Ideas: Monitor performance and conditions continuously, adjust pathways in real-time to optimise resource distribution and minimise disruptions, prioritise efficient routes, alternative routes to handle unexpected changes, networks that grow and evolve seamlessly with increasing demands and new nodes, individual nodes for faster decisions and responsive adjustments
5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
Dynamic adaptation
</td>
</tr>
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	• Monitor performance and conditions continuously. • Adjust pathways in real-time to optimise resource distribution and minimise disruptions. **Resource efficiency** • Prioritise efficient routes. • Quickly reconfigure to avoid bottlenecks and maintain optimal flow. **Resilience** • Build flexibility with multiple alternative routes. • Adapt quickly to unexpected changes or challenges. **Scalability** • Design the network to grow and evolve seamlessly. • Integrate new nodes and increase demands without compromising performance. **Decentralised control** • Empower individual nodes to make local decisions. • Allow for faster, more responsive adjustments. **Idea selected** The best idea is related to resilience: Build flexibility with multiple alternative routes that can adapt quickly to unexpected changes or challenges.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Technical feasibility** • **Network optimisation: Slime mould-inspired designs can optimise** subway or railway networks, reducing travel times and increasing resilience to disruptions. • **Algorithm development:** Algorithms simulating slime mould behaviour can create networks that balance cost, travel time, and vulnerability to disruptions. • **Integration with existing systems:** Integrating these designs with current transportation planning tools is feasible but requires significant computational resources and expertise. • **Scalability:** Slime mould-inspired models can be scaled to various sizes, ranging from small urban networks to large regional systems.

	Business model feasibility • **Cost efficiency:** Slime mould-inspired designs can lower costs by optimising network layouts, reducing infrastructure investments, and attracting stakeholders. • **Resilience and reliability:** These networks are less prone to disruptions, which improves service reliability and attracts more users, thereby increasing revenue. • **Sustainability:** Optimised routes reduce energy consumption, supporting sustainability goals and attracting environmentally conscious investors and governments. • **Market differentiation:** Innovative, nature-inspired designs can differentiate a transportation company, attracting more customers and partnerships. • **Regulatory and policy support:** Demonstrating the efficiency and resilience of these designs can help secure regulatory approval and policy support. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **The design should look into the following steps for a viable solution:** • **Research and development:** Conduct detailed studies on slime mould behaviour and its application to network design. Develop and test algorithms that simulate slime mould behaviour for network optimisation. • **Pilot projects:** Implement pilot projects in small urban areas to test the feasibility and effectiveness of the designs. Monitor performance and make necessary adjustments. • **Integration and scaling:** Integrate successful pilot project designs with existing transportation systems, and scale the designs to larger urban and regional networks. • **Stakeholder engagement:** Engage with stakeholders, including investors, government agencies, and the broader public, to highlight the benefits of cost efficiency, resilience, sustainability, and market differentiation. **Continuous monitoring and adaptation:** Continuously monitor network performance and environmental conditions. Adjust pathways and connections in real-time to optimise resource distribution and minimise disruptions..

Additional resources:

https://biomimicry.org/

https://phys.org/news/2022-01-virtual-slime-mold-subway-network.html

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https://www.sd-zen-zone.in/post/slime-mold-tokyo-subway-a-biomimicry-case-study-in-innovative-design

https://blogs.ubc.ca/communicatingscience2017w211/2018/01/29/brainless-slime-mold-grows-in-pattern-like-tokyos-subway-system/

https://www.linkedin.com/pulse/harnessing-natures-genius-how-slime-mold-inspired-sahil-srichandan-qa1gf

https://saugatadastider.medium.com/nature-as-an-innovator-lessons-from-slime-mold-to-tokyos-subway-265cdb1904ff

https://biodesign.berkeley.edu/2022/02/18/brainless-slime-mold-grows-in-pattern-like-tokyos-subway-system/

https://knowledge.carolina.com/discipline/life-science/biology/the-slime-mold-physarum-polycephalum/

https://www.freethink.com/science/slime-molds-subways

https://www.nature.com/articles/s41598-022-05439-w

https://www.utoronto.ca/news/researchers-use-virtual-slime-mould-design-ttc-subway-network-less-prone-disruption

https://www.ribaj.com/culture/reseaux-mondes-centre-pompidou-paris-ecologicstudio-slime-mould

https://www.theguardian.com/cities/2014/feb/18/slime-mould-rail-road-transport-routes

https://www.sciencedirect.com/science/article/pii/S2405844023042500

https://www.slideshare.net/slideshow/slime-mould-inspired-urban-planning-2pptx/266839877

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Strong and durable protection The Pangolin scale

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do animals enhance their flexibility and durability in critical contexts? **Context** Pangolins' scales are made of keratin, providing strength and adaptability. The overlapping, hexagonal scales allow flexibility and robust protection, enabling pangolins to roll into a ball. These scales are tough yet elastic, bending without cracking and adapting to various terrains. Pangolins can regenerate damaged scales, ensuring long-term durability. The interlocking scales distribute stress evenly, offering insights for designing flexible, durable products, such as backpacks. **2.b Ask yourself, "What do I want my design to do?"** • Provide flexibility and durability like pangolin scales. • Protect the contents of the backpack. • Adapt to various user needs. **2.c Flip the question. Consider opposite functions.** How do pangolins protect themselves?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Functions** • Protection: Pangolin scales, made of keratin, are tough and flexible. Their overlapping and interlocking arrangement absorbs and distributes impact forces, acting as nearly impenetrable armour when the pangolin curls into a ball. • Flexibility and adaptability: The scales' elasticity allows them to bend without cracking, enabling pangolins to adapt to various defensive postures and environments. • Regeneration: Pangolins can regenerate damaged scales, ensuring their protective armour remains effective over time. **Natural models**

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	• **Armadillos:** Like pangolins, armadillos have protective armour made of bony plates covered in keratin. They can roll into a ball to protect themselves from predators. • **Turtles:** Turtles have hard, protective shells made of bony plates covered by scutes, which are similar to the keratin scales of pangolins. Their shells provide excellent protection against predators. • **Alligator snapping turtles:** These turtles have rugged, spiked shells and powerful jaws. Their armour-like shells provide significant protection, similar to pangolin scales. • **Hedgehogs:** Hedgehogs have spines made of keratin that they use for protection. When threatened, they curl into a ball, much like pangolins. • **Ankylosaurus:** This extinct dinosaur had a body covered in bony plates and a club-like tail for defence. Its armour is reminiscent of the protective scales of pangolins. **3.b Identify experts & connect to communities of biologists and naturalists.** • **Dr. Ravi Sundaram, Dr. K. S. R. Reddy, and Dr. Andrew J. K. C. Wong published:** Journal of Biomimetic Materials and Engineering, 2021. • **Dr. Jonathan Baillie and Dr. Susie Ellis** have worked on pangolin conservation and may have insights into the structural aspects of pangolins.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Protection** • **Keratin scales:** Tough and flexible. • **Overlapping and interlocking arrangement:** Absorbs and distributes impact forces. • **Impenetrable armour:** Protects from predators when curled into a ball. **Flexibility and adaptability** • **Elasticity:** Scales bend without cracking. • **Defensive postures:** Adapt to various environments and threats. **Regeneration** • **Scale regeneration:** Maintains effective protective armour over time.

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	 https://www.discoverwildlife.com/animal-facts/mammals/facts-about-pangolins **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • **Material selection:** Use tough, flexible, and elastic materials that mimic keratin. • **Structural design:** Incorporate overlapping and interlocking layers to distribute stress and enhance flexibility. • **Protective features:** Integrate impact-absorbing padding and reinforce high-stress areas. • **Adaptability:** Design modular and adjustable components to suit various needs. • **Regenerative capabilities:** Use repairable or self-healing materials to maintain functionality. • **Ergonomics:** Ensure a comfortable fit with flexible support structures for better usability.  https://www.tomsguide.com/us/Armadillo-Shell-Backpack,news-11198.html
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • **Overlapping panels for flexibility:** Mimics pangolin scales, enhances flexibility and protection, allow independent movement, adapts to different loads and movements, distributes force widely, lightweight and comfortable. **Ideas:** expandable compartments, independent movement, layered protection, flexible hinges

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	• **Durable, lightweight materials:** inspired by keratin, these advanced, resilient materials withstand rough conditions, enhance mobility, and reduce fatigue, making them water-resistant or waterproof. **Ideas:** advanced composites, waterproof coatings, abrasion resistance, thermal insulation • **Modular design for adaptability:** Easy adjustment and customisation, independent sections maintain integrity, expand or reshape as needed, add or remove compartments, easier repairs and upgrades, supports sustainability. **Ideas:** customisable sections, interchangeable parts, expandable modules, sustainable materials, user-friendly assembly **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** • **Structural features:** expandable compartments, flexible hinges, interchangeable parts, expandable modules. • **Material properties:** Advanced Composites, Waterproof Coatings, Abrasion Resistance, Thermal Insulation, Sustainable Materials. • **Functional features:** Independent movement, Layered Protection, Customizable sections, User-Friendly Assembly. **Context and constraints** • **Context:** The design should be adaptable for various applications, such as outdoor gear, protective equipment, or modular storage solutions. • **Constraints:** Considerations include cost-effectiveness, ease of manufacturing, user safety, and environmental impact. **Idea selected** **Advanced composites** • **Strength and lightweight:** Advanced composites, such as carbon fibre or Kevlar, offer high strength-to-weight ratios. This means the backpack can be strong and durable without being heavy, making it comfortable to carry. • **Flexibility:** These materials can be engineered to provide flexibility, allowing the backpack to bend and move without breaking or losing its shape.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.**

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Criteria

- **Durability:** Advanced composites like carbon fibre and Kevlar offer high strength and durability, ideal for withstanding daily wear, abrasions, and impacts.
- **Flexibility:** These materials can be engineered for flexibility without compromising structural integrity, allowing the backpack to adapt to various movements and loads.
- **Lightweight:** Advanced composites provide a high strength-to-weight ratio, making the backpack lightweight and comfortable to carry.

Constraints

- **Cost:** Advanced composites are costly to produce, which affects their cost-effectiveness. Using recycled or bio-based composites can reduce costs.
- **Manufacturability:** Specialised equipment and processes are needed, creating challenges in scalability and manufacturing efficiency.
- **Environmental Impact:** Traditional composites have recycling challenges and environmental concerns due to their complex composition and energy-intensive production. Bio-based and recyclable composites are improving these issues.

Compatibility with the Earth's systems

- **Sustainability:** Bio-based composites and natural fibres (e.g., jute, flax) reduce environmental impact, promoting sustainability. These materials are renewable and biodegradable.
- **Recyclability:** Advances in recyclable thermoplastic composites enable a circular economy approach.
- **Energy consumption:** Manufacturing processes can be energy-intensive, but optimising these processes and using renewable energy sources can reduce the carbon footprint.

Feasibility of the technical model:

- **Technical feasibility:** Advanced composites are technically feasible, given their proven performance in industries such as aerospace and automotive. Ensuring the necessary technology, equipment, and expertise is crucial.
- **Prototyping and testing:** Developing prototypes and conducting rigorous testing (e.g., tensile strength, abrasion resistance, flexibility) are crucial for validating material performance and durability.

Feasibility of the business model

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	• **Cost management:** Utilising recycled materials and lean manufacturing techniques can help manage costs effectively. The modular design allows for cost-effective maintenance and upgrades. • **Market appeal:** Emphasising sustainability and durability can attract environmentally conscious consumers, enhancing market appeal. • **Scalability:** The business model should consider the scalability of production processes and material availability to meet market demand. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To refine the pangolin-inspired backpack, it's essential to continuously adjust and iterate the design based on feedback and testing. This involves addressing user-reported issues, such as discomfort or material performance, and making improvements to enhance functionality and user experience. By refining components like overlapping panels and modular elements, and validating each iteration through testing, the final product will meet design goals and exceed user expectations, resulting in a more effective, comfortable, and user-friendly backpack.

Additional resources:

https://biomimicry.org/

https://asknature.org/innovation/durable-backpack-inspired-by-the-pangolin/

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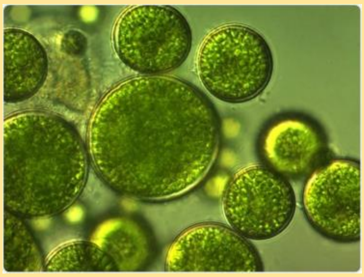
LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Biodegradability of algae organic matter

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How does marine life produce organic biodegradable compounds? **Context** Algae produce biodegradable materials through photosynthesis, converting sunlight, carbon dioxide, and water into organic compounds like carbohydrates, proteins, and lipids. Some algae generate biopolymers, including alginate, agar, and carrageenan, which can replace synthetic polymers. These compounds are inherently biodegradable and environmentally friendly. Algae can be cultivated in various environments, including freshwater, seawater, and wastewater, making them a sustainable resource with rapid growth rates. Researchers are enhancing the properties of algal materials to improve strength, flexibility, and water resistance, making them suitable for products such as biodegradable shoes. This aligns with the growing demand for eco-friendly alternatives. **2.b Ask yourself, "What do I want my design to do?"** • Provide biodegradable and sustainable fashion options. • Offer multi-functional features such as adaptability to different weather conditions or uses. **2.c Flip the question. Consider opposite functions.** How do marine ecosystems support nutrient cycling?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Pineapple leather:** Made from the fibres of pineapple leaves, Piñatex is used in fashion for shoes, bags, and accessories. It is a by-product of the pineapple harvest, making it an eco-friendly alternative to synthetic materials. • **Mushroom leather:** Created from mycelium, the root structure of mushrooms, Mylo is used in footwear and fashion. It offers a sustainable alternative to animal leather and synthetic materials. • **Cork:** Harvested from the bark of cork oak trees, cork is used in shoe soles and insoles. It is a renewable resource that provides comfort and sustainability.

	• **Apple leather:** Made from apple waste, AppleSkin is used in fashion for shoes and accessories. It combines apple waste with a small amount of PU to create a sustainable alternative to traditional leather. • **Cactus leather:** Made from the leaves of the nopal cactus, Desserto is used in footwear and fashion. It is an organic, sustainable alternative to synthetic leathers. **3.b Identify experts & connect to communities of biologists and naturalists.** • **Dr. Stephen Mayfield** professor of Biology at UC San Diego and the director of the California Centre for Algae Biotechnology and chief executive officer of BLUEVIEW.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords.** **Core functions:** • Renewable resource: Algae grows rapidly without needing fertile soil or large amounts of fresh water. • Biodegradable: Algae decompose naturally, reducing environmental impact. • Durability and flexibility: Algae possess structural properties that allow them to survive in dynamic aquatic environments, providing inspiration for durable and flexible shoe materials. • Water resistance: Algae's smooth, water-repellent nature helps keep shoes dry and clean. • Breathability: Inspired by algae's natural gas exchange processes, ensuring air circulation and preventing odor buildup. • Sustainability: Using algae reduces reliance on synthetic, non-degradable materials and minimizes the environmental impact of production.  https://www.news-medical.net/life-sciences/What-are-Algae.aspx **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.**

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	Core functions • **Renewable resource:** Using materials that grow quickly and don't require extensive resources. • **Biodegradable:** Ensuring materials break down naturally, reducing waste. • **Durability and flexibility:** Creating shoes that are strong and adaptable to various conditions. • **Water resistance:** Making shoes that repel water and stay dry. • **Breathability:** Designing shoes that allow air circulation to keep feet comfortable and odour-free. • **Sustainability:** Reducing reliance on synthetic materials and minimizing environmental impact. **Key elements of the strategy** • **Eco-friendly materials:** Develop shoes using natural, sustainable materials that decompose naturally, reducing environmental harm. • **Enhanced functionality:** Ensure the shoes are durable, flexible, water-resistant, and breathable to meet various needs. • **Modern design:** Maintain an attractive and contemporary look to appeal to consumers. • **Versatility:** Design shoes suitable for different activities, from casual wear to light athletic use. • **Environmental responsibility:** Promote sustainability by reducing reliance on non-renewable resources and minimizing the environmental footprint.  https://newatlas.com/environment/blueview-fully-biodegradable-shoes/
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Key information** • Material composition. • Design features. • Sustainability.

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Ideas

- Lightweight, water-resistant, compostable.
- Organic cotton or hemp for breathability and comfort.
- Durable, shock-absorbing sole.
- Non-toxic colouring.
- Detachable and changeable based on terrain.
- Algae-based hydrophobic treatments.
- Personalised fit.
- Organic shapes and textures of algae, wavy surface patterns, and a nature-inspired colour palette.
- All components can be composted.
- Suitable for various activities and environments.
- Switch from sneaker to sandal style.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Material composition

- **Algae-derived bioplastic:** Lightweight, water-resistant, compostable.
- **Natural fibres:** Organic cotton or hemp for breathability and comfort.
- **Algae-derived foam:** Durable, shock-absorbing sole.
- **Algae-based pigments:** Non-toxic colouring.

Design features

- **Modular sole:** Detachable and adjustable to suit various terrains.
- **Waterproof and breathable:** Algae-based hydrophobic treatments.
- **Adjustable lacing/strap system:** Personalized fit.
- **Aesthetic inspiration:** Organic shapes and textures of algae, wavy surface patterns, nature-inspired colour palette.

Sustainability

- **Fully biodegradable:** All components can be composted.
- **Versatility:** Suitable for various activities and environments.
- **Transformable design:** Switch from sneaker to sandal style.

Context

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	Urban, outdoor, and travel. **Constraints** • **Cost:** Algae-derived bioplastic and natural materials like hemp and organic cotton are more expensive than synthetic materials. • **Production feasibility:** Biodegradable materials must match the flexibility, strength, and waterproofing properties of traditional plastics. • **Durability:** Biodegradable materials may not be as wear-resistant as traditional synthetics. Shoes must withstand daily wear, particularly in outdoor and travel contexts.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Assess the biodegradability and functionality of the prototype** The prototype is biodegradable and functional, using algae-derived bioplastics and natural fibres like organic cotton or hemp for compostability. Certification would validate this. Comfort is ensured by breathable fibres and adjustable lacing, with modular soles adding versatility. However, durability, grip, and water resistance need testing. Its organic shapes and natural colours appeal to consumers. Overall, it's eco-friendly and functional, but thorough testing and user feedback are required before mass production. **Ensure the design is cost-effective and environmentally friendly** To make algae-inspired biodegradable shoes cost-effective and eco-friendly, use locally sourced algae and natural fibres to reduce costs and support local economies—bulk purchasing and efficient manufacturing, like 3D printing, lower costs and waste. Collaborations with eco-conscious brands can share resources and reduce overhead. Biodegradable materials and natural dyes ensure natural decomposition, avoiding harmful chemicals. Minimal, recyclable, or compostable packaging reduces waste, and renewable energy sources minimize the carbon footprint. A take-back program for recycling or composting promotes a circular economy, with clear composting guidelines ensuring responsible disposal. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Adjust based on feedback and testing** To refine algae-inspired biodegradable shoes, collect user feedback through surveys, interviews, focus groups, and social media. Test prototypes with diverse users to assess performance, durability, and flexibility. Analyse feedback to prioritise adjustments, refine materials, improve design, and enhance aesthetics. Develop and test updated prototypes, maintaining a continuous feedback loop. This approach

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	ensures the shoes meet consumer needs, improving functionality and satisfaction while supporting sustainability and innovation. **Iterate on the design to improve functionality and user experience.** To improve algae-inspired biodegradable shoes, analyse user feedback to identify pain points in comfort, fit, durability, and aesthetics. Enhance insoles for better support, add padding, and offer adjustable sizing. Expand modular soles for various activities and refine aesthetics based on user preferences. Test new features and materials, develop updated prototypes, and gather further feedback. Maintain ongoing dialogue with testers to foster community and continuously improve the design. This approach enhances functionality, user satisfaction, and customer loyalty, aligning with the demand for sustainable, high-performance footwear.

Additional resources:

https://biomimicry.org/

https://algaeplanet.com/ucsd-scientists-create-biodegradable-shoes/

https://phys.org/news/2020-08-science-biodegradable-algae-based-flip-flops.html

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Cat eyes glow in the dark

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do animals' eyes reflect light efficiently in various lighting conditions? **Context** Animal eyes reflect light efficiently through specialised adaptations that enhance vision in various lighting conditions. Key features include the tapetum lucidum, a reflective layer behind the retina that bounces light back into the eye, enhancing night vision. Many animals have a high density of rod cells in their retinas, which are sensitive to low light, and large, rounded pupils that let in more light. The curvature of the cornea and lens is optimised to focus light effectively onto the retina. Some animals also have reflective pigments in their eyes, enhancing vision in dark or murky environments. These adaptations improve vision across diverse lighting conditions, supporting survival in the wild. **2.b Ask yourself, "What do I want my design to do?"** • Provide highly reflective and durable road studs. • Ensure the studs are environmentally friendly and sustainable. **2.c Flip the question. Consider opposite functions.** How do eyes contribute to the survival of animals through their reflective properties?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Bioluminescence of fireflies:** Fireflies use a chemical reaction involving luciferin and luciferase to emit light, which could inspire road studs that glow at night using stored energy. • **Tapetum lucidum in nocturnal animals:** Nocturnal animals, such as raccoons, have a reflective layer behind their retinas called the tapetum lucidum, which enhances night vision by reflecting light back through the retina. Road studs could mimic this reflective layer to maximise light reflection when illuminated by car headlights. • **Fluorescent exoskeletons of scorpions:** Scorpions fluoresce under ultraviolet (UV) light due to compounds in their

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exoskeleton. This natural glow could inspire road studs that are visible under both headlights and specific street lighting.

Reflective scales of fish: Fish like sardines and herrings have reflective scales that help them blend with light in the water. Road studs could use similar reflective materials to maximize light efficiency and visibility in poor lighting conditions.
Bioluminescent fungi and glowworms: Bioluminescent fungi and glowworms emit light to attract insects or for reproduction. These organisms could inspire self-sustaining road studs that provide steady illumination throughout the night without external energy sources.

3.b Identify experts & connect to communities of biologists and naturalists.

AskNature.
American Institute of Biological Sciences (AIBS).
Society for Conservation Biology.
Online forums and social media groups.

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<td>Step 4 – Abstract</td>
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4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.
Core functions

Light reflection: The tapetum lucidum, a reflective layer behind the retina, acts like a mirror, bouncing light back through the retina to enhance vision in low-light conditions.
Light amplification: This reflection increases the amount of light available to photoreceptors, giving cats a second chance to absorb light and improving their night vision.
Eyeshine: The reflected light exits the eye, causing the characteristic glow seen in the dark.

Keywords
Tapetum lucidum, photoreceptors, eyeshine, night vision.


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	Copyright @Let's mimic project (designed by ATS) **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Reflective and amplifying materials** • Use special materials that reflect and amplify light from car headlights, making the studs glow and stand out clearly on the road. • Ensure these materials are durable enough to withstand heavy traffic and harsh weather conditions, providing consistent visibility over time. **Self-illuminating properties** • Explore materials that can absorb light during the day and glow at night, similar to certain natural materials. This ensures the studs are visible even without direct light from car headlights, adding an extra layer of safety on dark or unlit roads. **Sustainability and longevity** • Choose eco-friendly and long-lasting materials to reduce the need for frequent replacements. • Design the studs to be energy-efficient, minimizing environmental impact while improving road safety. **Testing and collaboration** • Conduct thorough testing and real-world trials to ensure the road studs are effective in all types of weather and lighting conditions. • Collaborate with experts in road safety, material science, and design to ensure the studs meet safety standards and perform well in diverse driving environments.  https://www.wistronchina.com/what-is-the-difference-between-cat-eyes-and-road-studs/
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • **Use materials that mimic the reflective properties of cat eyes:** Reflective materials inspired by cat eyes enhance visibility by reflecting light back to its source, similar to the tapetum

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	lucidum. Used in road studs, they improve nighttime and poor weather visibility, guiding drivers safely. These materials are also used in safety gear like vests and helmets. Recent innovations include intelligent road studs with LEDs and sensors for dynamic lighting and real-time information. • **Design road studs that are highly visible in various conditions:** Designing highly visible road studs involves using advanced materials and technologies. Retroreflective glass beads and prismatic lenses ensure high visibility by reflecting light back to its source. Durable materials like polycarbonate or stainless steel withstand harsh conditions. Solar-powered LEDs provide extra illumination, and smart sensors adjust brightness based on weather. Different colours improve safety for various road types. The studs should be visible from at least 100 meters in all conditions. Solar panels enhance energy efficiency, and the design ensures easy installation and maintenance, making the studs both visible and durable. • **Ensure the studs are durable and eco-friendly:** To ensure road studs are durable and eco-friendly, use recycled polycarbonate for housing and stainless steel for strength. Employ non-toxic, biodegradable adhesives. Integrate high-efficiency solar panels and energy-efficient LEDs, with smart sensors to adjust brightness. A modular design allows easy part replacement, extending lifespan and reducing waste. Seal studs against water and dust for protection. Design for easy recycling at the end of their lifecycle to maintain eco-friendliness. **5.b Organize your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** • **Features:** High reflectivity, durability, eco-friendly materials. • **Context:** Roads, highways, pedestrian crossings. • **Constraints**: Cost, production feasibility, durability. **Idea selected** Design road studs that are highly visible in various conditions by using smart sensors to adjust brightness based on weather.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** • **Assess reflectivity and durability. The** cat-eye-inspired road stud prototype demonstrates excellent reflectivity and durability. High visibility is ensured by retroreflective glass beads and prismatic lenses, even in low light. The recycled polycarbonate

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	housing, reinforced with stainless steel, offers robust protection. The design is water and dust-sealed, featuring solar panels and energy-efficient LEDs with smart sensors for long-lasting performance. Overall, it meets reflectivity and durability standards, making it a viable road safety solution. • **Ensure cost-effectiveness and eco-friendliness:** Use recycled polycarbonate for the housing to cut costs and reduce environmental impact. Stainless steel reinforcement ensures durability, minimising replacements. High-efficiency solar panels and LEDs offer long-term savings, while smart sensors adjust LED brightness to conserve energy. A modular design allows easy part replacement, extending lifespan and reducing waste. This approach balances economic viability and environmental sustainability, enhancing road safety. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To create effective cat-eye-inspired road studs, it's crucial to optimise all aspects. Use recycled polycarbonate for the housing to cut costs and reduce environmental impact, and reinforce critical components with stainless steel for durability. Integrate high-efficiency solar panels and energy-efficient LEDs with smart sensors for long-term energy savings and minimal maintenance. Maximise reflectivity with retroreflective glass beads and prismatic lenses for visibility in various conditions. A modular design allows easy part replacement, extending lifespan and reducing waste. This balanced approach ensures cost-effectiveness, durability, and environmental sustainability, enhancing road safety. Regularly revisiting these steps ensures the final product meets all standards.

Additional resources:

https://www.road-stud.com/shining-light-on-road-safety-the-ingenious-invention-of-the-cats-eye-road-stud/

https://medium.com/@seintodesignstudio/cats-eyes-and-road-safety-how-one-feline-friend-changed-the-course-of-road-safety-history-6111f2a37330

https://www.wistronchina.com/what-is-the-difference-between-cat-eyes-and-road-studs/

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: How Nature inspired sustainable packaging

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>
2.a Ask yourself how nature can solve this.
How does nature manage to sustain biodiversity and balance its ecosystems despite environmental changes?
Context
Nature has developed remarkable strategies to maintain biodiversity and ecosystem balance. Protection mechanisms are evident in various species, such as the shell of turtles, which shields them from predators and harsh environmental conditions. This natural armour allows turtles to thrive in diverse habitats, contributing to the overall health of their ecosystems. Durability is another key factor in sustaining ecosystems. Plant roots, for example, anchor plants firmly in the soil, providing stability and resistance to adverse conditions like strong winds and heavy rains. This not only helps individual plants survive but also supports the entire ecosystem by preventing soil erosion and maintaining soil structure.
Biodegradability plays a crucial role in nutrient cycling and soil health. Leaves that fall to the ground decompose, enriching the soil with essential nutrients and fostering plant growth, which in turn sustains the food web. This natural process of decomposition and nutrient recycling ensures that ecosystems remain productive and resilient over time.
2.b What do I want my design to do?
Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do.
Summary of key functions and nature's contexts
<table>
<tr><th>Design Function</th><th>Nature's Context (Adaptation)</th></tr>
<tr><td>Protection</td><td>The shell of turtles</td></tr>
<tr><td>Durability</td><td>Plant roots</td></tr>
<tr><td>Biodegradability</td><td>Leaves that decompose in the soil</td></tr>
</table>
2.c Flip the question. Consider opposite functions.
</td></tr>
</table>

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	How can sustainable packaging protect food from spoilage and contamination?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Natural protection. **Natural models** • **Turtle shell:** The shell acts as a protective shield, defending the turtle from predators and adverse climatic conditions. This rigid and waterproof structure is an example of how a natural material can provide adequate protection. • **Animal camouflage colour:** Many animals, such as deer or leopards, use camouflage to protect themselves from predators. This adaptive strategy can inspire packaging that blends into the environment, protecting by avoiding detection. • **Butterfly cocoon:** The cocoon provides exceptional protection for the larvae, defending them from predators and external conditions. This model can inspire packaging that creates a safe environment for food, protecting it from contamination. **3.b Identify experts & connect to communities of biologists and naturalists.** • Biologists ecologists. • Evolutionary biologists. • Bioengineering specialists. • Sustainability Experts. • Biological Societies (American Institute of Biological Sciences (AIBS), Ecological Society of America (ESA)). • Naturalist associations (National Audubon Society or The Nature Conservancy). • Online platforms (ResearchGate, LinkedIn). • Universities and research centres.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram/ drawing and/ or find images that can inform the design.** **Natural recycling of materials** **Keywords:** Degradation, circularity, reuse, sustainability. **Natural models:** Fungal, decomposing bacteria, and soil nutrient cycles.

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- **Function:** Transforms waste materials into nutrients or raw materials for new biological processes, ensuring a continuous cycle of recycling.

Natural protection

- **Keywords:** Resistance, barrier, conservation, safety.
- **Natural models:** Shells of molluscs, shells of crustaceans, eggshell.
- **Function:** Provides adequate protection against contamination and damage while maintaining content integrity.

Adaptability to the environment

- **Keywords:** Flexibility, resilience, evolution, diversity.
- **Natural models:** Camouflage of chameleons, adaptations of plants to varied climatic conditions.
- **Function:** Allows packaging to adjust to different environmental conditions and product types, ensuring they remain functional and efficient.

Waste reduction through reuse

- **Keywords:** Reuse, reduction, efficiency, innovation.
- **Natural models:** Social behaviours of some animals, ecosystems that capitalise on remains.
- **Function:** Maximises the use of available resources by reusing materials and minimising waste, contributing to a circular system.

https://en.bioxegy.com/post/circular-economy-biomimicry-and-it

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective. e.g. shark skin inspired swimsuit.

- **Recyclability:** The ability to decompose and be reused without losing quality.

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	• **Protection:** Ensures food safety by providing a barrier against contamination and physical damage. • **Adaptability:** The ability to adjust to various environmental conditions and different types of products. • **Waste reduction:** Focus on maximising material use and minimising waste through innovative reuse strategies.  https://planetark.org/newsroom/news/how-the-circular-economy-uses-biomimicry-to-imitate-natural-systems
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible**. • **Recyclability:** Ability to be recycled multiple times. • **Biodegradability:** Breaks down naturally without harming the environment. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • **Recyclability:** Ability to be recycled multiple times without degradation in quality and to promote the circular economy. • **Biodegradability:** Designed to decompose within a specific time frame and materials to break down naturally, reducing landfill waste. . • **Protection:** Safeguards products against contamination, moisture, and physical damage, providing a barrier against harmful external factors. **Context** • **Food Industry**: Restaurants, cafes, food delivery services, catering businesses. • **Consumers**: Eco-conscious individuals and families looking for sustainable options. • **Retailers**: Businesses aiming to enhance their sustainability image and meet consumer demand. **Constraints**

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	Technical limitations, economic factors, and regulatory compliance
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The evaluated design concepts align well with circular economy principles and address the criteria set by the design challenge. They demonstrate strong compatibility with Earth systems, promoting sustainability, resource efficiency and waste reduction. However, the technical and commercial feasibility of these concepts varies, emphasizing the need for careful analysis of infrastructure, consumer behaviour and production methods. With the right support and investment, these concepts have the potential to make a significant contribution to a more sustainable and circular economy. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** By revisiting and revising the previous steps, we have refined our approach to creating a viable solution that not only aligns with the principles of the circular economy but also meets the practical needs of consumers and businesses. The integrated eco-friendly packaging system combines the strengths of biodegradable materials, reusable systems, modular designs, and smart technology, ensuring a comprehensive solution that addresses the challenges of waste sustainably and innovatively. Continuous feedback and adaptation will be crucial to the successful implementation and acceptance of this solution.

Additional resources:

https://biomimicry.org/

https://asknature.org/collection/life-friendly-packaging/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: The bone structures of mammals

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td> 2.a Ask yourself how nature can solve this. How does the porous and resilient structure of mammalian bones sustain mechanical loading? Context Mammalian bone, consisting of the inner "Spongy bone" and the hard "Compact bone," is an excellent structural composite, allowing for strength combined with flexibility. The inner "Spongy bone" is the soft inner part of the bone and is structurally stabilized by the hard "Compact bone" surrounding it. The Spongy bone possesses a surface area ten times higher than the Compact bone. This creates the classic soft-hard composite effect, allowing the bone to flex under stress and yet structurally support the load of the body. 2.b Ask yourself, "What do I want my design to do?" For a sponge-like battery design inspired by the porous and resilient structure of mammalian bones, my design aims to achieve the following: Maximise energy storage efficiency.
Enhance mechanical durability.
Support sustainable energy solutions.
Maintain practicality and cost-effectiveness.
Ensure safety and reliability. 2.c Flip the question. Consider opposite functions. How do sponge-like bones of mammals absorb shock? </td></tr>
<tr><td>Step 3 – Discover</td><td> 3.a Search for natural models that match the same functions and context as your design solution. e.g. Read scientific literature. Nacre (mother of pearl): Nacre's layered structure can inspire high-density, efficient, durable, sustainable, scalable, and safe battery designs.
Spider silk: Spider silk's molecular structure can inspire high-capacity, flexible, durable, sustainable, cost-effective, and safe energy storage materials.</td></tr>
</table>

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	• **Lotus leaf:** Lotus leaves' superhydrophobic surface can inspire eco-friendly, durable, cost-effective, and safe battery coatings that prevent moisture ingress and enhance component longevity. • **Electric eel:** The electric eel's ability to generate electricity can inspire high-output, durable, sustainable, cost-effective, and safe bio-batteries and capacitors. • **Cactus spines:** The unique structure of cactus spines can inspire energy-efficient, durable, sustainable, cost-effective, and safe battery designs that enhance ion transport and mechanical stability. **3.b Identify experts & connect to communities of biologists and naturalists.** • American Society of Mammalogists (ASM). • Society for Integrative and Comparative Biology (SICB). • International Society of Biomimetics (ISB). • Sungkyunkwan University, the University of Texas at Austin, and Brookhaven National Laboratory.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** • **Energy storage efficiency:** Bones store essential minerals like calcium and phosphorus, which are crucial for muscle contractions, blood clotting, and nerve transmission. This storage and release help maintain metabolic balance and energy efficiency. • **Mechanical durability:** Bones remodel in response to mechanical loading, strengthening their structure and minimising energy use during physical activities. This adaptation makes movements more efficient and reduces injury risk. • **Sustainability:** Mammalian bones contribute to sustainability through their structural support, resource efficiency, role in mineral cycling, and their ecological importance, as well as the use of minimal-impact materials. • **Safety and reliability:** Mammalian bones ensure safety and reliability through structural integrity, organ protection, shock absorption, healing and remodelling, calcium regulation, and endocrine functions.

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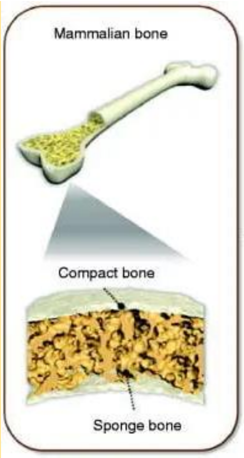

Image copyright: https://pubs.aip.org/aip/apr/article/7/4/041410/832047/Biomimetic-composite-architecture-achieves

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Core functions

1. Energy storage efficiency

- **Porous structure:** By mimicking the inner spongy bone (trabeculae), it could increase the surface area for ion transport.
- **Efficient ion transport:** Facilitates rapid movement of ions, enhancing charge and discharge rates.

2. Mechanical durability

- **Resilience:** A sponge-bone-like structure provides strength and flexibility, enabling ultrahigh charging rates and maintaining over 90% capacity after 10,000 cycles, ensuring durability and efficiency for long-term use.
- **Impact resistance:** Mimicking the outer compact layer of mammal bone enhances sodium ion transport. The combination of NVP and rGO creates a stable environment, improving the battery's cycling stability and thermal capabilities.

3. Safety and reliability

- **Thermal management:** Efficiently manages heat to prevent overheating.
- **Structural integrity:** Maintains stability and safety under various conditions.

4. Sustainability

- **Eco-friendly materials:** It can use sustainable materials and processes to minimize environmental impact. Abundant and cost-effective materials like sodium make this technology

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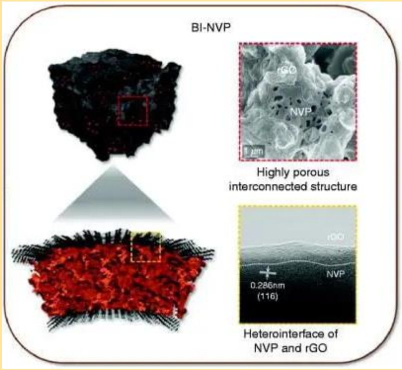
economically viable. Long-lasting, efficient batteries could attract significant industrial interest for cost reduction and improved sustainability.

- **Long lifespan:** Can ensure durability and longevity. Such a structure can make a battery highly durable and efficient for long-term use.



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Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

Key Information and ideas

- Porous architecture.
- Dense outer shell.
- Material composition.
- Performance enhancements.
- Sustainability.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

	Context	Features	Application
Porous architecture	Bio-Inspiration innovation in industries Research Collaboration Consumer electronics and larger-	The inner structure of mammalian bones, known as trabecular or spongy bone, features a porous architecture that provides	This porous design is replicated in the battery structure to distribute mechanical stress evenly, preventing fractures and enhancing durability.

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	scale applications.	strength while being lightweight.	
	Constraints: • **Structural integrity:** Balance porosity and strength; too much weakness, too little reduces stress distribution benefits. • **Material compatibility:** Ensure materials are chemically compatible and durable. • **Manufacturing complexity:** Precise control over pore size and distribution is complex and costly. • Thermal management: Porous structures can affect thermal properties, risking overheating or uneven temperatures. • **Scalability:** Scaling production from lab to commercial is challenging. • **Cost:** Advanced materials and techniques increase production costs.		
Dense outer shell	Bio-Inspiration innovation in industries Research Collaboration Consumer electronics and larger-scale applications.	The outer layer of bones, called cortical bone, is dense and provides structural support.	The battery's outer shell is made from reduced graphene oxide (rGO), which offers high mechanical strength and protects the inner components.
	Constraints: • **Material selection:** Use materials with high strength and chemical stability. • **Thickness optimisation:** Optimise thickness for protection without excess weight or volume. • **Manufacturing complexity:** Precise thickness and uniformity are complex and costly. • **Thermal management:** Manage heat to prevent overheating and ensure uniform temperature. • **Structural integrity:** Maintain integrity under stress and during operation.		

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	• **Cost:** High-performance materials and techniques increase costs.		
Material composition	Bio-Inspiration innovation in industries Research Collaboration Consumer electronics and larger-scale applications.	The battery utilises Na_3v_2 $(PO_4)_3$ (NVP) as the cathode material, which is effective in transporting sodium ions. The integration of NVP with rgo creates a stable environment for sodium ions, thereby improving the battery's cycling stability and thermal performance.	Materials that are resistant to chemical reactions with the electrolyte and other battery components. For example, reduced graphene oxide (rGO), $Na_3V_2(PO_4)_3$ (NVP), combined with rGO, can provide the necessary mechanical properties, and materials with high thermal conductivity can help dissipate heat more efficiently.
	Constraints: • **Chemical stability:** Materials must be stable in the battery's environment to prevent degradation. • **Mechanical properties:** Provide strength to withstand operational stresses. • **Thermal management:** Effectively manage heat to prevent overheating and ensure uniform temperature. • **Manufacturing complexity:** Compatible with existing processes to avoid increased complexity and cost. • **Cost and availability:** Cost-effective and readily available. • **Environmental impact:** Minimal impact in sourcing and disposal.		
Performance enhancement	Bio-Inspiration innovation in industries	The bio-inspired design allows the battery to	Use materials with high energy storage capacity and design the architecture to

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	Research Collaboration Consumer electronics and larger-scale applications.	charge at ultrahigh rates. The battery maintains over 90% of its capacity after 10,000 cycles of discharging and recharging, demonstrating exceptional durability.	maximise the active material's utilisation. Develop materials and structures that facilitate rapid ion transport and minimize resistance within the battery. Design the porous architecture to enhance thermal conductivity and integrate cooling mechanisms if necessary.
	Constraints: • **Power density:** Achieving high power density while maintaining the structural integrity of the porous architecture • **Energy density:** Ensuring the battery can store a high amount of energy per unit volume or weight. • **Charge/ Discharge rates:** Maintaining high charge and discharge rates without degrading the battery's performance over time. • **Thermal management:** Managing heat generation during high-power operations to prevent overheating and ensure uniform temperature distribution. • **Cycle life:** Ensuring the battery maintains its performance over many charge and discharge cycles. • **Scalability:** Scaling up the production of batteries with advanced architectures from laboratory settings to commercial manufacturing.		
Sustainability	Bio-Inspiration innovation in industries	The use of sodium, which is abundant and cost-effective, makes the battery more	Abundant and renewable materials, such as sodium, which is more readily

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	Research Collaboration Consumer electronics and larger-scale applications.	sustainable compared to lithium-based batteries. Mimicking natural structures helps reduce the environmental footprint of battery production and disposal.	.available than lithium. Develop processes that minimize environmental impact, such as using biodegradable materials and implementing recycling programs. Optimise manufacturing processes to reduce energy consumption and explore the use of renewable energy sources in production. Design for disassembly and recycling, and use materials that can be easily reclaimed and reused.
	Constraints • **Resource scarcity:** The availability of sustainable materials can be limited, leading to competition and higher costs. • **Environmental impact:** The production and disposal of battery materials can have significant environmental impacts, including pollution and resource depletion. • **Energy consumption:** Manufacturing processes for advanced materials and structures can be energy-intensive. • **Lifecycle management:** Ensuring that the entire battery lifecycle, from production to disposal, is sustainable. • **Economic viability:** Sustainable materials and processes can be more expensive, impacting the overall cost of the battery.		

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	<table><tr><td></td><td>• Regulatory compliance: Meeting stringent environmental regulations and standards for battery production and disposal.</td></tr></table> **Idea selected:** Porous architecture with dense outer shell.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** • **Rationale:** This design mimics the natural structure of bones, providing both strength and flexibility. The porous interior distributes stress, while the dense outer shell protects the battery components. • **Implementation:** Utilise advanced manufacturing techniques to create a composite structure comprising Na3v2 (PO4)3 (NVP) and reduced graphene oxide (rgo). • **Compatibility with the Earth's systems:** Using eco-friendly and abundant materials like sodium helps reduce the environmental footprint. Sodium is more readily available and less environmentally damaging than lithium. **Feasibility evaluation** • **Technical feasibility:** The selected design concepts are based on existing research and have shown promising results in laboratory settings. Further development and testing are needed to scale up production. • **Business model feasibility:** The use of cost-effective and sustainable materials, combined with the potential for significant performance improvements, makes this approach economically viable. Market demand for efficient and eco-friendly batteries supports the business case. • **Environmental compatibility:** The design aligns with sustainability goals by using eco-friendly materials and reducing the environmental impact of battery production and disposal. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** A viable solution is to use abundant and eco-friendly materials like sodium to allow an ultrahigh charge rate and maintain over 90% capacity after 10,000 cycles. As such, a sponge-like istructure nspired by mammals' bones can provide a design to enhance thermal conductivity and efficient heat dissipation.

Additional resources:

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https://link.springer.com/article/10.1007/s10853-011-5914-9

https://hal.science/hal-04002794/document

https://link.springer.com/chapter/10.1007/978-1-4939-3002-9_7

https://asknature.org/innovation/sponge-like-battery-structure-inspired-by-mammalian-bones/#profile

https://en.wikipedia.org/wiki/Pore_structure

https://hbr.org/2021/07/the-green-economy-has-a-resource-scarcity-problem

https://www.ansys.com/content/dam/amp/2021/august/webpage-requests/education-resources-dam-upload-batch-2/material-property-data-for-eng-materials-BOKENGEN21.pdf

https://ocw.mit.edu/courses/3-080-economic-environmental-issues-in-materials-selection-fall-2005/0a9684aa33bdabd205be6eb0635d6dcf_lec_ms2.pdf

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LET'S MIMIC SOLUTIONS

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Solution: The aerodynamic efficiency, stealth and manoeuvrability of the Peregrine Falcon

BIOMIMICRY DESIGN	Description
Step 2 – Biologiσe	**2.a Ask yourself how nature can solve this.** How can peregrine falcons be stealthy, precise, and have such high speed when diving to catch their target or prey? **Context** The peregrine falcon is built for speed, with wings and body designed for aerodynamic efficiency. When hunting, it can reach speeds close to 200 miles per hour by folding its wings to minimise drag. This incredible speed allows it to dive bomb prey with precision, unfolding its wings at the last moment to catch its target. Scientists have studied how peregrines manage such feats without injury. One theory suggests they unfurl their wings just before striking to reduce speed and make final adjustments. The falcon's innate navigational system, similar to military-grade missiles, helps it predict and adjust its path. Peregrines use proportional navigation, making slight adjustments in wing position and speed before impact. This method, combined with high-speed diving, enhances their manoeuvrability and accuracy. The bird's controlled trajectory is akin to a Formula 1 driver maintaining stability at high speeds. **2.b Ask yourself: What do I want my design to do?** • Deliver both nuclear and conventional payloads with precision and efficiency. • Evade detection through advanced stealth and silent operation. • Perform long-range missions across the globe with minimal refuelling needs. • Adapt to diverse mission requirements, from reconnaissance to electronic warfare. • Integrate seamlessly into modern multi-domain battlefields. • Maintain sustainability and efficiency in line with evolving environmental considerations. **2.c Flip the question. Consider opposite functions.** How do weather conditions impact the hunting success of peregrine falcons?

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Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Birds like albatrosses:** Albatrosses use their long wings to soar efficiently over vast distances with minimal energy expenditure, mimicking the bomber's need for range and efficiency. • **Owls:** Owls have serrated wing feathers that reduce noise during flight, enabling silent hunting. Their muted colouration and body shape make them difficult to spot, mimicking radar-absorbing stealth designs. • **Hummingbirds:** Hummingbirds have precise control over their movements, allowing them to hover and manoeuvre quickly. • **Migratory birds** (e.g., Arctic Terns) migrate thousands of miles, relying on efficient flight patterns and energy conservation. • **Bats:** Bats use silent flight and echolocation for hunting in the dark, avoiding detection by prey. • **Octopuses:** Octopuses can adapt their behaviour, camouflage, and movement to suit various environments and tasks. • **Polar bears:** The fur and skin of polar bears effectively manage heat while blending into snowy environments. • **Sharks:** Sharks have hydrodynamic skin structures to reduce drag and enhance speed while maintaining stealth. **3.b Identify experts & connect to communities of biologists and naturalists.**
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** • **Aerodynamic efficiency:** The Peregrine Falcon is known for its exceptional aerodynamic capabilities, particularly during high-speed dives. • **Stealth and manoeuvrability:** Falcons, with their ability to hunt with precision and speed, showcase remarkable agility in the air. • **Wing design:** The falcon's wings are long and pointed, which reduces drag and enables faster flight. This design helps them reach speeds of over 240 mph (386 km/h) during a dive. • **Adaptability to flight conditions:** Falcons are renowned for adjusting their wings to accommodate various flight conditions. • **Silent flight:** Peregrine Falcons are skilled in flying silently to avoid alerting their prey.

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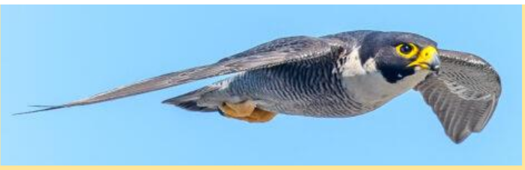

https://chirpforbirds.com/nature-advocacy/biomimicry-and-birds/?srsltid=AfmBOopiHtajWZ6_7sjZCwemSmFLUNUOz-pQ_NTtywhyZIDm2NYC8JI5

https://medium.com/@abhishek_sawant/b-2-bomber-nature-inspired-design-marvel-2d717c5c09d8

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

The peregrine falcon's design has influenced the engineering of the B-2 Spirit Bomber, making it one of the most iconic planes in the U.S. military arsenal. This connection between nature and advanced aviation technology highlights several key aspects:

- **Aerodynamic efficiency:** Engineers have studied the falcon's flight patterns and wing shapes to enhance the aerodynamic efficiency of aircraft, including the B-2 Spirit Bomber.
- **Stealth and manoeuvrability: The B-2's design for stealth missions incorporates advanced aerodynamics to reduce radar cross-section and enhance manoeuvrability**, inspired by the falcon's efficiency in flight.
- **Wing design:** The principles of sleek, streamlined wings that minimise drag and improve speed are derived from observations of birds of prey like the peregrine falcon.
- **Adaptability to flight conditions:** The B-2's variable geometry wings can adjust their configuration based on different flight phases, similar to how falcons adapt their wings.
- **Silent flight:** While the B-2 is not silent, its design includes features to reduce its radar signature, allowing it to operate with a higher level of stealth.

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https://medium.com/@abhishek_sawant/b-2-bomber-nature-inspired-design-marvel-2d717c5c09d8

Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

Key information

Aerodynamic efficiency, stealth, manoeuvrability, and silence.

Ideas

Flying wing configuration, optimisation of airfoil, use of radar-absorbing materials or coatings that minimise detectability, materials that absorb and dampen sound, Fly-by-wire technology, Engines integrated within the wing structure, variable cycle engines, and advanced turbofans.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

	Context	Features	Constraints
Aerodynamic efficiency	Military applications technological integration	Flying wing configuration Optimised air foil design Advanced materials Integrated propulsion	Stealth requirements Weight and payload balance Cost and complexity Maintenance and durability
Stealth		Low Radar cross-section (RCS) Radar-absorbing Materials (RAM) Infrared signature reduction Acoustic signature reduction	Design Complexity Weight and Payload Cost and Feasibility Maintenance and Durability

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Manoeuvrability		Fly-by-wire systems Distributed Propulsion Advanced avionics Control surfaces	Stealth requirements Structural integrity Weight and balance Cost and complexity
Silence		Engine design Noise-dampening materials Exhaust management Aerodynamic design	Stealth requirements Weight and balance Cost and complexity Performance trade-offs

For the challenge, given, all the ideas are applicable.

Step 6 – Evaluate

6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

Constraints

- **Stealth requirements:** Balancing low observability with aerodynamic performance.
- **Weight and payload:** Managing the weight of advanced materials and technologies while maintaining payload capacity.
- **Cost and complexity:** High development and production costs due to advanced technologies.
- **Maintenance and durability:** Specialised maintenance for advanced materials and systems.

Compatibility with the Earth's Systems

- **Environmental impact:** The use of advanced materials and technologies should consider environmental sustainability. Efforts to reduce noise and emissions align with environmental regulations, thereby minimising the ecological footprint.
- **Operational environments:** The aircraft must be capable of operating in diverse environments, from high-altitude missions to low-level penetration, while maintaining performance and stealth.

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	Feasibility evaluation • **Technical feasibility:** The integration of cutting-edge technologies in aerodynamics, stealth, and propulsion is technically feasible but requires significant R&D investment. Existing aircraft, such as the B-2 Spirit and the upcoming B-21 Raider, demonstrate the viability of flying wing designs for stealth and efficiency. • **Business model feasibility:** The initial investment is substantial, but the long-term benefits in terms of strategic capabilities and operational efficiency justify the expenditure. Strong demand from military sectors for advanced strategic bombers ensures a viable market. While maintenance and operational costs are high, the strategic advantages and extended service life provide a favourable return on investment. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Designing an aerodynamically efficient, subsonic, stealthy, manoeuvrable, and silent flying wing heavy strategic bomber involves addressing several design challenges, criteria, and constraints. The primary challenge is to integrate multiple advanced technologies and design principles to achieve a balance between aerodynamic efficiency, stealth, manoeuvrability, and silence. This involves overcoming technical complexities and ensuring the aircraft meets stringent military requirements. In conclusion, the design of an aerodynamically efficient, subsonic, stealthy, manoeuvrable, and silent flying wing heavy strategic bomber is both technically and economically feasible, given the significant strategic advantages and the alignment with modern military needs.

Additional resources:

https://biomimicry.org/

https://www.audubon.org/news/research-reveals-exactly-why-peregrine-falcons-are-so-deadly

https://www.pnas.org/doi/10.1073/pnas.1714532114#executive-summary-abstract

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0086506

https://web.stanford.edu/group/stanfordbirds/text/essays/Raptor_Hunting.html

https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1006044#abstract1

https://medium.com/@abhishek_sawant/b-2-bomber-nature-inspired-design-marvel-2d717c5c09d8

https://www.icr.org/article/a-bird-in-the-hand

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Mimicking prairie ecosystems

BIOMIMICRY DESIGN	**Description**
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do prairie ecosystems naturally maintain soil fertility and structure? **Context** The variety of species in a prairie ecosystem enables plants to make efficient use of water and nutrients. Additionally, natural systems exhibit greater resilience to disturbances, possess self-regulating capabilities, maintain more stable soils, and enhance carbon sequestration, nutrient cycling, food production, and biodiversity. **2.b Ask yourself, "What do I want my design to do?"** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do. • **Enhance soil health:** Use deep-rooted plants and natural soil aeration to improve soil structure and fertility. • **Promote biodiversity:** Integrate diverse crops to create a resilient system against pests, diseases, and stresses. • **Optimize water use:** Implement water management strategies like cover crops and organic mulches to retain soil moisture. • **Natural pest control:** Encourage beneficial insects and predators to reduce the need for chemical pesticides. • **Nitrogen fixation:** Use nitrogen-fixing plants to enrich soil naturally, reducing synthetic fertilizer use. • **Carbon sequestration:** Adopt practices that enhance soil carbon storage to mitigate climate change and improve soil health. • **Pollinator support:** Plant native flowers and maintain natural areas to support pollinators and improve crop yields. • **Resilience to disturbances:** Design systems that recover from disturbances by incorporating adaptive strategies. • **Energy efficiency:** Use renewable energy sources to reduce the carbon footprint of agricultural operations.

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	• **Community and education:** Promote educational programs and community involvement in sustainable farming practices. **2.c Flip the question. Consider opposite functions.** How do prairie ecosystems respond to and recover from disturbances resulting from climate change?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** There are several natural models that match the functions and context of the design solution for sustainable and efficient agriculture, similar to prairie ecosystem: • **Forest ecosystems:** Forests maintain soil health, support biodiversity, and manage water resources. • **Wetland ecosystems:** Wetlands filter water, store carbon, and support diverse plant and animal life. • **Savanna ecosystems:** Savannas are characterized by a mix of grasses and trees, which support diverse herbivore populations and maintain soil health. • **Coral reef ecosystems:** Coral reefs support high biodiversity and protect coastlines from erosion. • **Desert ecosystems:** Deserts have plants adapted to extreme conditions, conserving water and nutrients. • **Mangrove ecosystems:** Mangroves protect coastlines, store carbon, and provide nursery habitats for marine life. • **Grassland ecosystems:** Grasslands support herbivores, maintain soil health, and sequester carbon. **3.b Identify experts & connect to communities of biologists and naturalists.** • The Land Institute. • American Society of Naturalists (ASN). • International Union for Conservation of Nature. • Natural History Network. • Society for Conservation Biology (SCB).
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** • **Soil health and fertility** (deep root systems, nutrient cycling). • **Water management** (water retention, drought resistance).

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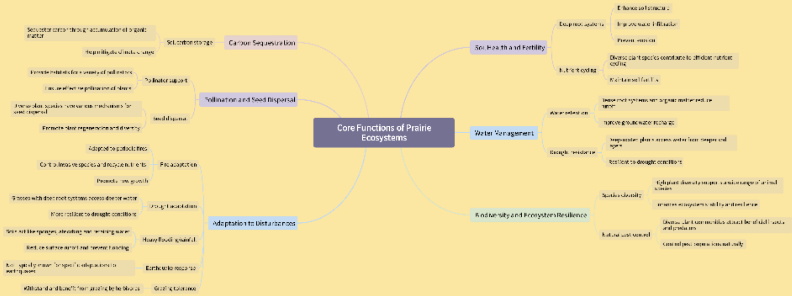
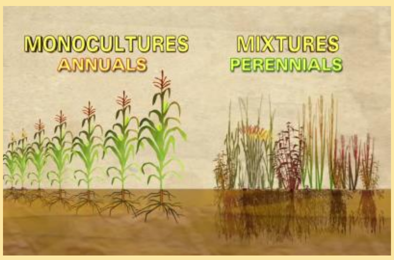
- **Biodiversity and ecosystem resilience** (species diversity, natural pest control).
- **Carbon sequestration** (soil carbon storage).
- **Pollination and seed dispersal** (Pollinator support, seed dispersal).
- Adaptation to disturbances .



4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

- **Soil health and fertility:** Use deep-rooted plants and crop rotation to improve soil structure, prevent erosion, and maintain fertility.
- **Water management:** Retain water with cover crops and mulches, and select drought-resistant crops to ensure stable production.
- **Biodiversity and ecosystem resilience:** Cultivate diverse crops and encourage the presence of beneficial insects for natural pest control.
- **Carbon sequestration:** Increase soil organic matter through composting and reduced tillage to store carbon.
- **Pollination and seed dispersal:** Support pollinators by using native plants and employing diverse planting strategies for crop regeneration.
- **Adaptation to disturbances:** Mimic natural fire regimes, utilise polycultures for drought resilience, enhance soil quality for flood and earthquake stability, and manage grazing to maintain ecosystem health.



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Video copyright:
https://www.youtube.com/@KansasCityPBS
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<tr>
<td>Step 5 – Emulate</td>
<td>5.a List your key information and explore as many ideas as possible.
Key information and ideas

Vertical Farming.
Permaculture.
Aquaponics.
Regenerative agriculture.
Agroecology.
Precision agriculture.
Urban agriculture.
Agroforestry.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
Contexts applied to all ideas: Polyculture and Biodiversity,
Nutrient Cycling, Water Efficiency, Energy Efficiency, Integrated Pest Management, Local Food Production, Technological Advancements
<table>
<tr><td></td><td>Features</td><td>Application</td></tr>
<tr><td>Vertical Farming</td><td>Multiple crops: Grow various crop species together.
Ecosystem stability: Enhance stability and productivity.
Resource recycling: Use waste from one process as input for another.
Water and nutrient recycling: Recycle water and nutrients.
Urban integration: Integrate into urban environments.</td><td>Urban agriculture
Controlled environment agriculture
Specialized crop production farms
Research and development
Commercial and industrial applications</td></tr>
<tr><td></td><td colspan="2">Constraints:</td></tr>
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		High energy consumption, Initial capital costs, Technical expertise, Limited crop variety, Resource use efficiency, Economic viability, Environmental impact	
	Permaculture	• Diverse crops: Promote growing a variety of crops together. • Ecosystem stability: Enhance stability. • Pest resistance: Improve resistance to pests. • Disease resilience: Increase resilience against diseases. • Resource recycling: Use waste from one process as input for another. • Community involvement: Often involve local communities.	• Home gardens • Community gardens • Urban permaculture • Rural permaculture • Permaculture farms • Educational and demonstration sites
		Constraints: High initial costs, Labour intensity, Knowledge and training, Adaptation to local conditions, Market demand and economic Viability, Scalability, Pest and disease management	
	Aquaponics	• Multiple species can coexist and support each other • Growing a variety of plants in the aquaponic system can enhance resilience and productivity • Fish waste can be used as fertilizer providing nutrients to plants • Recycling of water which can significantly reduce water waste • Introduction of natural predators and beneficial insects can reduce the need for chemical pesticides • Can be integrated into urban environments	• Home Gardens • Commercial farms • Urban Agriculture • Educational Institutions • Humanitarian Relief

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	Constraints: High initial costs, Energy consumption, Technical complexity, Water quality management, Limited crop variety, Economic viability, Scalability, Environmental impact	
Regenerative agriculture	• No-till farming reduces soil disturbance • Planting cover crops helps prevent soil erosion, improves soil fertility, and enhances water retention • crop rotations can break pest and disease cycles, improve soil health, and increase resilience • Rotational grazing of livestock can help manage vegetation • regenerative landscapes can help in retention of water, preventing erosion and improving water infiltration • cover cropping can reduce tillage, and organic amendments can increase soil organic matter and sequester carbon, helping mitigate climate change	• No-till or reduced-till farms • Cover-cropping farms • Agroforestry • Polyculture • Swales and contour farms • Companion planting sites • Urban agriculture • Commercial and industrial applications
	Constraints: Transition period, Knowledge and skills, Initial costs, Market access, Policy and support, Research and data, Climate and environmental Variability, Economic viability	
Agroecology	• Crop diversification can improve soil health, reduce pest outbreaks, and increase resilience • Planting cover crops like clover or rye prevents soil erosion, improves soil fertility, and enhances water retention	• Polyculture and crop rotation farms • Agroforestry • Smallholder farms • Urban and Peri-Urban Agriculture • Fisheries and Aquaculture

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		• Reduces the need for synthetic fertilizers and maintains soil fertility • Maintain ecological balance and reduces environmental pollution • Reduce pest and disease outbreaks, improve soil health, and increase overall farm productivity • Enhance the resilience of farming systems to climate change • Improve food security, and enhance the livelihoods of smallholder farmers	• Education and Community Development
		Constraints: Knowledge and training, Initial costs, Need for manual labour, Market access and economic viability, Policy and institutional support, Research and data, Adaptation to local conditions, Scalability	
	Precision Agriculture	• Targeted inputs: Apply water, fertilizers, and pesticides only where needed to reduce waste and environmental impact. • Precision techniques: Optimize resource use, enhance crop health, and increase yields while minimizing environmental footprint. • Informed decisions: Enable farmers to make informed decisions. • Continuous monitoring: Detect issues early and intervene timely to improve productivity and sustainability. • Water optimization: Use soil moisture sensors and automated irrigation systems. • Chemical reduction: Reduce overall use of chemicals.	• Crop yields across different field areas • Automated Irrigation Systems • Soil Mapping systems • Forestry • Environmental Monitoring sites • Urban and Peri-Urban Agriculture • Aquaculture

		• Soil health: Promote practices like reduced tillage and cover cropping to maintain and improve soil health.	
		Constraints: High initial costs, Technical expertise, Data management, Energy consumption, Infrastructure requirements, Economic viability, Environmental impact	
	Urban Agriculture	• Diverse crops and green spaces: Cultivate various crops and integrate green spaces. • Urban food production: Use rooftops, vacant lots, and community gardens to maximize space and create resilient food systems. • Soil health: Improve soil with composting, organic amendments, and raised beds. • Water optimization: Employ rainwater harvesting, drip irrigation, and greywater use. • Ecological balance: Reduce chemical pesticides and promote ecological balance. • Community participation: Foster social cohesion and empower residents. • Climate resilience: Increase green spaces, improve air quality, and reduce stormwater runoff.	• Rooftop Gardens • Vertical Farming • Hydroponics and Aquaponics farms • Community Gardens • Urban and Peri-Urban unused areas • Abandoned or underutilized industrial sites
		Constraints Space limitations, soil contamination, high initial costs, water management, technical expertise, economic viability, policy and regulatory barriers, community engagement	
	Agroforestr y	• **Promotes diversity:** Enhances ecosystem resilience, supports wildlife habitats, and improves pollination with diverse plant species.	• Alley Cropping • Silvopasture • Riparian Buffers

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		• **Soil health:** Adds organic matter, improves soil structure, and enhances nutrient cycling. • Water quality: Improves water quality and availability. • **Climate resilience:** Provides shade, reduces wind speed, and acts as a carbon sink. • **Natural pest control:** Supports natural pest predators, reducing the need for chemical pesticides. • **Multiple income streams:** Produces fruits, nuts, timber, and other forest products. • **Ecosystem services:** Offers carbon sequestration, habitat provision, and landscape beautification. • **Resource optimisation:** Leads to more efficient and productive farming systems.	• Timber and Wood Products • Bioenergy Production systems • Pharmaceuticals and botanical industries • Urban Areas • Rehabilitation of Degraded Lands • Environments affected by Climate Change
		Constraints High initial costs, Labour intensity, Knowledge and training, Market access and economic viability, Policy and institutional support, Adaptation to local conditions	
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** **Design concept selected** **Permaculture** Perennial grain cropping, or permaculture, is a form of agriculture developed to mimic natural systems. Natural Systems Agriculture is an industrial agriculture system that uses perennial polycultures and mutually beneficial relationships to increase the health and productivity of crops. This strategy leverages the benefits found in natural systems, such as pest control, fertility and nutrient cycling, erosion control, drought resistance, water management, and carbon sequestration. **Alignment with sustainable and efficient agriculture**		

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- **Ecological harmony:** Works with natural processes to enhance soil fertility, manage pests, and conserve water.
- **Diversity and resilience:** Promotes diverse species and polycultures to improve ecosystem stability and reduce pest outbreaks.
- Maximises resource use by integrating elements where outputs of one serve as inputs for another.
- **Soil health:** Utilises composting, mulching, and cover crops to enhance soil structure and improve nutrient cycling.

Compatibility with the Earth's systems

- **Biodiversity and ecosystem services:** Enhances biodiversity and provides essential services, such as pollination and water regulation.
- **Climate resilience:** Promotes diverse systems to withstand climate change and buffer against extreme weather.
- **Carbon sequestration:** Maintaining perennial plants and improving soil health sequesters carbon and mitigates climate change.
- **Water conservation:** This includes techniques such as rainwater harvesting and efficient irrigation to manage water sustainably.

Technical feasibility

- **Technical feasibility:** Uses ecological principles to design systems that enhance biodiversity, soil health, and resilience.
- **Resource efficiency:** Integrates elements to reduce waste and enhance productivity.
- **Soil health and water management:** Improves soil structure and conserves water through composting, mulching, and the use of swales.
- **Climate resilience:** Designs systems that are resilient to climate change, utilising diverse, perennial plants.

Business model feasibility

- **Initial investment and costs:** Requires upfront investment but offers long-term savings and increased productivity.
- **Economic viability:** Diversifies income through various crops, livestock, and value-added products.
- **Market access:** Develops direct-to-consumer sales channels and finds markets that value sustainable goods.
- **Policy and institutional support:** Needs supportive policies and incentives for widespread adoption.

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	• **Community and education:** Builds community support and educates on permaculture principles for success. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To generate a viable solution for implementing permaculture sustainably and efficiently, we can revisit and refine the following key aspects: • **Ecological design:** Create diverse polycultures and integrate agroforestry using native and perennial species. Develop site-specific designs tailored to local conditions. • **Resource efficiency:** Optimise resource use with rainwater harvesting, composting, and renewable energy. Implement nutrient and water recycling systems. • **Soil health and water management:** Improve soil with cover crops, mulching, and organic amendments. Utilise swales to manage water and monitor soil health and water usage. • **Climate resilience:** Utilise climate-resilient species and develop contingency plans for extreme weather events. Adapt practices based on monitoring and feedback. • **Carbon sequestration:** Enhance carbon storage with perennial plants and improve soil health. Communicate benefits to attract support and funding. • **Initial investment and costs:** Seek financial support through grants, subsidies, and loans. Develop a comprehensive financial plan with a phased implementation approach. • **Economic viability:** Diversify income with various crops, livestock, and value-added products. Explore niche markets and direct sales channels. • **Market access:** Build relationships with local markets and consumers. Invest in branding and outreach to educate them about the benefits of permaculture.

Additional resources:

https://asknature.org/innovation/sustainable-industrial-agriculture-inspired-by-prairie-ecosystems/

https://asknature.org/strategy/natural-ecosystem-demonstrates-sustainability/

https://www.youtube.com/watch?v=RwUyL9ox_ts

https://landinstitute.org/

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: The sustained and powered flight, aerodynamic structure, energetic efficient and muscle enabled controlled aerial movement of bats

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can bats use flight for everything, from capturing prey, breeding, avoiding predators to long-distance migration? **Context** Bats are the only flying mammals, divided into two main groups: fruit-eating megabats and echolocating microbats. They are mostly nocturnal and live in caves. Bats use echolocation to navigate and hunt, emitting ultrasonic sounds to produce echoes. Their calls can reach 140 decibels and range from 14,000 to over 100,000 Hz. Bats' ears are sensitive to prey sounds, and they can construct a mental image of their environment through repeated scanning. Bats are found worldwide, except in very cold regions, and are essential for pollinating flowers and dispersing seeds. They have evolved specialised features for flight, like flexible wings and strong muscles. Bats have good vision adapted to their environment, with some relying more on echolocation than sight. **2.b What do I want my design to do?** **Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do.** The primary purpose of a new, lightweight, highly efficient, and stealthy robotic micro-air vehicle (MAV) specifically designed for military applications is to enhance operational capabilities in various challenging environments. In addition, my design aims to provide real-time intelligence, track threats, assist ground forces, locate survivors, act as a communication hub, detect threats, and use deception tactics. Furthermore, it can be adapted for civilian applications, including disaster response, environmental monitoring, urban planning, and agriculture. **Summary of key functions and nature's contexts** **Key functions**

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	• **Surveillance and reconnaissance:** Collect and transmit real-time intelligence from hostile or inaccessible environments while remaining undetected. • **Target identification and tracking:** Utilise advanced sensors and algorithms to precisely locate, identify, and monitor targets, even in complex, cluttered, or dynamic environments. • **Tactical support:** Provide on-ground forces with situational awareness, deliver payloads, or assist in precision strikes. • **Environmental monitoring:** Detects chemical, biological, or radiological threats and assesses environmental conditions in real-time. • **Energy efficiency and extended operation:** Maximise flight endurance through efficient energy use and sustainable power systems. • **Stealth and camouflage:** Avoid detection by radar, thermal imaging, or visual observation. • **Communication and signal relay:** Serve as mobile communication hubs to support military units in areas with compromised signals. • **Autonomous navigation in complex environments:** Operate independently in GPS-denied areas with obstacle detection and dynamic route planning. **2.c Flip the question. Consider opposite functions.** How do bats use their other senses, such as echolocation and vision, to compensate for the lack of flight in certain situations?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Owls** are known for their silent flight due to specialised feathers that dampen sound; they excel in covert hunting, making them an ideal inspiration for stealthy MAVs. • **Dragonflies,** with their excellent visual acuity and ability to hover in place, can serve as models for surveillance drones that require stable and precise observation. • **Peregrine falcons** utilize proportional navigation during high-speed dives to intercept prey, providing a blueprint for tracking and interception in MAVs. • **Honeybees** use coordinated foraging and navigation to deliver resources precisely to their hive, mirroring MAVs that deliver small payloads in complex environments. • **Birds of prey, such as hawks, can accurately drop or manipulate objects mid-flight, which** can inspire the MAV payload design.

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- **Butterflies and moths** are sensitive to environmental changes like temperature and humidity; they can inspire MAV sensors for detecting subtle atmospheric shifts.
- **Vultures** can locate carcasses over vast areas; this ability can highlight aerial strategies for wide-scale monitoring.
- **Albatrosses** use dynamic soaring to exploit wind currents and conserve energy, and can inspire MAV flight strategies for endurance.
- **Hummingbirds** are very efficient in hovering with minimal energy expenditure and can be a direct influence on designing high-performance MAVs.
- **Insects** like stick insects and moths blend seamlessly with their environment, and can inspire MAV designs for urban or wilderness camouflage.
- **Nocturnal creatures** like owls operate undetected at night and can inspire research in MAVs on optimisation for low-light missions.
- **Ant colonies** use pheromone trails for communication over long distances, much like MAVs relaying signals.
- **Fireflies** with their bioluminescent signalling can inspire efficient, low-energy communication systems in MAVs.
- **Pigeons** rely on geomagnetic fields and visual landmarks for precise navigation, which in turn influences the autonomy of MAVs.

3.b Identify experts & connect to communities of biologists and naturalists.

- University of California at Berkeley.
- University of New Mexico.
- Southampton and Imperial College.
- California Institute of Technology.
- Boston University.
- University of Maryland.
- The Pentagon.
- Conservationists in several states.
- Swiss Federal Institute of Technology in Lausanne (EPFL).
- Researchers lead by Dr Stefan Seelecke from North Carolina University.
- Northeastern University, led by Alireza Ramezani.

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Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Flight adaptations** • **Forelimbs as wings:** Bats are the only mammals capable of true and sustained flight. • **Membrane surface area:** Increased between digits, forelimbs, and hindlimbs. • **Thinner cortical bone:** Reduces torsional stresses. • **Innervation and musculature:** Rerouted innervation and increased muscle strength for powerful wingbeats. • **Metabolic adaptations:** High metabolic rate, increased lung capacity, and aerobic respiration. **Echolocation** • **Ultrasonic sounds:** Emitted by microbats and some megabats to produce echoes. • **Sound intensity:** Dependent on subglottic pressure, with calls reaching up to 140 decibels. • **Frequency range:** 14,000 to over 100,000 Hz, beyond human hearing. • **Prey detection:** Bats compare outgoing pulses with returning echoes to locate prey. • **Tragus and interference patterns:** Used to estimate target elevation. **Diet and behaviour:** • **Diet:** Insectivores, frugivores, nectarivores, and some species feed on animals. • **Nocturnal:** Most bats are active at night and often live in caves or refuges. • **Ecosystem role:** Pollinating flowers and dispersing seeds, crucial for many tropical plants. **Visual capabilities** • **Functional vision:** Contrary to myths, bats generally have vision adapted to their environment. • **Nocturnal adaptations:** Eyes adapted for low-light conditions. • **Dichromatic vision:** Ability to see two colours, usually green and ultraviolet.

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- **Rod and cone cells:** Rich in rod cells for dim light, fewer cone cells for colour detection.

Manoeuvrability and dexterity

- **Flexible joints:** More manoeuvrable and dexterous than gliding mammals.
- **Wing structure:** Thinner wings with more bones, allowing precise manoeuvring.
- **Energy efficiency:** Folding wings on the upstroke saves energy.

Specialised features:

- **Occipito-pollicalis muscle:** Unique to bats, necessary for flight.
- **Plagiopatagium:** Skin overlapping the forelimb, similar to flying squirrels.
- **Regenerative membranes:** Delicate but can regrow and heal quickly.

https://dronelife.com/2018/01/05/laser-powered-bat-drones-really/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Key features and adaptations

Flight mechanics

- **Flexible membranes:** Mimicking bat wings, MAVs can be designed with flexible materials to navigate through narrow corridors.
- **Efficient flapping motion:** Utilising shape-memory metal alloys, MAVs can replicate the flapping motion of bats, providing a full range of motion and returning to the original position.

Autonomous control systems

- **3D thermal imaging and radar:** These technologies enable researchers to study bat flight in groups and track their migration, providing valuable insights for MAV navigation.

Microelectronics and sensors

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	• **Stereo cameras and microphones:** MAVs can be equipped with tiny cameras and microphones to gather visual and auditory data. • **Environmental sensors:** Sensors for detecting nuclear radiation, poisonous gases, and other threats can be integrated into MAVs. • **Low-power radar:** Enables MAVs to navigate in the dark and detect obstacles. **Energy efficiency** • **Energy scavenging:** MAVs can harness energy from solar, wind, and vibrations to recharge their batteries, ensuring sustained operations. • **Lightweight design:** Using advanced materials, MAVs can be designed to be lightweight yet durable, similar to bat skeletons.   https://record.umich.edu/articles/com-bat-research-takes-flight/ https://newatlas.com/bat-inspired-drone-flies-walks/35744/
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • **Lightweight construction:** use of advanced Materials, miniaturisation. • **Aerodynamic efficiency:** optimised airfoil design, flapping wing mechanisms. • **Stealth Capabilities:** radar-absorbing materials (RAM), infrared and acoustic signature reduction. • **Advanced sensors and avionics:** high-resolution cameras, real-time data transmission. • **Autonomous operation:** AI and machine learning, swarm capabilities. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.**

	Context	Features	Constraints
Lightweight Construction	Militaryappli cations	Advanced materials	Structural integrity

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		Technological integration	Miniaturisation efficient design Modular construction	Cost Environmental factors Manufacturing complexity
	Aerodynamic Efficiency		Lift-to-drag ratio (L/D) Wing design Smooth surface Optimised airfoil Shapes	Structural Integrity Weight and Balance Environmental Factors Cost and Complexity
	Stealth Capabilities		Low radar cross-section (RCS) Infrared suppression Acoustic signature reduction Visual camouflage	Design complexity Weight and payload Cost and feasibility Maintenance and durability
	Advanced Sensors and Avionics		High-resolution sensors Autonomous navigation Systems Real-time data processing Secure communication systems Integrated avionics suite	Size, weight, and power (SWaP) Environmental durability Cost and complexity Maintenance and upgradability
	Autonomous Operation		AI and Machine Learning Advanced sensors Real-time data processing	Regulatory and ethical considerations Environmental factors Size, weight, and power (SWaP)

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		Secure communication systems Redundancy and fail-safe mechanisms	Cost and complexity Maintenance and upgradability

Idea selected

Stealth capabilities.

Step 6 – Evaluate

6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

Stealth capabilities

- **Radar-absorbing materials (RAM)**: Using materials that absorb radar waves to reduce the MAV's radar cross-section (RCS) and enhance stealth.
- **Infrared and acoustic signature reduction**: Advanced cooling systems and noise-dampening materials to minimise heat and sound emissions, making the MAV harder to detect.

Constraints

- **Power and endurance:** Balancing the MAV's power requirements with its endurance is critical. Efficient energy storage and management systems are necessary to maximise flight time.
- **Payload capacity:** The MAV must be able to carry necessary sensors and communication equipment without compromising its flight performance.
- **Environmental factors:** The MAV must be capable of operating in various environmental conditions, including wind, rain, and varying temperatures.
- **Cost and scalability:** Developing cost-effective MAVs that can be produced at scale while maintaining high performance and reliability.

Compatibility with the Earth's systems

- **Environmental impact:** Using environmentally friendly materials and energy-efficient systems to minimize the ecological footprint. Ensuring the MAV does not interfere with local wildlife and ecosystems.
- **Operational environments:** The MAV must be versatile enough to operate in diverse environments, from urban areas to remote locations, while maintaining stealth and efficiency.

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	Technical feasibility • **Advanced technologies:** The integration of cutting-edge materials, sensors, and AI technologies is technically feasible but requires significant R&D investment. • **Proven concepts:** Existing MAVs and similar technologies demonstrate the viability of lightweight, efficient, and stealthy designs for military applications. **Business model feasibility** • **High development costs:** The initial investment is substantial, but the long-term benefits, in terms of strategic capabilities and operational efficiency, justify the expenditure. • **Market demand:** Strong demand from military sectors for advanced reconnaissance and surveillance capabilities ensures a viable market. **Lifecycle costs** While maintenance and operational costs are high, the strategic advantages and extended service life provide a favourable return on investment. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Designing a lightweight, highly efficient, and stealth robotic micro-air vehicle (MAV) for military applications involves addressing several design challenges, criteria, and constraints. The primary challenge is to integrate multiple advanced technologies and design principles to achieve a balance between lightweight construction, aerodynamic efficiency, stealth capabilities, and autonomous operation. This involves overcoming technical complexities and ensuring the MAV meets stringent military requirements. In conclusion, the design of a lightweight, highly efficient, and stealth robotic MAV for military applications is both technically and economically feasible, given the significant strategic advantages and the alignment with modern military needs.

Additional resources:

https://biomimicry.org/

https://en.wikipedia.org/wiki/Bat#References

https://news.umich.edu/sensors-for-bat-inspired-spy-plane-under-development/

https://www.popsci.com/science/article/2010-11/bat-research-inspires-disciplines-far-beyond-biology/

https://newatlas.com/bat-inspired-drone-flies-walks/35744/

https://newatlas.com/metal-muscled-robo-bat/12188/

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Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

https://www.popsci.com/technology/bats-weird-wings-inspired-this-drone/

https://en.wikipedia.org/wiki/Bat_wing_development

https://en.wikipedia.org/wiki/Bat_flight#Evolution

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: A novel non-clogging feeding mechanism of manta rays

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can manta rays filter food more efficiently and feed without clogging? **Context** Manta rays, belonging to the genus Mobula, can reach widths of up to 7 meters (23 feet) and weigh up to 1,360 kg. They are close relatives of sharks and inhabit warm temperate, subtropical, and tropical waters. Manta rays are filter feeders and macropredators, consuming large quantities of zooplankton and small to medium-sized fish. They filter feed by swimming with their mouths open, using specialized filtering organs to trap food particles. Their filtration system is highly efficient and resistant to clogging, using leaf-like lobes to bounce food particles away from the filter. Manta rays play a crucial role in their ecosystems by concentrating biomass and removing excess nutrients from the water. They engage in various feeding behaviours, including horizontal swimming, somersaults, and group feeding formations like "cyclones." Unfortunately, manta rays are listed as Vulnerable by the International Union for Conservation of Nature due to threats such as pollution, fishing net entanglement, and the harvesting of their gill rakers. They are protected in international waters but remain vulnerable closer to shore. **2.b Ask yourself "What do I want my design to do?"** • **Reduce microplastic pollution:** The primary goal is to filter out fine plastic particles from water, thereby reducing pollution and its harmful effects on marine life and ecosystems. • **Improve filtration efficiency:** Inspired by the manta ray's natural filtration system, the design aims to achieve high filtration efficiency while minimizing clogging and maintenance. • **Provide a sustainable solution for the given challenge:** The filter aims to be designed to be energy-efficient and sustainable, aligning with environmental goals such as those outlined in the United Nations Sustainable Development Goals (SDGs), particularly Goal 11: Sustainable Cities and Communities.

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	2.c Flip the question. Consider opposite functions. How do manta rays manage to filter and ingest plankton while avoiding excessive seawater intake?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Sponges**: Marine sponges filter water through their porous bodies, capturing particles as small as bacteria. Their structure and the flow dynamics they create can inspire low-energy, high-efficiency filtration systems. • **Tree leaves**: The microstructures on the surface of tree leaves can capture particulate matter from the air. This natural filtration process can inspire designs that use similar surface structures to enhance particle capture. • **Honeycombs**: The hexagonal structure of honeycombs provides a large surface area for filtration while maintaining structural integrity. This design can be mimicked to create filters that are both efficient and durable. **3.b Identify experts & connect to communities of biologists and naturalists.** • MIT Engineers. • Biomimicry Institute. • California State University-Fullerton. • AskNature. • ResearchGate. • Biomimicry Global Network..
Step 4 – Abstract	**4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** • **Filter feeding:** Manta rays are filter feeders, consuming zooplankton and small fish by filtering water through specialized gill structures. • **Non-clogging filtration:** They use a ricochet separation mechanism to filter particles smaller than the pore size, allowing high flow rates and resisting clogging. • **Nutrient acquisition:** They gather nutrients by feeding on organic matter and smaller organisms suspended in water. • **Ecosystem engineering:** Manta rays play a role in condensing biomass, removing excess nutrients, and bioaccumulation, acting as indicator organisms.

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https://www.earth.com/news/manta-rays-inspire-a-new-design-for-water-filters/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Efficient filtration

- **Objective:** Develop a filtration system capable of handling high flow rates and effectively capturing small plastic particles.
- **Inspiration:** Manta rays use a method where water flows through structures that create turbulence, causing particles to bounce off and be captured.
- **Implementation:** Design filters with angled fins or plates that create swirling currents, directing plastic particles into a collection area while allowing clean water to pass through.

Non-clogging mechanism

- **Objective:** Ensure the filtration system remains functional without frequent maintenance.
- **Inspiration:** Manta rays' filtration system resists clogging by using a ricochet mechanism.
- **Implementation:** Incorporate structures that cause particles to ricochet off surfaces, preventing buildup and clogging. Utilise adjustable fins to redirect the water flow and clear any trapped particles.

Modular design

- **Objective:** Create a scalable and adaptable system that can be deployed in various water bodies.
- **Inspiration:** The modular nature of manta rays' gill structures.
- **Implementation:** Develop modular units that can be combined to form larger filtration systems. Each unit should have an opening to draw in water and internal structures to filter out plastics.

Circular economy

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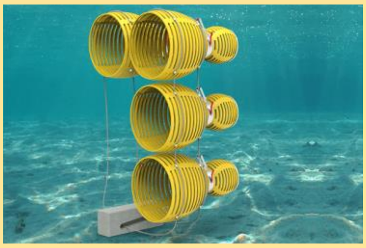
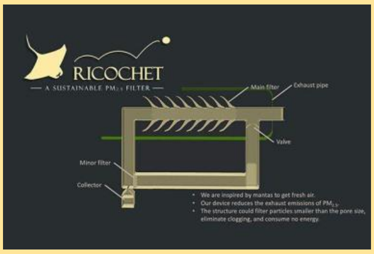
- **Objective:** Utilise collected plastic waste to create new filtration units, promoting sustainability.
- **Inspiration:** The continuous cycle of nutrient capture and utilisation in manta rays.
- **Implementation:** Design the system to collect and compact plastic waste, which can then be recycled into new filtration units, reducing overall plastic waste and supporting a circular economy.

Community and ecosystem Impact

- **Objective:** Engage local communities in the deployment and maintenance of the filtration systems.
- **Inspiration:** The collaborative feeding behaviours of manta rays.
- **Implementation:** Involve local communities in the installation and upkeep of the filtration systems, providing education on plastic pollution and its impacts. Encourage community ownership and participation to ensure long-term success.





https://asknature.org/innovation/plastic-filtering-device-inspired-by-the-manta-ray-and-basking-shark/

https://asknature.org/innovation/rticulate-matter-filters-inspired-by-manta-rays/

Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

Key Information

- **Filtration mechanism**: The filter should employ a mechanism that effectively captures fine plastic particles, which can include physical barriers, electrostatic attraction, or chemical adsorption.
- **Material selection**: Choosing the right materials is crucial. Materials like polypropylene, polyester, and nylon are commonly used due to their durability and filtration efficiency. The material should also be resistant to clogging and easy to clean or replace.
- **Filter structure**: The structure of the filter plays a significant role in its efficiency. Depth filters, which have multiple layers, can capture particles of different sizes. The design should maximize surface area while maintaining airflow.

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- **Energy efficiency**: The filter should operate with low energy consumption. This involves optimizing the design to reduce resistance to airflow, which can help in reducing the energy required for filtration.
- **Durability and maintenance**: The filter should be durable and require minimal maintenance. This includes ensuring that the materials used can withstand the operational environment and that the filter can be easily cleaned or replaced.

Innovative ideas

use of nanomaterials such as nanofibers or other sustainable materials, electrostatic filters, smart filters, modular Design, Self-Cleaning Mechanism, Adaptive Filtering

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

<table>
<tr><th></th><th>Context</th><th>Features</th><th>Constraints</th></tr>
<tr><td>Filtration mechanism</td><td rowspan="3">Environmental applications

Technological integration</td><td>Filtration efficiency

Multi-stage filtration

Porous structure

High flow rates and low clogging

Self-cleaning mechanisms

Advanced materials</td><td>Particle size range

Flow rate and pressure drop

Durability and Maintenance

Cost and scalability

Environmental compatibility and impact</td></tr>
<tr><td>Material selection</td><td>High filtration efficiency

Durability and chemical resistance

Low pressure drop

Non-toxic and environmentally friendly</td><td>Cost

Manufacturability

Maintenance and longevity

Compatibility with existing systems</td></tr>
<tr><td>Filter structure</td><td>Porous structure

Multi-layer design

High Permeability</td><td>Particle size range

Durability and maintenance</td></tr>
</table>

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		Self-cleaning mechanism	Cost and scalability Environmental compatibility
Energy efficiency		Low pressure drop High permeability Advanced materials Self-cleaning mechanisms	Cost Durability and maintenance Scalability Environmental compatibility
Durability and maintenance		Durable materials Moisture and chemical resistance Robust structural design Self-cleaning mechanisms	Cost Maintenance accessibility Environmental compatibility Operational lifespan

Idea selected

Filtration mechanisms.

Step 6 – Evaluate

6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

- **Multi-stage filtration**: Incorporating multiple stages to capture a wide range of particle sizes, from large debris to microplastics.
- **Porous structure**: Utilising a three-dimensional porous structure to maximise surface area for filtration and enhance efficiency.

Constraints

- **Particle size range**: The filter must capture a wide range of particle sizes, requiring precise control over pore size and distribution.
- **Flow rate and pressure drop**: Maintaining high flow rates while minimizing pressure drop is crucial for efficiency and operational cost.
- **Cost and scalability**: Developing a cost-effective solution that can be produced at scale is essential for widespread adoption.

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- **Durability and maintenance**: Ensuring the filter materials and design can withstand prolonged use and environmental stressors while being easy to maintain.

Compatibility with the Earth's systems

- **Environmental impact**: Using environmentally friendly materials and energy-efficient systems to minimise the ecological footprint. Ensuring the filter does not interfere with local wildlife and ecosystems.
- **Operational environments**: The filter must be versatile enough to operate in diverse environments, from urban areas to remote locations, while maintaining efficiency.

Technical feasibility

- **Advanced technologies**: The integration of cutting-edge materials and design principles is technically feasible but requires significant R&D investment.
- **Proven concepts**: Existing filtration technologies and natural filtration mechanisms demonstrate the viability of efficient and durable designs.

Business model feasibility

- **High development costs**: Initial investment is substantial, but the long-term benefits in terms of environmental impact and operational efficiency justify the expenditure.
- **Market demand**: Strong demand for solutions to microplastic pollution ensures a viable market for the filter.
- **Lifecycle Costs**: While maintenance and operational costs are high, the strategic advantages and extended service life provide a favourable return on investment.

6.b Revise and revisit previous steps as necessary to generate a viable solution.

Designing a **fine plastic particulate matter filter** involves addressing several design challenges, criteria, and constraints.

The primary challenge is to create a filter that effectively captures fine plastic particles from water while maintaining high flow rates, minimizing pressure drop, and ensuring durability and ease of maintenance. This involves integrating advanced materials and innovative design principles inspired by natural filtration mechanisms, such as those used by manta rays.

In conclusion, the design of a fine plastic particulate matter filter is both technically and economically feasible, given the significant environmental benefits and the alignment with sustainability goals.

Additional resources

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https://biomimicry.org/

https://en.wikipedia.org/wiki/Filter_feeder#See_also

https://en.wikipedia.org/wiki/Manta_ray#Feeding

https://www.science.org/doi/10.1126/sciadv.aat9533

https://asknature.org/innovation/rticulate-matter-filters-inspired-by-manta-rays/

https://asknature.org/strategy/fins-funnel-food/

https://asknature.org/innovation/plastic-filtering-device-inspired-by-the-manta-ray-and-basking-shark/

https://scitechdaily.com/what-mit-scientists-discovered-about-manta-rays-is-revolutionizing-water-filtration/

https://www.kickstarter.com/projects/367174604/floating-coconet-cleaning-plastic-rivers

https://www.weforum.org/stories/2016/12/using-technology-inspired-by-manta-rays-to-count-the-plastic-in-our-oceans/

https://marinemegafauna.org/field-updates/microplastics-no-small-problem

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: The unique signalling substances of fruits and vegetables

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do fruits and vegetables activate their defence mechanisms upon detachment from the parent plant? **Context** When fruits and vegetables are detached from the parent plant, they activate several defence mechanisms to protect themselves from spoilage and microbial attacks, such as: • **Activation of defence mechanisms:** Ethylene production and regulation, Phytoalexins production, Natural antimicrobials, ROS production, Antioxidant response • **Hormonal cross-talk, chemical cues and communication:** Volatile Organic Compounds (VOCs), Jasmonic acid and Salicylic acid, Synergistic effects • **Structural Changes:** Cell wall reinforcement, Cuticle strengthening **2.b Ask yourself, "What do I want my design to do?"** The goal of the design is to develop innovative sachets that leverage the natural defence mechanisms of fruits and vegetables to extend their shelf life, by looking into the unique signals of plants. The sachets should work at ambient temperatures, keeping food fresh even in areas without access to cold storage and cold supply chain facilities. The sachets should extend the shelf life of the targeted fruits and vegetables by 40 to 60 per cent. This will reduce food waste, improve food security, and support the livelihoods of small-scale farmers, local communities, and affected areas. **2.c Flip the question. Consider opposite functions.** How do environmental factors such as temperature and humidity influence the production and response to ripening signals in harvested produce?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.**

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	• **Grains and seeds:** Natural dormancy, Hard outer shells. • **Nuts:** Oil content, Protective shells. • **Herbs and Spices:** Essential oils, Natural preservatives. • **Algae:** Polysaccharides, Antioxidant compounds. • **Honey:** Natural antimicrobial properties, long shelf life. **3.b Identify experts & connect to communities of biologists and naturalists.** • GreenPod Labs. • European Union's Farm to Fork Strategy. • National Policies on Food Security.
Step 4 – Abstract	**4.a Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** • **Ethylene regulation**: Modulate ethylene levels to control the ripening process. • **Antimicrobial defence**: Stimulate the production of natural antimicrobial compounds to protect against microbial infections. • **Antioxidant activity**: Increase antioxidant defences to reduce oxidative stress and delay spoilage. • **Volatile Organic Compounds (VOCs)**: Release VOCs to enhance defence signalling and deter pests and pathogens. • **Structural integrity**: Reinforce structural defences such as cell walls and cuticles to create barriers against pathogens. • **Hormonal cross-talk**: Facilitate interaction between different hormonal pathways to ensure a balanced defence response.  *Image copyright* https://pubmed.ncbi.nlm.nih.gov/27005823

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4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

A strategy is to create a way to harness the unique natural signalling substances of different fruits and vegetables and capture them in small sachets that can be placed in crates of specific produce.

The key points that the strategy could implement are:

- **Controlling ripening:** use of materials that can manage the natural gases produced by fruits and vegetables to slow down their ripening process.
- **Human perspective:** Implement a solution to keep the fruits and vegetables from ripening too quickly, so they stay fresh longer and reduce waste.
- **Preventing infections:** Incorporate substances that naturally fight off bacteria and mould, keeping the produce safe to eat.
- **Human perspective:** Having a built-in sanitizer that protects the food from going bad due to germs and mould.
- **Reducing Spoilage:** Enhance the produce's ability to stay fresh by using elements that protect against damage from the environment.
- **Human Perspective:** Look into the antioxidants used in skincare to keep the skin healthy and youthful, and apply it to fruits and vegetables.
- **Deterring pests:** Implement a solution to release natural scents that repel insects and other pests, preventing them from damaging the produce.
- **Human Perspective:** Look into solutions such as natural insect repellent that keep bugs away from food, ensuring the food remains untouched.
- **Strengthening protection:** Implement a solution to reinforce the outer layers of the produce to make it harder for pests and microbes to penetrate.
- **Human Perspective:** Add an extra layer of protection, like a durable coating to prevent scratches and damage.

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Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

- Active ingredient sachets added to the packaging.
- Packaging with colour-changing/ properties-changing indicators.
- Humidity control packs.
- Edible coating.
- Modified atmosphere packaging.
- Vacuum packaging.
- Antimicrobial packaging.

5.b Organize your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

	Context	**Features**	**Constraints**
Active ingredient sachets added in packaging	Food preservation Food waste reduction Developing regions Sustainability	Natural plant extracts Biodegradable materials Versatility Ease of use Cost-effective	Temperature sensitivity Limited shelf life Initial adoption Scalability Regulatory approval
Packaging with colour-changing/properties-changing indicators	Food waste reduction Consumer demand Technological advancements	Visual freshness indicators Real-time monitoring Customizable	Cost Accuracy and reliability Environmental sensitivity Regulatory approval Consumer acceptance
Humidity control packs	Food preservation Wide application of	Humidity control Long lasting Easy to use	Cost Environmental sensitivity Disposal

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	products in food industry Developing regions	Use of natural ingredients into composition	Regulatory approval
Edible coating	Food preservation Global application Sustainability	Natural ingredients Barrier properties Antimicrobial properties Biodegradable Versatile	Cost Application techniques Shelf life of coating Regulatory approval Consumer acceptance
Modified atmosphere packaging	Food preservation Technological Advancements	Gas mixture Barrier films Extended shelf life	Cost Complexity Environmental impact Temperature sensitivity Regulatory approval
Vacuum packaging	Wide application of products in food industry Non-consumable products	Extended shelf life Preservation of quality Space efficiency Versatility Barrier protection	Cost Material limitation Environmental concerns

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Antimicrobial packaging	Wide application of products in food industry Organic produce Exported produce	Extended shelf life Food safety Quality preservation Controlled release	Cost Material compatibility Regulatory approval Environmental impact

The best design concept is the **Active ingredient sachets added in packaging**:

- **Extended shelf life:** Active ingredient sachets maintain optimal conditions inside packaging, reducing food spoilage and waste.
- **Targeted protection:** Tailored to address specific spoilage mechanisms, preserving product quality and safety.
- **Reduced need for preservatives:** Minimizes the need for chemical preservatives, making food healthier and reducing environmental impact.
- **Minimized packaging material:** More efficient protection compared to multiple layers of packaging, reducing waste.
- **Sustainability:** Many sachets are biodegradable or recyclable, contributing to sustainable packaging solutions.
- **Consumer convenience:** Maintains freshness even after opening, reducing the likelihood of discarding partially used items.
- **Cost-effectiveness:** The initial cost is offset by reduced food waste and extended shelf life, resulting in cost savings over time..

Step 6 – Evaluate

6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Constraints	Premise	Evaluation of solution
Limited shelf life	Fresh fruits and vegetables have a	Implement active packaging technologies, such as active ingredient sachets added in

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	short shelf life, leading to significant waste.	packaging, to extend the freshness and shelf life of produce
Consumer behaviour	Consumers often discard food due to confusion over expiration dates or improper storage	Educate consumers on the benefits and proper use of these sachets
Supply chain inefficiencies	Inefficiencies in the supply chain can lead to delays and spoilage of fresh produce	Develop sachets tailored to specific types of produce. Different fruits and vegetables have unique storage requirements, so customized solutions can optimize their preservation in case of delays in supply
Aesthetic standards	Retailers often reject packaging that detract from the overall user experience	Sachets can be designed in various shapes, sizes, and colours to match the packaging aesthetics. This customization helps maintain the visual harmony of the product
High cost of advanced packaging	Advanced packaging solutions can be expensive, limiting their adoption	Invest in research and development to create cost-effective packaging alternatives
Environmental impact of packaging	Traditional packaging materials contribute to environmental pollution	Develop and use biodegradable or recyclable packaging materials
Lack of infrastructure for food donation	Surplus produce often goes to waste due to inadequate donation infrastructure	Establish robust networks for food donation, including partnerships with food banks and charities

Compatibility with the Earth's systems

- **Biodegradability:** Sachets made from biodegradable materials break down naturally, reducing environmental impact.
- **Recyclability:** Recyclable sachets reduce waste by allowing materials to be reprocessed and reused.
- **Non-toxic components:** Using non-toxic materials prevents harmful chemicals from affecting soil and water quality.
- **Energy efficiency:** Energy-efficient production minimises the carbon footprint, using renewable energy sources.
- **Waste reduction:** Extending shelf life reduces food waste, decreasing greenhouse gas emissions from landfills.
- **Sustainable sourcing:** Materials should be sustainably sourced, using renewable resources without harming the environment.

Technical feasibility for implementing an Active ingredient sachet added in packaging to reduce waste

Current state

Active packaging technologies are well-researched and have been implemented in various forms. Continuous innovation is leading to more efficient and cost-effective solutions. Advances in nanotechnology and materials science are enhancing the effectiveness of active packaging.

Feasibility

While there is an initial investment in developing and implementing these sachets, the reduction in food waste and extended shelf life can lead to significant cost savings over time. Active ingredient sachets can be scaled to meet the needs of various food products and packaging sizes. This flexibility makes them suitable for a wide range of applications.

Business model feasibility

1. Value proposition

- **Extended shelf life**: The primary value is extending the shelf life of fruits and vegetables, reducing food waste and saving costs for both retailers and consumers.
- **Sustainability**: Emphasise the environmental benefits, such as reduced food waste and the use of biodegradable or recyclable materials.
- **Quality assurance**: Ensure that the produce remains fresh and of high quality for a longer period, enhancing customer satisfaction.

2. Customer segments

- **Retailers:** Supermarkets and grocery stores looking to reduce waste and improve the shelf life of their produce.

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	• **Food distributors:** Companies that transport and store large quantities of perishable goods. • **Consumers:** End-users who want to keep their produce fresh for longer periods. • **Farmers and producers:** Agricultural businesses aiming to reduce post-harvest losses. **3. Revenue streams** • **Direct sales**: Selling sachets directly to retailers, distributors, and consumers. • **Subscription services**: Offering a subscription model where customers receive regular shipments of sachets. • **Partnerships**: Collaborating with packaging companies to integrate sachets into their products. • **Licensing**: Licensing the technology to other companies in the food packaging industry. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Implementation plan** • Conduct R&D and develop prototypes. • Obtain regulatory approvals and set up manufacturing. • Pilot production and refine processes. • Launch a marketing campaign and begin sales. • Collect feedback and make continuous improvements..

Additional resources

https://greenpodlabs.com/

https://www.youtube.com/channel/UCilmiV8719puQI1NwnBQoPA

https://asknature.org/innovation/natural-produce-preservative-packets-inspired-by-plants/

https://changestarted.com/solving-food-wastage-through-a-small-sachet-greenpod-labs-deepak-rajmohan/

https://www.foodinfotech.com/greenpod-labs-sailing-against-odds-with-tiny-sachets-of-wonder/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LETSMIMIC CHALLENGES & SOLUTIONS

A **challenge** concerns an example of a past, real life problem that was solved through biomimicry. This task aims to identify and document the challenge and the solution that was applied.

Solution: The surface of butterfly wings

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** **How are butterflies able to absorb light and reflect almost none of it back?** **Context** Butterflies have evolved fascinating mechanisms to absorb light and reflect almost none of it back, primarily through the unique structures on their wings. The wings of butterflies possess anti-reflective properties, which are highly efficient at trapping light, making the wings appear almost black. **2.b Ask yourself, "What do I want my design to do?"** **Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish.** • **Light absorption and energy conversion:** Efficiently absorb light and convert it into usable energy to power the sensor. • **Hydrogen detection:** Accurately detect the presence of hydrogen gas at various concentrations. • **Environmental adaptability:** Operate reliably in varying environmental conditions, including changes in light intensity, temperature, and humidity. • **Durability and longevity:** Ensure the sensor is durable and maintains performance over time. • **Energy efficiency:** Operate with minimal energy consumption to maximize efficiency. **2.c Flip the question. Consider opposite functions.** How do butterflies channel light for communication?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **White Fur of polar bears:** Polar bears have white fur that reflects most of the sunlight, helping them blend into their

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	snowy environment and avoid overheating. The structure of their fur scatters light, making it appear white and reflective. • **Silvery scales of fish:** Many fish, such as sardines and herring, have silvery scales that reflect light, making them less visible to predators in the water. The scales contain layers of guanine crystals that create a mirror-like effect, reflecting light and providing camouflage. • **Reflective leaves of desert plants:** Some desert plants, like the silverleaf nightshade, have leaves covered with fine hairs or a waxy coating that reflects sunlight. This adaptation helps reduce water loss and protect the plant from intense solar radiation. • **Brightly coloured feathers of birds:** Birds like peacocks and hummingbirds have feathers with microscopic structures that reflect light, creating iridescent colours. These structures, such as photonic crystals, reflect specific wavelengths of light, resulting in vibrant and reflective plumage. • **Reflective Surfaces in Insects:** Certain insects, like beetles, have exoskeletons with reflective surfaces. These surfaces are often composed of multi-layered structures that reflect light, creating metallic or iridescent appearances. This can serve as camouflage or a means of attracting mates. **3.b Identify experts & connect to communities of biologists and naturalists.** • Natural History Network. • Society for Conservation Biology (SCB). • ResearchGate. • INaturalist..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** **Light absorption and reflection** • **Structural colouration:** Butterflies use nano- and microscale structures on their wing scales to diffract and interfere with light, creating vibrant colours. • **Reflective scales:** Specialised scales reflect specific wavelengths of light through constructive interference, resulting in iridescent colours. **2. Ultraviolet communication:**

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- **UV reflectance:** Certain butterflies have wing scales that reflect UV light, which is used for communication, especially during mating rituals.
- **Directional reflectance:** The UV reflection is highly directional, visible only at specific angles, aiding in discreet communication.
- **Pigmentation** (Pterin pigments): Some butterflies use pigments that absorb UV light, preventing it from being reflected and enhancing contrast for communication.

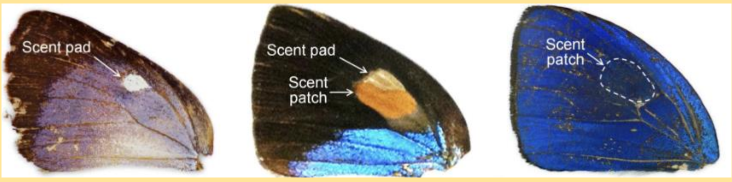

Image copyright

https://scitechdaily.com/nanostructures-and-living-cells-in-butterfly-wings-could-inspire-radiative-cooling-materials-advanced-flying-machines/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Core functions

- **Light absorption and reflection:** Implementation of micro- and nano-structured surfaces in hydrogen sensors to maximize light absorption. These structures can enhance the sensor's sensitivity by increasing the interaction between light and the sensor material, improving the detection of hydrogen gas.
- **Ultraviolet communication:** Utilise UV-sensitive materials in hydrogen sensors. These materials can change their properties when exposed to UV light, allowing for the detection of hydrogen gas through changes in UV reflectance or absorption. This approach can provide a more precise and responsive sensing mechanism.
- **Pigmentation:** Incorporate pigments or dyes in hydrogen sensors that react to the presence of hydrogen gas by changing colour. This visual indication can be an additional feature for easy and quick detection of hydrogen leaks.

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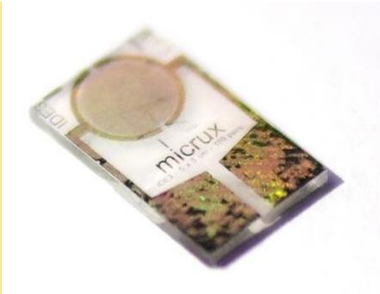

Image copyright: https://www.rmit.edu.au/news/all-news/2020/dec/hydrogen-sensor

Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

Key information and ideas

- **Integration of photonic crystals**: Incorporate photonic crystals into the sensor design to harness light for powering the sensor. This can improve energy efficiency and enable operation at room temperature.
- **Use of titanium palladium**: Create a layered structure with palladium nano-disks as the top layer. These disks will change their optical properties in the presence of hydrogen, providing a reliable detection mechanism.
- **Optical readout systems**: Implement a fiber-coupled setup with an LED, a sensor body containing the reactive sample, and a photodiode to read out the reflectance changes. This setup ensures accurate and reliable detection.
- **Use of materials to operate at room temperature**: Utilise materials that enable the sensor to operate at room temperature, thereby reducing energy consumption and enhancing safety.
- **Broad detection range design**: Design sensors to detect a wide range of hydrogen concentrations, from very low levels for medical diagnostics to higher levels for industrial safety.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context applied to all ideas

Nuclear power plants, renewable energy systems, space exploration, industrial applications, transportation, residential and commercial buildings, research and development

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	Features	Application
Integration of photonic crystals	High sensitivity related to enhanced light-matter interaction Thermal stability Energy efficiency Compact and lightweight	Industrial safety Renewable energy Environmental monitoring
	Constraints • Fabrication complexity regarding precision manufacturing and quality control • Environmental sensitivity related to temperature, humidity and contamination • Integration challenges regarding system compatibility and signal processing	
Use of titanium palladium	High surface area Sensitivity Reversibility	Leak detection in different activity sectors Energy sector including renewable energy Automotive industry
	Constraints • Temperature sensitivity • Cost of palladium is an expensive material • Durability	
Optical readout systems	Non-electrical readout High sensitivity Fast response time	Industrial safety Energy sector Environmental monitoring
	Constraints • Temperature sensitivity • Complexity and cost • Interference	
Use of materials to operate at room temperature	High sensitivity High affinity Compatibility with semiconductor technologies	Industrial safety Energy sector Environmental monitoring

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Large surface area</td><td></td></tr>
<tr><td colspan="2">Constraints
• Temperature sensitivity
• Cost
• Durability</td></tr>
<tr><td rowspan="2">Broad detection range design</td><td>Wide Concentration Range

High Sensitivity and Selectivity

Rapid Response and Recovery</td><td>Industrial safety

Energy sector

Automotive industry</td></tr>
<tr><td colspan="2">Constraints
• Environmental factors
• Cost and complexity
• Calibration and maintenance</td></tr>
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Idea selected

Integration of photonic crystals.
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<td>Step 6 – Evaluate</td>
<td>
6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Design concept selected is the Integration of photonic crystals

1. Features

High sensitivity and selectivity: Photonic crystals can be engineered to have specific optical properties that change in the presence of hydrogen, providing high sensitivity and selectivity.
Optical readout: These sensors can be powered by light, eliminating the need for electrical power and reducing the risk of ignition in hydrogen-rich environments.
Fast response time: Photonic crystal-based sensors typically exhibit rapid response times, which is crucial for real-time monitoring.

Applications
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- Industrial safety: Used in environments where hydrogen is produced, stored, or used, such as chemical plants and refineries, to detect leaks and prevent accidents.
- Energy sector: Critical for monitoring hydrogen in fuel cells and storage systems, ensuring safe operation and efficiency.
- Automotive industry: Integrated into hydrogen-powered vehicles to monitor hydrogen levels and ensure safe operation.

Compatibility with the Earth's systems

- **Sustainability:** Photonic crystal sensors, being powered by light, align well with sustainable practices by reducing reliance on electrical power and minimizing environmental impact.
- **Material use:** The materials used in photonic crystals, such as silicon dioxide, tantalum oxide, and palladium, are non-toxic; however, some of them can be costly.

Technical feasibility

- **Proven technology:** Photonic crystal-based sensors have been successfully demonstrated in laboratory settings, yielding promising results.
- **Integration potential:** These sensors can be integrated into existing hydrogen detection systems, enhancing their performance and reliability.

Business model feasibility

- **Market demand:** There is a growing demand for reliable hydrogen sensors in various industries, driven by the increasing adoption of hydrogen as a clean energy source.
- **Cost considerations:** Although the initial cost of photonic crystal sensors may be high, economies of scale and advancements in manufacturing techniques could lead to reduced costs over time.
- **Regulatory support:** Governments and regulatory bodies are increasingly supporting the development and deployment of hydrogen technologies, which could facilitate market adoption.

6.b Revise and revisit previous steps as necessary to generate a viable solution.

- **Define requirements and objectives:** Identify detection range, set sensitivity and selectivity goals, and define the operational conditions.
- **Material selection:** Photonic crystals, catalytic layer.
- **Design and fabrication:** Photonic crystal structure, layer deposition, integration with optical readout.

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	• **Testing and calibration:** Sensitivity testing, selectivity testing, environmental testing. • **Optimisation:** Performance tuning, Durability enhancement. • **Prototype development:** Prototype fabrication, field testing. • **Commercialisation:** Cost analysis, regulatory compliance, market strategy..

Additional resources:

https://asknature.org/innovation/precise-hydrogen-sensor-inspired-by-butterflies/

https://pubs.acs.org/doi/10.1021/acssensors.0c01387

https://www.rmit.edu.au/news/all-news/2020/dec/hydrogen-sensor

https://www.photonics.com/Articles/Light_Powers_Butterfly-Inspired_Hydrogen_Sensor/a66469

https://www.mdpi.com/2673-4141/5/1/7

https://blog.msasafety.com/hydrogen-big-potential-big-safety-challenges-are-you-ready/

https://light.nju.edu.cn/upload/20140227/201402272036572070.pdf

https://h2tools.org/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Natural Bone Healing Through Osteoblastic Mineralisation

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can we inspire the human body to mimic its regeneration and healing? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. **Key functions of the design** • **Self-healing capability:** Osteoclasts and osteoblasts work together to facilitate bone healing by promoting cell growth and mineralisation. • **Crack detection and response:** The osteoblasts work in groups to deposit calcium and phosphate crystals into the damaged site, which combine with collagen to form new bone. • **Restoration of structural strength:** Osteoclast cells remove any unwanted bone around the fracture site, allowing the repaired bone to assume a shape similar to its original appearance before the injury. By incorporating these biological principles, this design will aim to create a new concrete that can not only autonomously repair cracks but also sense or respond to the formation of cracks, triggering the self-healing mechanisms at the right time. It is also vital that this self-healing process not only fills the cracks but also restores the original strength of the concrete, ensuring that the repaired material can withstand similar loads and stresses as before. **2.c Flip the question. Consider opposite functions.** How does the human body automatically heal its bones? How do bones stay strong and regenerate after being fractured? In nature, bones have the remarkable ability to heal themselves when fractured. The body deposits new mineral tissue to bridge the broken sections, restoring the bone's strength. This process parallels the concept of self-healing concrete, where the material regenerates to repair cracks and regain its integrity.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Self-healing ability.

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Natural models

- **Bone healing (humans and animals):** When bones are fractured, the body initiates a healing process, followed by the generation of new bone tissue to bridge the gap.
- **Skin regeneration (humans and animals):** Skin can regenerate and heal itself when cut or injured.
- **Tree bark regeneration:** When a tree's bark is damaged, it can regenerate by growing new bark tissue around the wound to seal it off and prevent the entry of pests or diseases.
- **Plant stem healing:** When a plant stem is damaged, certain plants can form a protective layer of cells over the wound. In some cases, the stem can regenerate new growth to replace the damaged area.
- **Liver regeneration (humans and other vertebrates):** The liver is one of the few organs that can regenerate itself after damage.
- **Spider silk repairs:** Some spider species can repair damaged webs by reinforcing or rebuilding sections that have been torn.
- **Mollusc shell repair:** They can repair minor damage to their shells by secreting additional layers of calcium carbonate to fill cracks or chips.

3.b Identify experts & connect to communities of biologists and naturalists.

Universities and research institutions

- **Delft University of Technology (TU Delft):** TU Delft has expertise in self-healing materials and sustainable construction.
- **Wageningen University & Research (WUR):** Offers expertise in microbiology and biotechnology, which is useful for understanding and optimising the bacterial processes involved in self-healing concrete.
- **Harvard Wyss Institute for Biologically Inspired Engineering:** Focuses on translating biological principles into engineering solutions, including biomimetic materials and self-repairing technologies.

Professional communities

- **Biomimicry Institute:** promotes biomimicry as a design approach, offering resources and opportunities for collaboration between engineers and biologists.
- **International Society for Microbial Ecology (ISME):** Brings together microbiologists who specialise in environmental applications, including the use of bacteria in materials science.
- **Society for Experimental Biology (SEB):** A platform for researchers studying various aspects of biology, including plant and microbial self-repair mechanisms that can inform material design.

Online forums and groups

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	• **ResearchGate:** A social network that connects researchers, who may be specialised in biomaterials, microbiology, and sustainable engineering, where self-healing concrete applications can be discussed. • **LinkedIn groups:** a social network that features groups focused on biomimicry, civil engineering, or materials science, allowing interaction with experts in fields related to self-healing technologies. **Local organisations and events** • **European Biomaterials Conference:** A conference dedicated to biomaterials that could provide opportunities to network with experts in materials science and bioengineering. • **Universities and research institutions:** can offer public lectures, seminars, or workshops at local universities focused on microbiology, sustainable construction, or bio-inspired innovations.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Microbial Induction** • **Nature model**: Bacillus subtilis (Dormant spores) • **Keywords**: Dormancy, Activation, Resilience, Regeneration • **Function**: Bacteria remain inactive until cracks form, allowing them to activate and initiate a healing process, mimicking natural survival strategies in harsh conditions. **Biomineralisation** • **Nature model**: Coral reefs, Molluscs (Oysters) • **Keywords**: Natural Repair, Mineral Production, Structural Integrity, Sustainability • **Function**: These organisms produce minerals to repair and strengthen their structures. This process can be replicated in concrete to fill cracks with calcium carbonate, restoring structural integrity. **Biopolymers** • **Nature model**: Spider silk, Silkworm silk • **Keywords**: Flexibility, Strength, Natural Composition, Eco-friendliness • **Function**: Biopolymers enhance the mechanical properties of concrete, providing flexibility and strength while being environmentally friendly, much like silk in nature. **Encapsulation techniques** • **Nature model**: Seed dispersal (e.g., fruits, seed pods) • **Keywords**: Controlled Release, Protection, Activation, Efficiency

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- **Function**: Encapsulation protects healing agents until they are needed, much like seeds are protected until conditions are favourable for growth.

Nutrient supply

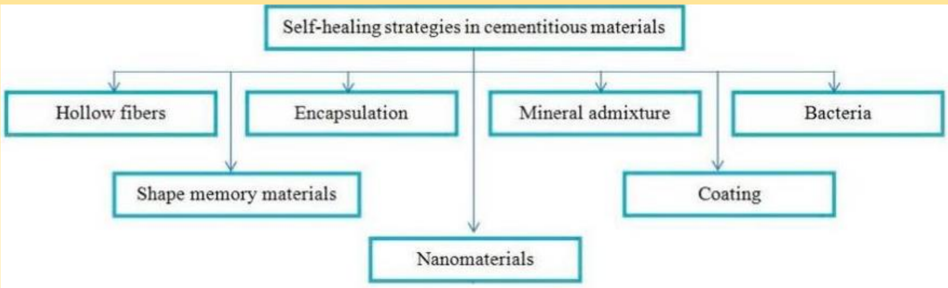
- **Nature model**: Mycorrhizal networks (Fungi and plant roots).
- **Keywords**: Sustenance, activation, growth, maintenance.
- **Function**: Just as mycorrhizal networks facilitate nutrient exchange for plants, providing essential nutrients to bacteria, they also support sustained healing in concrete.

Environmental considerations

- **Nature model**: Wetlands, rainforests.
- **Keywords**: Moisture, habitat suitability, microbial activity, adaptability.
- **Function**: Moist environments support microbial life and healing processes in concrete, much like ecosystems thrive in suitable habitats.

Hybrid approaches

- **Nature model**: Symbiotic relationships (e.g., clownfish and anemones).
- **Keywords**: Synergy, adaptation, innovation, robustness.
- **Function**: Combining biological methods with traditional repair techniques enhances the overall system's robustness, much like symbiotic relationships enhance survival.



Developed strategies for self-healing in cement based materials

https://pmc.ncbi.nlm.nih.gov/articles/PMC7709490/figure/biomimetics-05-00047-f004/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

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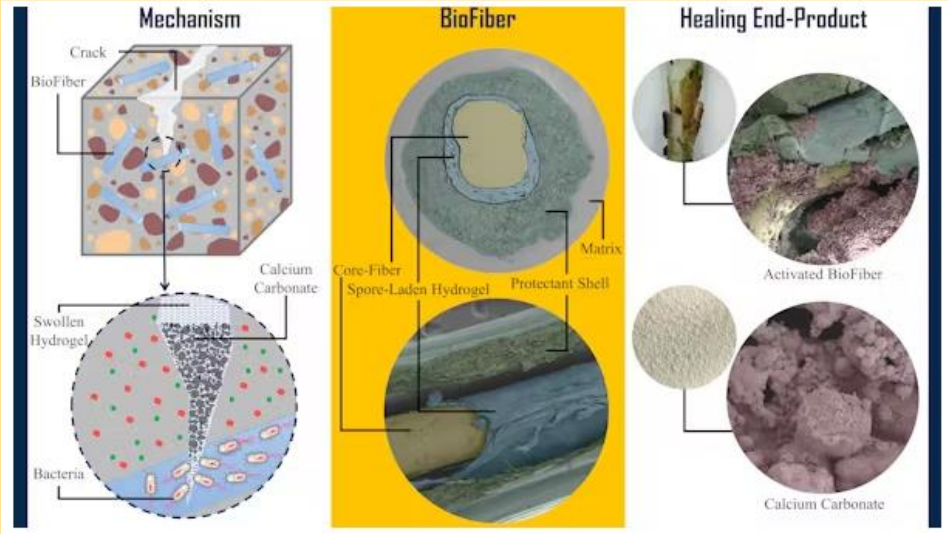

https://theconversation.com/thin-bacteria-coated-fibers-could-lead-to-self-healing-concrete-that-fills-in-its-own-cracks-220190

Triggered healing activation

- **Design strategy:** Develop a system that activates healing materials only when a crack or damage is detected, ensuring resources are conserved until necessary.

Natural repair mechanism

- **Design strategy:** Create a concrete that can autonomously fill cracks without needing manual repairs, similar to how some natural structures heal over time.

Flexibility and strength

- **Design strategy:** Utilise materials that can bend and flex under stress, striking a balance between strength and adaptability in response to changing conditions.
- **Function:** This allows buildings and structures to endure various environmental pressures while maintaining safety and longevity.

Smart release system

- **Design strategy:** Incorporate a protective system that releases healing agents when cracks form, similar to how natural systems protect seeds until they can grow.

Supportive environment for healing

- **Design strategy:** Design the concrete to retain moisture and provide an environment conducive to healing, much like particular ecosystems that support growth.

Responsive design

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	• **Design strategy:** Develop materials that can adapt to environmental changes, ensuring they remain effective and resilient in various conditions. **Collaborative material use** • **Design strategy:** Combine different materials in the concrete to enhance its overall strength and healing capabilities, similar to how other species work together in nature.  Piece of the Bio Concrete (self-healing concrete) https://www.certifiedenergy.com.au/emerging-materials/the-concrete-of-the-future
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Self-healing capability** • The core feature of the material would be its ability to repair cracks autonomously. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • **Self-healing capability:** The primary feature is the ability to repair itself without external intervention. The concrete heals cracks automatically, enhancing durability. • **Crack detection and response:** The healing process is explicitly triggered where damage occurs, enabling localised repair that matches the level of damage. • **Restoration of structural strength:** By sealing cracks promptly, self-healing concrete prevents water and other harmful substances from entering and causing corrosion or further degradation. The self-healing process extends the lifespan of concrete structures, making them more resistant to wear and tear.

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	Context
	
	- **Target groups:**
	  - **Construction and civil engineering companies:** Companies would benefit from reduced maintenance and repair costs.
	  - **Infrastructure owners (public or private):** Owners can use this new and more durable concrete to ensure the safety and longevity of the works.
	  - **Sustainability-focused organisations**: The new material and technology can be used to reduce the carbon footprint associated with concrete production and repairs.
	
	Constraints
	
	There are various obstacles to using osteoblastic mineralisation, a natural bone healing process, as a paradigm for self-healing concrete. It is challenging to discover suitable healing agents (such as bacteria or microencapsulated chemicals) for concrete, as it lacks biological activity in contrast to organic bone tissue. The healing process of concrete, which depends on a steady supply of water, might be hampered by its exposure to changing external factors like temperature and moisture. Cost-effective implementation is essential because incorporating self-healing chemicals may also affect the material's structural strength, longevity, and economic feasibility. To overcome these obstacles, long-term concrete restoration can be supported by advancements in encapsulating techniques, long-lasting healing chemicals, and moisture control.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) about their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The self-healing capability is assessed for feasibility, including technical performance, economic viability, and environmental impact. In this sense, the design needs to be refined to meet the requirements for durability, cost reduction, and compatibility with various environments. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** We can make the self-healing concrete solution more workable by continually refining and improving each step. The technology will advance by concentrating on developing better materials, identifying efficient healing techniques, and optimising production. It will be easier to integrate into existing construction methods and gain broader acceptance if it is designed with users in mind. The solution will also be in line with environmental objectives if sustainable materials are used. As the self-healing concrete develops, it will be crucial to conduct frequent testing through pilot projects and collaborate with industry partners.

Additional resources:

https://biomimicry.org/ https://asknature.org/innovation/self-healing-concrete-cracking-repair-solution-inspired-by-bones/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Ability to grab tenaciously like a cocklebur

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How does the cocklebur attach itself securely to animals or fabrics? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. The design must securely attach two surfaces, easily detach without causing damage, and be durable for repeated use. **Key functions of the design** • **Attachment:** Give surfaces a firm, short-term grip. • **Detachment:** When necessary, detachment allows for easy, non-destructive separation. • **Reusability:** Preserve functionality across several applications. • **Adaptability:** Able to perform well in a range of environmental circumstances and materials. **2.c Flip the question. Consider opposite functions.** How can a fastener prevent unintended attachment to surfaces or accidental detachment? Cockleburs only cling to surfaces that are sufficiently textured for their hooks to latch onto, such as animal fur. The absence of the required fibres smooth surfaces like leaves or rocks prevents unwanted attachment. Similarly, to prevent unintentional separation from smooth or non-fibrous surfaces, a Velcro design can concentrate on interlocking only with particular looping materials.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** The cocklebur, a plant seed belonging to the burdock family, clings firmly to passing animals' fur thanks to a special structure of tiny, hook-like projections on its exterior. Because each hook is bent and flexible, it may attach to fibres and organic textures with little effort. Because of this structure, cockleburs can adhere to soft, fibrous surfaces, like fabric or animal fur, while staying detached from rougher surfaces. As animals move, the cocklebur's attachment

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<table>
<tr><td></td><td>strategy enables it to cover great distances, efficiently dispersing seeds to new locations. The design of Velcro, which has hooks on one surface and loops on the other that mimic the fibrous texture of fur, was inspired by this natural hook-and-fibre interlock and produces a robust, reusable fastening device.

3.b Identify experts & connect to communities of biologists and naturalists.

Botanists can shed light on the composition and operations of cockleburs and other natural attachment systems. Ecologists who specialise in the interactions between plants and animals can provide further insights into the attachment and movement of seeds. Additionally, material scientists and biomimicry engineers who specialise in microstructure replication and adhesive technology facilitate the translation of natural hook-and-loop designs into robust, scalable materials. Technical assistance may also be offered by research teams that focus on biological surface interactions or biomimetic materials, such as those at the Biomimicry Institute or Harvard's Wyss Institute for Biologically Inspired Engineering.</td></tr>
<tr><td>Step 4 – Abstract</td><td>4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.

The inspiration behind this product stems from the way burdock burrs (seed pods) adhere to animal fur and clothing. The structure of these burrs allows them to latch onto various surfaces using a "hook and loop" mechanism. Having this in mind, the core functions of our product would be:

• The attachment mechanism is designed to create a hook-and-loop system that is both non-invasive and highly effective. It recreates how the hooks of the burr attach to loops in the animal's fur or tissue, allowing for fixation and retention.

• Its reusability to repeatedly attach and detach without losing effectiveness,

• Its adaptability: it adapts to various surfaces and situations while maintaining durability and ease of use.

In this sense, the keywords could be the following: hook and loop mechanism, attachment and release, reusability, and adaptability.

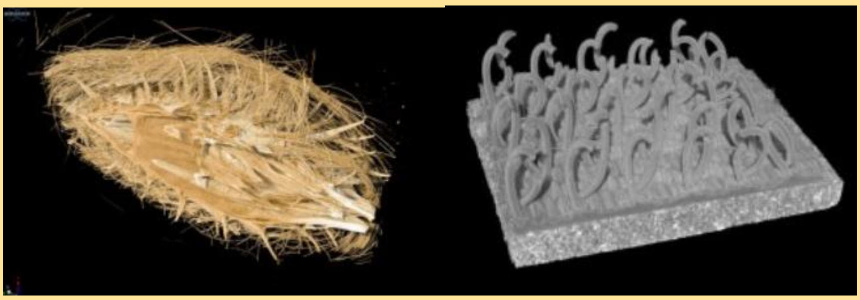

Figure 1. Biomimicry of a burr (Left) for the invention of Velcro (Right).</td></tr>
</table>

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	Source: https://www.microphotonics.com/biomimicry-burr-invention-velcro/ **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** To provide a reliable, reusable attachment solution that is easy to use, adaptable and low-maintenance, it's necessary to develop a fastener with one surface featuring tiny flexible hooks and the other surface containing loops, allowing them to interlock. By doing this, a strong connection will be produced that can be secured and untied repeatedly without losing its grasp. This hook-and-loop technique can work well for products that require closures that are both secure and detachable.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** The primary features of this product include the creation of an attachment mechanism featuring hooks. One side of the fastener is covered with small, flexible hooks, and the other side contains loops that interlock with the hooks. Its main functions would be ease of use, adaptability, reusability, and safety in the attachment and release mechanism. By containing all these elements, the product will be a durable, long-lasting, and non-invasive fastening solution. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • Reusable attachment. • Easy fastening and release. • Versatility across materials. • Durability. **Context** These designs are best suited for environments where quick, secure fastening and adaptability are essential, particularly in situations that benefit from reusability and simplicity. **Target groups** • Textile manufacturers. • Outdoor gear companies. • Automotive industry. • Home goods and furniture. • Educational institutions and research organisations. **Constraints** • **Material durability:** Ensuring Velcro's durability and strength over repeated use is challenging, especially in high-stress applications.

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	• **Manufacturing consistency:** Precision is required to replicate the hook-and-loop structure at scale, which poses production challenges for maintaining quality and uniformity. • **Cost of quality materials:** High-quality, durable materials can be costly, challenging the goal of affordability across different markets.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The best way to assess whether the product meets the design challenges and constraints is to determine whether the product developed (the Velcro) meets the following parameters: • **Functionality and ease of use:** Offers simple, secure attachment and detachment. This simplicity makes them suitable for a range of applications, aligning well with criteria requiring ease of use, adaptability, and convenience. • **Durability and longevity:** The design's reusability and resilience enable it to withstand multiple attachment cycles without losing effectiveness, thereby reducing the need for frequent replacements. • **Sustainability:** These designs also work well in applications that emphasise reducing single-use materials, such as packaging or modular furniture. In terms of **compatibility with Earth's systems**, a Velcro system minimises the need for adhesives, mechanical parts, and other resource-intensive materials. In particular, reusability aligns with Earth's natural cycles, reducing overall resource consumption and supporting circular economy goals. Additionally, velcro fasteners reduce waste compared to single-use adhesives or disposable fastening mechanisms. Finally, regarding the **technical and business model**, velcro fasteners are simple and widely applicable, requiring only basic manufacturing processes. In addition, they have a broad market due to their versatility across multiple industries and represent an offer of cost-effectiveness, appealing to consumers and businesses focused on reducing long-term costs. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** We have identified the natural model, cockleburrs, and analysed their unique attachment mechanism through tiny hooks that interlock with loops. Next, we extracted key strategies from this biological example, focusing on the functionality of secure and reusable fasteners. We then translated these insights into a design concept that emphasises user-friendliness, durability, and environmental sustainability by selecting eco-friendly materials. Prototyping and testing various designs allowed us to refine the product further, ensuring it meets both functional and ecological criteria. In order to integrate our solution with the fundamental tenet of biomimicry—learning from and imitating nature—we lastly set up an iterative feedback loop to continuously enhance

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	the design based on user experiences and advancements in sustainable practices.

Additional resources:

https://www.microphotonics.com/biomimicry-burr-invention-velcro/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Shark skin to reduce drag

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.
How can the texture of shark skin inspire the creation of a swimsuit that reduces drag and enhances swimming speed?
2.b Ask yourself what your design wants to do.
Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish.
Key functions of the design
Drag reduction: To minimise resistance in water, allowing swimmers to move faster and with less effort.
Improvement in hydrodynamics: To facilitate smooth water flow over the body, similar to how shark skin reduces turbulence, thereby improving overall speed.
Comfort and flexibility: The swimsuit must allow for a full range of motion, ensuring that swimmers can perform at their best without feeling restricted.
Durability: The material should withstand the rigours of swimming and various water conditions, similar to the resilience of shark skin.
It is possible to create a swimsuit design that successfully meets the demand of competitive swimming by recognising these essential roles and situations in nature. In addition to improving athletic performance, the emphasis on lowering drag through biomimicry promotes material science innovation.
2.c Flip the question. Consider opposite functions.
How does a poorly designed swimsuit increase drag and impede swimming performance?
The distinctive texture of shark skin is made up of dermal denticles, which obstruct water flow to reduce drag. This unique structure enables sharks to move through the water more effectively and with less turbulence. In contrast, a poorly designed swimsuit may lack this textured surface, which would increase drag. For example, a swimsuit composed of flat, smooth materials might slow down the swimmer by increasing resistance to the water. Therefore, to ensure minimal drag while swimming, a swimsuit design should</td></tr>
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	include features that mimic the effective textures of shark skin in order to maximise performance.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** If we consider the primary function of reducing drag while swimming, the following natural models can serve as inspiration: • **Dolphins:** Dolphins have smooth, streamlined bodies that minimise drag, allowing them to move efficiently at high speeds. • **Penguins:** They have sleek, hydrodynamic bodies that help them glide effortlessly through water. • **Fish scales:** Certain fast-swimming fish, like tuna, have overlapping scales that create a streamlined body shape. • **Aquatic plants:** Certain aquatic plants have narrow, streamlined shapes to avoid excess drag in water currents. Their shape and flexibility allow them to move seamlessly with the water. 3.b Identify experts & connect to communities of biologists and naturalists. Considering the scope of the design, the following experts may be relevant: • **Marine biologists:** can offer expertise on how aquatic animals like sharks, dolphins, and fish reduce drag. Marine research institutes, or organisations like the Marine Biological Association (MBA) or the Society for Integrative and Comparative Biology (SICB) can be valuable. • **Fluid dynamics specialists**: like the American Institute of Aeronautics and Astronautics (AIAA) can provide valuable insights into how different textures and structures impact fluid flow. • **Aquatic research facilities and marine labs**: labs such as Scripps Institution of Oceanography or Woods Hole Oceanographic Institution conduct research on marine animal locomotion and water dynamics;
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** The inspiration behind this product is the unique texture of shark skin, specifically the dermal denticles that cover its surface. These tiny, tooth-like structures create a natural "drag-reduction" system, allowing sharks to move efficiently through water by minimising turbulence and resistance with this in mind. **Core functions of the product** • **Drag reduction:** To minimise resistance when moving through water, improving speed and efficiency. • **Turbulence control:** By interrupting the flow of water to reduce turbulence and keep the movement smooth.

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- **Adaptive hydrodynamics:** having a texture that adapts to various swimming speeds, optimising water flow in different conditions.

In this sense, the **keywords** could be the following: dermal denticles, rough surface texture, hydrodynamic efficiency and flow disruption.

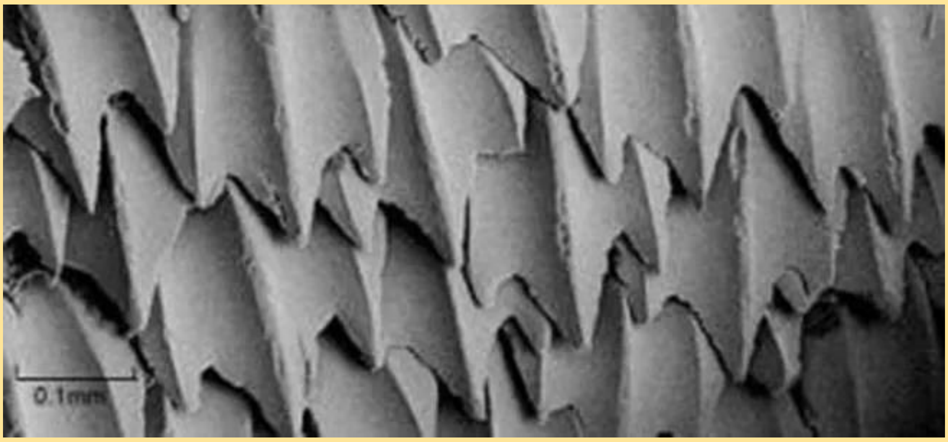

Figure 1. Dermal denticles.

Source: https://www.popsci.com/technology/article/2012-07/speedos-super-fast-sharkskin-inspired-swimsuit-actually-nothing-sharks-skin/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

To decrease the friction in water, our product's surface will be textured with small, carefully placed patterns. Smoother water flow will be possible by this structured surface, which reduces resistance and improves movement efficiency.

These patterns could be used in swimsuits where lowering drag is crucial to help swimmers move through the water more quickly and with less effort. By adding a specific texture to the swimsuit material, we can create a sleek look that improves performance and saves energy when swimming.

Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

The primary benefits of this product include improved swimming speed, reduced water resistance, and a flexible and comfortable fit. These components will be combined to create a lightweight, performance-enhancing swimsuit that enhances durability, reduces drag, and permits unhindered movement, all of which will increase swimming efficiency and endurance.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Features

- Texture surface.
- 3D printed or silicone-enhanced panels.

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	• Hydrophobic coating. • Seamless construction. • Strategic compression zones. **Context** The drag-reducing swimsuit will be designed for competitive swimmers who aim to achieve maximum speed and efficiency, making it an ideal choice for races and training sessions where every second counts. It will also be suitable for recreational swimmers seeking high-performance gear that enhances comfort and flexibility in the water. Additionally, the swimsuit's design may appeal to athletes in aquatic sports such as triathlons, where drag reduction is essential. With sustainable material options, this product will align with eco-conscious values, appealing to consumers who prioritise both performance and environmental responsibility in their swimwear choices. **Constraints** • **Material durability:** The textured and coated surfaces must withstand repeated exposure to chlorine and saltwater. • **Cost efficiency:** A balance between performance enhancement and affordability for different swimmer levels is needed. • **Flexibility:** The texture must maintain a smooth, flexible fit without limiting the range of motion. • **Regulatory compliance:** It must adhere to the swimming federation standards for competition apparel. • **Eco-friendly requirements:** Recyclable or biodegradable materials in product design should be considered.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The best way to assess whether the product meets the design challenges and constraints is to determine whether the product developed meets the following parameters: • Drag reduction. • Improvement in hydrodynamics. • Comfort and flexibility. • Durability. The design should aim to improve swim speed and efficiency while also considering sustainability and environmental impact. Any materials used must be non-toxic, environmentally friendly, and sustainable, and must meet performance standards for competitive swimming. **Compatibility with the Earth's systems**

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	The use of synthetic materials poses environmental concerns regarding pollution and waste. Ideally, a design that mimics natural systems would use biodegradable or recyclable materials to minimise its impact on Earth's systems. **Technical and business model** The feasibility of the Speedo swimsuit's technical model hinges on its performance and innovation. Additionally, there is a robust demand for high-performance swimwear in competitive sports, but consumers are increasingly prioritising sustainability. Therefore, a successful business model must emphasise eco-friendly practices while balancing performance and affordability. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** After determining that sharkskin was our natural model, we examined its hydrodynamic characteristics, especially its drag-reducing texture. Important tactics centred on surface interaction and performance improvement were taken from this. By using eco-friendly materials that mimic the texture of sharkskin, we were able to translate these insights into a design concept that emphasises usability, longevity, and sustainability.

Additional resources:

https://www.microphotonics.com/biomimicry-burr-invention-velcro/

https://illumin.usc.edu/from-shark-skin-to-speed/

https://www.just-style.com/news/shark-skin-inspires-latest-speedo-swimwear-line/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Inspiration from nacre of abalone, a single-shelled marine mollusc

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can the hierarchical structure of mollusc shells inspire the development of tougher ceramics that resist cracking and enhance durability? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. **Key functions of the design** • **Resistance to impact:** To absorb and distribute forces, preventing cracking or breaking under stress, similar to how mollusc shells protect the organism from predators and environmental effects. • **Flexibility:** Incorporating a degree of flexibility into the ceramic structure can help it withstand deformation without fracturing, much like mollusc shells, which can bend slightly under pressure. • **Lightweight strength:** Similar to the way mollusc shells provide robust protection without excessive weight. • **Self-healing properties:** The ability to repair micro-damage over time would enhance longevity, much like how certain biological materials can self-repair after sustaining minor injuries. • **Water resistance:** Inspired by the way mollusc shells repel water and prevent erosion, this feature can be crucial for applications in moist or underwater environments. A ceramic design that successfully satisfies the need for increased toughness and durability can be produced by acknowledging these crucial functions and natural structures. The design can attain greater flexibility and impact resistance by mimicking the layered structure of mollusc shells. **2.c Flip the question. Consider opposite functions.** How might the design unintentionally increase the fragility of ceramics, making them more prone to cracking and reducing their overall durability?

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	Mollusc shells have a hierarchical structure made up of layered aragonite and organic material arrangements that give them exceptional flexibility and toughness. Molluscs can withstand impacts and defend themselves against predators and environmental obstacles thanks to their special design. A poorly designed ceramic, on the other hand, might not have this layered composition, which would make it more brittle and prone to cracking. For example, failure under impact may occur from a ceramic's ineffective stress distribution due to its uniform, dense structure. Consequently, material designs should incorporate elements that replicate the efficient layering found in mollusc shells to ensure resilience against damage, thereby improving durability and performance.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Natural models** • **Mollusc shells**: the layered composition and organisation of aragonite and organic proteins that contribute to toughness and flexibility. • **Bone structure**: the natural hierarchical organisation of bone provides strength while remaining lightweight, with the ability to adapt and remodel. • **Wood**: the structure of wood, with its combination of strong cellulose fibres and flexible lignin, showcases how layers can provide both strength and resilience. **3.b Identify experts & connect to communities of biologists and naturalists.** **Experts** • **Marine biologists:** can give insights related to mollusc shell structures, connecting with marine biologists who study molluscs can provide valuable information on their adaptations and material properties; • **Structural biologists**: these experts study the structural properties of biological materials at the molecular level, which can inform design decisions for tougher ceramics. • **Naturalists**: connecting with local naturalist groups or nature organisations can offer perspectives on observing and understanding biological structures in their natural contexts. **Online forums and social media** • Platforms like ResearchGate, LinkedIn, and specialised Facebook groups for biomimicry and materials science can facilitate discussions and connections with experts and peers. **Citizen science projects** • Participate in or connect with citizen science initiatives focused on natural observation. Platforms like iNaturalist can help to engage with a community of nature enthusiasts and experts.

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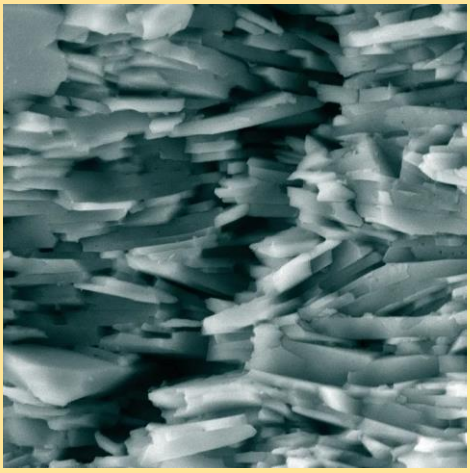
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** The layered patterns of aragonite and organic materials found in mollusc shells serve as the model for this product's hierarchical structure. Molluscs can tolerate a variety of environmental challenges thanks to their exceptional toughness and flexibility, which come from their unique design. **Key features of the design** • **Impact resistance**: The layered structure will distribute stress effectively, preventing cracking and enhancing durability. • **Material composition**: The combination of rigid and flexible materials will allow for deformation without breaking, improving resilience. • **Self-healing ability**: The incorporation of a repair mechanism will ensure that micro-damage can be addressed over time, extending the lifespan of the material. • **Water resistance**: This design will protect against moisture and erosion, making it suitable for diverse environments. **Keywords** Layered structure, aragonite, toughness, self-healing, and water resistance.  Figure 1. A crack must zig-zag its way through the stacked platelets in the new ceramic. Source: https://www.livescience.com/44705-breaking-the-mold-nature-inspires-tougher-ceramics.html **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Our product will have a layered surface structure that effectively distributes stress to increase its durability. This design will guarantee that the material can sustain impacts over time and prevent cracks. We can design a product that

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	adjusts to changing circumstances without losing strength by combining materials that are both rigid and flexible. These characteristics will be especially helpful for applications that need to be very durable, like construction materials or protective coatings. The product's overall performance can be enhanced while maintaining its durability and resilience in a variety of environments by implementing this creative layered design.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** This product will primarily aim to improve ceramics' toughness and durability by imitating the mollusc shell's hierarchical structure. Key characteristics will be a material composition that combines stiffness and flexibility, a layered design that efficiently distributes stress, and self-healing qualities that guarantee longevity. Together, these components will produce a lightweight, durable ceramic that reduces damage and cracking, enhances performance under pressure, and maintains its water resistance. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • Layered structure. • Material composition. • Self-healing mechanism. • Water resistance. • Lightweight design. **Context** This advanced ceramic can be used to improve the durability and impact resistance of sports equipment such as helmets and pads. Additionally, it is suitable for biomedical applications where toughness and biocompatibility are crucial, including dental materials and bone implants. Additionally, the ceramics could be used in building materials to provide water resistance and strength in high-stress situations. By appealing to sectors that value sustainable and innovative materials, the product can help meet the need for environmentally friendly solutions. **Constraints** The design must consider certain constraints, including material costs, which may impact the selection of high-quality raw materials. Manufacturing techniques must be scalable to meet production demands for the layered ceramics. Additionally, the product must adhere to performance standards for strength, durability, and safety in relevant applications.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.**

	The best way to assess whether the product meets the design challenges and constraints is to determine whether the product developed meets the following parameters: • Impact resistance. • Material flexibility. • Self-healing properties. • Water resistance. • Sustainability. The design can improve performance and durability while addressing environmental impact concerns by concentrating on these parameters. Overall, this approach ensures that advanced ceramics not only meet industry standards but also respond to the growing demand for sustainable and responsible product solutions. **Compatibility with the Earth's systems** The use of sustainable materials is of great importance, contributing to mitigating the environmental impact associated with traditional ceramic production. Additionally, the manufacturing process for these advanced ceramics can be designed to minimise energy consumption. **Technical model** The use of advanced manufacturing techniques (e.g., 3D printing) to create the layered structure is technically viable and has been successfully implemented in other industries. Regarding the business model, there is a growing market for high-performance materials in sports, biomedical, and construction applications, presenting significant business opportunities. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** It is possible to refine the advanced ceramics concept into a workable solution that satisfies the requirements and limitations of the design challenge by revisiting and revising these steps. Constant iteration based on research, testing, and feedback will guarantee that the finished product not only works incredibly well but also complies with market demands and sustainable practices.

Additional resources:

https://www.livescience.com/44705-breaking-the-mold-nature-inspires-tougher-ceramics.html

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Suckers found along the underside of octopus tentacles

BIOMIMICRY DESIGN	Description
Step 2 – Biolsgize	**2.a Ask yourself how nature can solve this.** How can the adaptive camouflage of octopus skin inspire the development of a medical patch that changes colour to indicate changes in health or the presence of infection? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do. **Key functions of the design** • **Adhesion:** the patch must securely adhere to various surfaces, including skin, while being gentle enough to prevent irritation upon removal. This function can be inspired by how octopus suckers attach to surfaces using suction. • **Flexibility and comfort:** the product needs to be flexible to accommodate body movements and contours without causing discomfort. This function could be informed by the adaptive skin of tree frogs, which allows them to move freely in diverse environments. • **Signal response:** The ability to change colour or indicate health status (e.g., detecting infections) could be essential. This can draw inspiration from the colour-changing abilities of octopuses, which they use for communication and camouflage. • **Self-healing:** If the patch can somehow mimic the self-repair mechanisms seen in certain organisms, it would enhance durability and usability, similar to how some plants can heal their wounds or how certain amphibians regenerate lost tissue. • **Water resistance:** the design should be resistant to moisture and bodily fluids, ensuring it remains effective in various conditions. This design can improve user comfort and effectiveness by taking inspiration from the self-healing abilities of some organisms, the flexibility of tree frog skin, and the adhesion qualities of octopus suckers. Furthermore, adding features like colour-changing indicators for health monitoring promotes biomaterials innovation while also improving patient outcomes. This focus on

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	natural remedies prioritises user experience and safety while promoting advancements in medical technology. **2.c Flip the question. Consider opposite functions.** How does a poorly designed medical patch hinder adhesion and compromise treatment effectiveness? Due to their special structure, octopus suckers can adhere securely to a variety of surfaces, enabling efficient skin contact. Even in difficult situations, octopuses can maintain a firm grip thanks to this ability. On the other hand, a badly made medical patch might not have the required adhesive qualities, which would result in insufficient skin contact and decreased efficacy. For example, a patch composed of non-tacky or low-friction materials may shift or peel off when moved, interfering with the therapeutic effect. To maximise its performance in medical applications and ensure optimal adhesion and treatment efficacy, a medical patch design should incorporate elements that replicate the effective attachment mechanisms of octopus suckers.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** The following natural models can serve as inspiration: • **Gecko feet**: With tiny hair-like structures on their toe pads, geckos can adhere to various surfaces without adhesives. • **Mussels**: They use a natural adhesive called byssus to cling to surfaces in water, which could inform the development of a waterproof medical patch with strong adhesion. • **Tree frog skin**: The flexible, waterproof skin of tree frogs adapts well to their environment, suggesting a patch design that is comfortable, breathable, and conforming to skin contours. • **Pufferfish skin**: Known for its ability to inflate and change texture, pufferfish skin could inspire a patch that adjusts adhesion based on environmental conditions. • **Caterpillar adhesives**: Certain caterpillars produce a silk-like substance for attachment, serving as a model for creating a patch that adheres securely yet is easily removable. **3.b Identify experts & connect to communities of biologists and naturalists.** **Experts** • **National Geographic Society**: supports research and conservation efforts. • **American Society of Naturalists**: This organisation focuses on promoting the study of natural history. • **Society for Integrative and Comparative Biology (SICB):** This society brings together scientists studying various aspects of biology.

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Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.**

This product is inspired by the remarkable adhesion mechanisms of octopus suckers, particularly their unique suction capability that enables safe attachment to a variety of surfaces. Because of the natural "grip-enhancing" mechanism these specialised structures produce, octopuses are able to hold their own even in dynamic environments.

Key functions of the design

- **Secure adhesion:** To ensure a reliable bond to the skin, enhancing treatment effectiveness.
- **Flexible design:** To allow the patch to conform comfortably to body contours and movements.
- **Health monitoring:** Through features that signal changes in colour or texture in response to environmental factors.

Keywords

Suction mechanisms, flexible attachment, health indicators, and adaptive conformability.

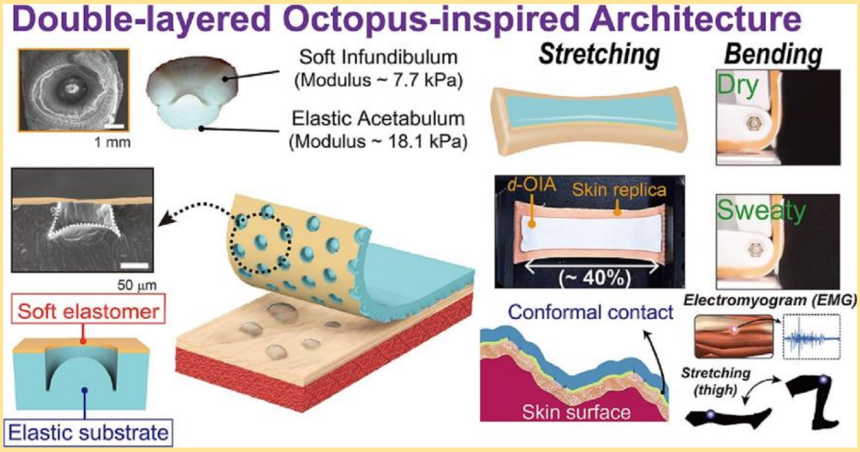

Figure 1. Double-layered octopus-inspired architecture

Source:
https://www.sciencedirect.com/science/article/abs/pii/S1385894723025238

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

The design strategy for this medical patch focuses on secure adhesion, comfort, and responsiveness to meet user needs in real-life conditions. The patch will adhere reliably to the skin, reducing the risk of peeling or slipping, even on areas with movement. Its flexible design will conform seamlessly to body contours, enhancing comfort and making it suitable for long-term wear. A built-in feature could provide visual feedback, such as colour change, to alert users to potential health changes like infection, allowing intuitive health

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	monitoring. The patch will also be durable, withstanding minor wear and reducing the need for frequent replacements, while its moisture-resistant properties ensure performance in damp or sweaty conditions. Together, these strategies will provide a reliable, comfortable, and responsive patch design that supports treatment in various environments.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** This medical patch design uses breathable materials for comfort and micro-suction technology for a dependable grip, with an emphasis on secure adhesion, flexibility, and health monitoring. Waterproof and self-healing materials improve durability, and a colour-changing layer indicates changes in health. An easy-release edge guarantees painless removal, and hypoallergenic layers guard against irritation. The patch is sustainable because it combines comfort, functionality, and environmental responsibility with reusable and eco-friendly options. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • Adhesion. • Flexibility. • Health monitoring. • Durability. • Moisture resistance. • Removability. • Sustainability. **Context** This medical patch will be designed for use in healthcare settings that require reliable monitoring and long-term wear, such as wound care or post-surgical treatment. It will be suitable for active daily use, capable of withstanding movement, exposure to sweat, and other environmental factors. Additionally, it will address the needs of individuals with sensitive skin by using hypoallergenic, gentle materials to prevent irritation. These features will ensure that the patch remains comfortable and effective across various conditions, providing a practical solution for both medical professionals and everyday users. **Constraints** • **Non-irritating materials:** Hypoallergenic materials must be used to prevent skin irritation. • **Affordable production:** Components must be cost-effective to support accessibility and scalability.

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	• **Extended wear:** Must maintain performance over long periods, with features that prevent peeling and discomfort. • **Eco-friendly options:** Emphasis on sustainable materials that don't compromise durability or function should be considered
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** The best way to assess whether the product meets the design challenges and constraints is to determine whether the product developed meets the following parameters: • Adhesion. • Flexibility and comfort. • Health monitoring. • Durability and reusability. • Sustainability. **Compatibility with the Earth's systems** The design should prioritise secure adhesion, comfort, and health monitoring while also being environmentally sustainable. Materials must be hypoallergenic, non-toxic, and eco-friendly, ensuring they meet both durability and comfort requirements for extended medical use. The patch should be effective in providing reliable health feedback, adaptable to daily activities, and made from sustainable resources that minimise environmental impact, ensuring its **compatibility with Earth's systems**. **Technical and business model** The micro-suction technology, colour-changing indicators, and self-healing materials are all achievable with current manufacturing techniques, making this design technically feasible. Additionally, the patch could reach medical markets through partnerships with healthcare providers and consumer markets via pharmacies or direct-to-consumer channels. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To generate a viable solution for the medical patch design, it's essential to revisit and refine previous steps, ensuring alignment with user needs, environmental considerations, and technical feasibility. In this sense, we should: • Reassess the design criteria and constraints. • Explore additional features. • Evaluate technical feasibility. • Assess market and business model. • Iterate and test prototypes.

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	• Finalise our design.

Additional resources:

https://wearable-technologies.com/news/octopus-suckers-inspire-irritation-free-adhesive

https://www.sciencedirect.com/science/article/abs/pii/S1385894723025238

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Bumps on the leading edge of the humpback whale's flipper

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can the hydrodynamic efficiency of humpback whale fins inspire the design of wind turbine blades that maximise energy output in low-wind conditions? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do. **Key functions of the design** • **Energy capture maximisation:** The primary function of the turbine blade design is to capture as much energy from the wind as possible, even in low-wind conditions. • **Drag reduction:** The blades need to move smoothly through the air, minimising drag to improve overall efficiency. • **Stability and stall prevention:** in varying wind speeds, the blades should maintain stable operation, avoiding stalling and maximising lift for consistent energy generation. • **Adaptation to variable conditions:** The design should perform well in various wind speeds and directions, much like certain animals adapt their movement to changing fluid environments. Inspired by the hydrodynamic accuracy of humpback whale fins, the stability and lift control of albatross wings, and the streamlined propulsion of shark fins, this wind turbine design can increase energy efficiency and adaptability. **2.c Flip the question. Consider opposite functions.** In what ways does an ineffective wind turbine blade design limit energy capture and reduce efficiency? Humpback whale fins possess a specialised structure, with tubercles along the leading edge that enhance lift and reduce drag, allowing efficient movement through water. This adaptation enables the whale to navigate fluid environments with stability and control. In contrast, a poorly designed wind turbine blade lacking these structural innovations may suffer from increased drag and limited lift, especially in variable wind conditions, leading to reduced

	energy capture. For instance, a blade with a flat or blunt edge may stall or experience turbulent airflow, diminishing its efficiency. Incorporating features inspired by whale fin tubercle structure can improve wind turbine performance by increasing lift and lowering drag, resulting in greater energy capture and operational reliability.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Natural models** • **Humpback whale fins:** The tubercles on the leading edges of humpback whale fins create channels that reduce drag and increase lift, allowing the whale to manoeuvre smoothly through water. This adaptation aligns with the turbine blade's need to optimise airflow and minimise energy loss. • **Albatross wings:** They adjust their wings to control airflow and optimise efficiency, which mirrors the goal of turbine blades to adapt to varying wind conditions. • **Maple seeds (samara):** The single-winged structure of maple seeds allows them to spin and descend slowly, maximising surface area and controlling descent through air resistance. This structure offers insights into achieving stability and rotation in wind, relevant for maximising energy capture. • **Shark skin:** Features small, tooth-like structures called dermal denticles, which streamline water flow and reduce drag. This adaptation allows sharks to move efficiently through water, providing a model for reducing drag on wind turbine blades in air, a similar fluid medium. • **Dragonfly wings:** They have microstructures that reduce drag and allow high manoeuvrability. The veins and mesh-like design enable them to adapt to fast and variable airflows, maintaining stability, a function that wind turbine blades also need in fluctuating wind conditions. **3.b Identify experts & connect to communities of biologists and naturalists.** **Experts** • **Marine biologists**: Experts studying marine life, such as humpback whales and other marine animals, can provide insights into adaptations that enhance fluid movement. • **Aerodynamics engineers**: Engineers with a focus on aerodynamics can bridge the gap between biological adaptations and engineering applications, particularly for wind turbine design. • **Ecologists:** Ecologists studying animal behaviour and adaptations in various environments can offer valuable context for understanding how different organisms interact with their fluid environments. **Communities**

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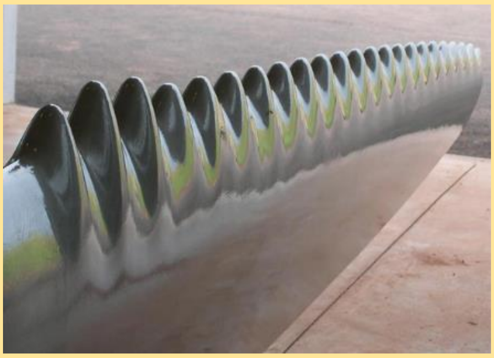
	• **Society for Biological Engineering (SBE):** It focuses on applying biological principles in engineering and technology, providing a platform for networking and collaboration with experts in related fields. • **National Geographic Society:** This organisation connects naturalists and biologists through various programs and initiatives.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** This product will be inspired by the unique tubercles on humpback whale fins, which enhance their swimming efficiency by improving lift and reducing drag. This natural adaptation allows the whales to manoeuvre effectively in turbulent waters. **Core functions of the solution** • **Enhanced energy capture:** Optimising performance by increasing wind interaction with turbine blades. • **Reduced noise:** Leading to quieter operation, which benefits both wildlife and nearby communities. • **Increased stability:** Ensuring consistent energy output in varying wind conditions. **Keywrods** Tubercles, aerodynamic efficiency, energy optimisation, and operational stability.  Figure 1. Wind-turbine blade at a wind-testing facility in Prince Edward Island Source:https://www.technologyreview.com/2008/03/06/221447/whale-inspired-wind-turbines/

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	4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective. The design strategy for this medical patch focuses on secure adhesion, comfort, and responsiveness to meet user needs in real-life conditions. The patch will adhere reliably to the skin, reducing the risk of peeling or slipping, even on areas with movement. Its flexible design will conform seamlessly to body contours, enhancing comfort and making it suitable for long-term wear. A built-in feature could provide visual feedback, such as colour change, to alert users to potential health changes like infection, allowing intuitive health monitoring. The patch will also be durable, withstanding minor wear and reducing the need for frequent replacements, while its moisture-resistant properties ensure performance in damp or sweaty conditions. Together, these strategies will provide a reliable, comfortable, and responsive patch design that supports treatment in various environments.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** To apply the lessons learned from nature to design effective strategies, we focus on developing surfaces that optimise wind interaction, resulting in improved energy capture. This entails incorporating stability features to guarantee consistent performance under various circumstances and designing shapes that reduce noise for a more enjoyable user experience. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • Enhanced energy capture. • Noise reduction. • Stability. **Context** This design's context centres on the growing demand for sustainable energy solutions in the face of rising energy demands and climate change. As a cleaner substitute for fossil fuels, wind energy is an essential part of the renewable energy landscape. To increase public acceptance and mitigate environmental impacts, wind turbines must become quieter and more efficient as technology advances. This background emphasises the value of innovation in wind turbine design, with the goal of producing machines that are efficient, easy to use, and environmentally adaptive. **Constraints** • **Material limitations**: It must use durable, weather-resistant materials. • **Cost-effectiveness**: The design must remain economically viable for production.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with**

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	Earth's systems. Assess the feasibility of both the technical and business models. The design ideas fit the challenge's requirements of increasing stability, lowering noise, and improving energy efficiency. By promoting the use of renewable energy sources, they align with Earth's systems and contribute to reducing greenhouse gas emissions. In addition, technical elements are feasible because developments in materials and aerodynamics support these innovations. Given investment in more efficient wind technologies being driven by the growing demand for sustainable energy solutions, the business model seems favourable as well. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To create a viable solution, we can revise the design concepts to ensure they align with user needs and environmental considerations. This includes optimising turbine blade geometry for maximum performance, incorporating advanced materials that increase durability while reducing weight, and ensuring noise reduction features are both effective and cost-effective.

Additional resources:

https://biomimicry.net/the-buzz/resources/case-examples-learning-whales-create-efficient-wind-power/

https://www.technologyreview.com/2008/03/06/221447/whale-inspired-wind-turbines/

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Lizard-Skin-Inspired Nanofibrous Capillary Network

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How does the nanofibrous capillary network inspired by lizard skin improve moisture management in materials? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something you need your design solution to do. **Key functions of the design** • **Moisture management**: The design should efficiently absorb and release moisture, mimicking how lizard skin regulates water retention and evaporation. • **Temperature regulation**: It should maintain a stable temperature, adapting to environmental changes while ensuring comfort for the user. • **Lightweight and flexible structure**: The materials should be lightweight and flexible, allowing for ease of movement without compromising durability. • **Durability and resistance to wear**: The design must be resilient to external stresses and conditions, similar to how lizard skin withstands harsh environments. **2.c Flip the question. Consider opposite functions.** How might the design unintentionally enhance moisture retention in materials, leading to mould growth and reducing their overall effectiveness? The unique nanofibrous capillary network in lizard skin enables efficient temperature and moisture regulation, allowing lizards to flourish in a variety of environments. A poorly designed material, on the other hand, may lack this complex system, which would lead to poor moisture management and a higher risk of overheating. For instance, dense and homogeneous structures may retain moisture, which could result in the growth of mould or discomfort from the heat. Replicating the adaptive properties of lizard skin through

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	improved moisture regulation and thermal balance for increased user comfort is one way to improve performance.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Natural models** • **Lizard skin**: Certain species exhibit a specialised nanofibrous capillary network that facilitates efficient moisture harvesting and temperature regulation. Their skin structures allow for rapid absorption and passive transport of moisture, helping them survive in arid environments. • **Cacti**: Cacti have evolved thick, waxy skins and specialised pores (stomata) that help reduce water loss while optimising moisture retention. Their adaptations allow them to thrive in hot, dry climates by efficiently managing both water and temperature • **Plant leaves**: Many plant species possess leaf structures that optimise moisture management through transpiration. For example, leaves with a waxy cuticle help minimise evaporation while still allowing for gas exchange, illustrating an effective balance between moisture retention and environmental interaction. **3.b Identify experts & connect to communities of biologists and naturalists.** **Societies** • **The Society for Integrative and Comparative Biology (SICB):** This organisation brings together researchers and students in various fields of biology, focusing on the integration of biological research and education. • **The American Institute of Biological Sciences (AIBS)**: AIBS promotes research and education in the biological sciences, offering networking opportunities and resources to connect biologists focused on ecology, evolution, and biodiversity.

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Step 4 – Abstract

4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.

Core features of the product

- **Moisture absorption:** The nanofibrous structure of lizard skin creates a highly efficient moisture-collecting surface that captures water from dew or rain. This design can be replicated to enhance moisture management in various applications, allowing for better hydration and resource utilisation.
- **Temperature regulation**: The micro-ornamentation found on lizard skin aids in thermoregulation by optimising heat dissipation. This feature can be integrated into product designs to maintain stable internal temperatures, which is essential for performance in fluctuating environmental conditions.
- **Structural flexibility**: Lizard skin's ability to remain flexible while providing strength allows these reptiles to navigate their habitats without sacrificing moisture management. Mimicking this characteristic can enhance the resilience and adaptability of products used in various settings.
- **Self-cleaning mechanism**: The surface properties of lizard skin facilitate the removal of dirt and other contaminants, helping to maintain functionality over time. Incorporating self-cleaning features into product designs can extend their lifespan and effectiveness

Keywords

Moisture absorption, temperature regulation, flexible structure, and self-cleaning properties.

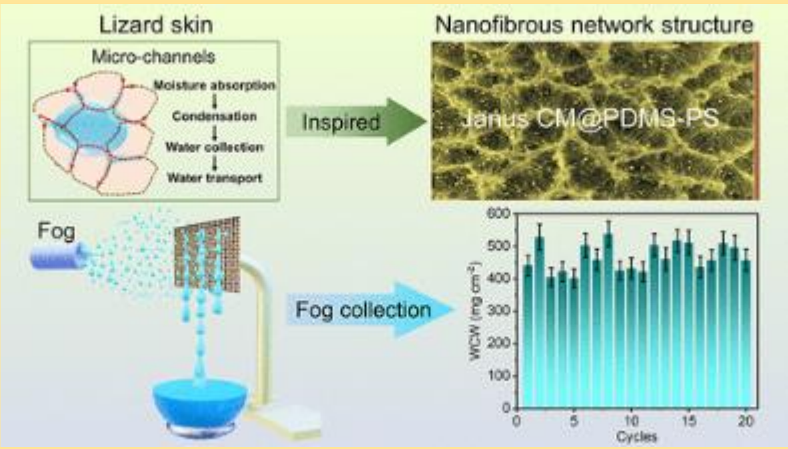

Figure 1. Lizard-Skin-Inspired Nanofibrous Capillary Network Combined with a Slippery Surface for Efficient Fog Collection

Source: https://pubs.acs.org/doi/abs/10.1021/acsami.1c10067

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4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Inspired by the special qualities of lizard skin, our product will feature a surface optimised for temperature regulation and moisture absorption. This innovative design will enable the material to absorb and retain moisture from the surroundings efficiently, enhancing resource efficiency and hydration. Advanced microstructures that aid in moisture transport can be incorporated to guarantee the product's dependable performance under a range of circumstances.

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Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** This product will focus on enhancing moisture collection efficiency by mimicking the specialised surface structures of lizard skin. Key features will include a textured design that facilitates the condensation of water droplets from fog, allowing for effective harvesting. The integration of micro- and nanostructures will optimise water adhesion and coalescence, maximising the amount of moisture collected. Additionally, the product will be designed to maintain durability and functionality in diverse environmental conditions, ensuring reliability for applications in arid regions or areas with high fog incidence. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • Textured surface. • Moisture harvesting system. • Durability. • Lightweight design. **Context** • Ideal for use in fog-prone areas and arid regions where traditional water sources are limited. • Potential applications include agricultural water systems, building materials, and portable water harvesters. • Contributes to sustainable water management practices by utilising natural moisture sources. **Constraints** • **Material limitations:** The choice of materials must balance durability with lightweight properties to ensure functionality and ease of use. • **Installation and maintenance:** The design must consider ease of installation and minimal maintenance requirements to encourage widespread use. • **Cost of production:** Economic feasibility is critical. The design should be cost-effective to manufacture and deploy.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The best way to assess whether the product meets the design challenges and constraints is to determine whether the product developed meets the following parameters:

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	• **Efficiency in moisture collection:** The textured surfaces inspired by lizard skin are specifically designed to enhance the condensation and coalescence of water droplets from fog, ensuring maximum efficiency in water harvesting. • **Environmental sustainability:** This design encourages sustainable water management techniques by using natural fog and dew as water sources, which is essential for areas experiencing water scarcity. • **Adaptability:** Fog nets and harvesters are examples of lightweight, portable design concepts that provide versatility in deployment, making them appropriate for a range of environments and applications. To ensure compatibility with Earth's systems, the materials must be sourced from eco-friendly and sustainable resources, minimising environmental impact. This means selecting non-toxic, biodegradable, or recyclable materials that maintain both performance and environmental integrity. Finally, regarding the technical and business model, the principles of moisture collection and material adaptability are achievable with existing manufacturing technologies, making this design technically feasible. The integration of textured surfaces that mimic lizard skin can be implemented using advanced material fabrication methods. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** The design challenge's requirements can be successfully met by improving the lizard skin-inspired fog collection design's steps. The product's functionality will be improved through ongoing iteration through research, testing, and feedback, all the while making sure it complies with sustainability standards and market demands. This strategy will optimise its ability to effectively address water scarcity.

Additional resources:

https://pubs.acs.org/doi/abs/10.1021/acsami.1c10067

https://www.sciencedirect.com/science/article/abs/pii/S0169433216328306

https://projects.research-and-innovation.ec.europa.eu/en/projects/success-stories/all/mimicking-lizard-skin-save-energy-industrial-scale

https://projects.research-and-innovation.ec.europa.eu/en/projects/success-stories/all/mimicking-lizard-skin-save-energy-industrial-scale

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Inspiration from dolphins who can communicate complex information

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How does underwater acoustic communication inspired by dolphins improve data transmission in underwater environments? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. **Key functions of the design** • **Efficient long-distance transmission**: The design should transmit signals over large distances with minimal energy loss. • **Noise filtering and signal clarity**: The system must maintain clear communication in noisy environments. • **Directionally focused transmission**: The design should enable targeted, directionally focused communication to minimise energy waste and improve accuracy, drawing from the echolocation techniques of bats and dolphins, which concentrate sound waves toward specific points. • **Environmental adaptability**: The system should adapt to varying underwater conditions, adjusting signal strength and frequency as needed, ensuring optimised performance in different underwater environments. **2.c Flip the question. Consider opposite functions.** How might the design unintentionally enhance moisture retention in materials, leading to mould growth and reducing their overall effectiveness? If the underwater communication design unintentionally amplifies ambient sounds, it could make distinguishing between relevant signals and background noise more difficult. This might lead to messages becoming muddled or lost, particularly in areas with high levels of natural sound, such as near coral reefs or marine traffic zones. Instead of clear communication, receivers could struggle to interpret signals accurately, which would reduce the reliability and effectiveness of the system. In addition to this, this unintended enhancement

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	of noise could increase energy consumption as the system compensates by boosting signal strength to overcome interference.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Natural models** • **Dolphins (echolocation and communication)**: Dolphins use echolocation and vocalisations to communicate and navigate underwater, making them ideal models for clear, targeted sound transmission in water. • **Whales (low-frequency communication)**: Blue and humpback whales produce low-frequency calls that can travel across vast distances underwater, making them models for long-distance communication. • **Frogs (noise filtering in choruses)**: Frogs in wetland environments adjust their call patterns to avoid overlapping with others in loud, communal choruses. • **Electric fish (communication in murky waters):** Electric fish, like electric eels, use electric fields for navigation and communication in foggy or dark waters where vision is limited. • **Elephants (adaptive low-frequency rumbles):** elephants communicate using low-frequency rumbles that travel through the ground and air, adjusting their calls based on distance, wind, and obstacles. • **Pistol shrimp (bubble snap communication):** Pistol shrimp communicate and hunt by snapping their claws to produce high-intensity sound waves that travel through water. **3.b Identify experts & connect to communities of biologists and naturalists.** **Societies** • **Wyss Institute for Biologically Inspired Engineering (Harvard University)**: Focuses on creating sustainable solutions through biomimicry. Collaborations with Wyss Institute researchers can support the design of energy-efficient and adaptable underwater communication systems inspired by animal models. • **The Center for Biomimicry at Arizona State University**: Their work on biologically inspired solutions, especially in adaptive materials and communication methods, could aid in creating adaptable communication technologies. • **Society for Marine Mammalogy**: An international organisation of marine mammal experts, which offers conferences, workshops, and online forums to connect with leading researchers in dolphin, whale, and other marine animal communication. • **Acoustical Society of America (ASA)**: with a focus on underwater acoustics, ASA members include leading bio acousticians and engineers

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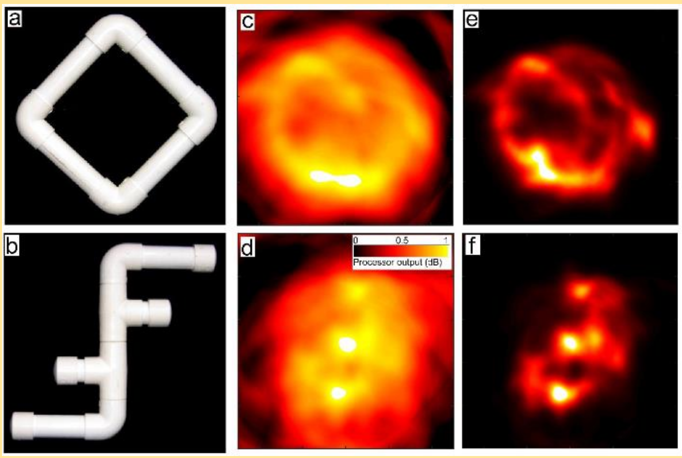
	developing new acoustic technologies, ideal for sharing knowledge on noise filtering and directional sound in aquatic environments. • **Ocean Networks Canada (ONC)**: This ocean observatory network gathers acoustic data from marine environments, supporting research on how animals use sound for communication. ONC's resources could offer real-world data and connections with experts monitoring underwater ecosystems.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Core features of the product** • **Efficient long-distance transmission:** Dolphins use adaptive frequency modulation for sound transmission over great distances with minimal energy loss. This principle can optimise signal strength and clarity in deep underwater environments. • **Noise filtering and signal clarity:** Dolphins excel at distinguishing their vocalisations from ambient noise. This capability can be emulated in our system to enhance communication clarity in acoustically challenging conditions. • **Directional sound projection:** The dolphin's melon focuses sound waves in specific directions for targeted communication. Incorporating this feature can improve transmission efficiency and reduce interference. • **Environmental adaptability:** Dolphins adjust their communication in response to changing environmental conditions. Designing our system to adapt to different depths and currents will enhance its reliability in diverse aquatic environments. **Keywords** Long-distance transmission, noise filtering, directional projection, environmental adaptability.  Figure 1. Sparsity-aware processing produces clearer biomimetic-sonar data visualisations (images e and f) than those produced via conventional image

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	processing methods (images c and d). The original objects can be seen in a and b. Source: https://news.nus.edu.sg/dolphin-inspired-compact-sonar/ **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Our product will have a system that is designed for long-distance transmission and signal clarity, drawing inspiration from the exceptional communication abilities of dolphins. Adaptive frequency modulation will be used in the design to minimise energy consumption and guarantee efficient communication over long underwater distances. To improve the clarity of transmitted signals in difficult acoustic environments, sophisticated algorithms will be used to filter out background noise. Furthermore, targeted communication will be possible thanks to focused sound projection technology, which will also lower interference and increase transmission efficiency. This innovative approach will guarantee dependable performance in a range of underwater conditions, enabling seamless interactions in deep-sea environments.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** This product will prioritise improving underwater communication by drawing inspiration from the sophisticated sound mechanisms used by dolphins. One of the main features will be a system that dynamically modifies sound intensities and frequencies, allowing for efficient long-distance communication while using less energy. Advanced filtering techniques will be implemented to isolate and enhance specific signals, ensuring clarity in environments with high background noise. To precisely direct signals and reduce interference from ambient noise, the design will also include focused sound transmission capabilities. This communication system will be engineered for durability and resilience in a range of underwater conditions, ensuring reliable operation in diverse marine environments. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** • Adaptive frequency modulation. • Advanced noise filtering. • Directional sound projection. • Real-time environmental response. **Context** • Designed for use in various aquatic environments, including the deep sea, coastal areas, and those with high ambient noise. • Suitable for divers, marine researchers, underwater survey teams, and rescue operations needing reliable communication. • Addresses the challenges of effective communication in noisy scenarios

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	and over long distances, thereby enhancing safety and coordination. **Constraints** • **Environmental conditions**: The system must perform reliably in varying water temperatures, depths, and currents. • **Battery life and energy efficiency**: It should prioritise low energy consumption to extend operational time and minimise battery replacement. • **Durability**: It must withstand marine conditions, including corrosion, pressure, and potential impacts from marine life or debris. • **User-friendliness**: The interface should be intuitive and easy to operate for users with varying levels of technical expertise, ensuring accessibility.
Step 6 – Evaluate	6.a **Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** Overall, the suggested design concepts meet the requirements and limitations of the design challenge and effectively address the essential requirements for underwater communication. Their attractiveness is enhanced by their sustainable practices, which make them compatible with Earth's systems. To overcome early development and production obstacles, a strong business plan and careful consideration of technical complexities are necessary for successful implementation. Long-term survival and success in this cutting-edge communication sector will depend on ongoing market analysis and adaptation. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To develop a practical dolphin-inspired underwater communication system, we will concentrate on improving important design ideas like compact directional sound projection to reduce interference, improved noise filtering with user customization for clarity in a variety of settings, and simplified adaptive frequency modulation for efficient long-distance transmission. A modular approach to real-time environmental response will enable users to add sensors as needed. To ensure economic viability, we will prioritise cost control and, when practical, use off-the-shelf components and long-lasting, environmentally friendly materials. The efficacy of the system will be confirmed by interacting with potential users via surveys and collaborations with marine research organisations. Through the use of an iterative testing procedure, we hope to improve the product in response to user input, culminating in a phased launch that emphasises its effectiveness and safety.

Additional resources:

https://www.nature.com/articles/s44172-022-00010-x

https://asknature.org/innovation/underwater-acoustic-communication-inspired-by-dolphins/

https://news.nus.edu.sg/dolphin-inspired-compact-sonar/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Inspiration from the Moths' eyes

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can the light-absorbing structure of moth eyes enhance camera sensitivity in low-light conditions? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. **Key functions of the design** • **Enhanced light absorption:** The design should maximise light capture, especially in low-light conditions, to improve sensitivity, inspired by the microstructures on moth eyes that absorb ambient light efficiently. • **Reflection minimisation:** It must minimise surface reflection to reduce glare and improve image clarity, mimicking the non-reflective properties of moth eyes that prevent light from bouncing off. • **High resolution in low-light:** It should enable clear, high-resolution imaging even in dim environments, similar to nocturnal animals that have adapted to see with sharp detail in near darkness. • **Environmental adaptability:** It should adjust to different lighting conditions to maintain optimal performance, drawing from adaptive mechanisms in animals that thrive in varying light levels. **2.c Flip the question. Consider opposite functions.** In what ways could the design inadvertently cause excessive light bounce, resulting in glare that diminishes image quality in dim environments? The design's functions could be considered oppositely by prioritising light reflection instead of absorption, useful for applications requiring high visibility like safety gear. It could also intentionally create glare to diffuse light for specific effects or deterrents. Rather than enhancing resolution in low-light, the design might reduce resolution in bright settings to prevent overexposure, optimising for stable, high-light conditions instead.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.**

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	Natural models • **Moth eyes:** Moths have microstructured eyes that minimise reflection and maximise light absorption, aiding navigation in low light. • **Nocturnal animals:** Like owls and cats possess retinas with numerous rod cells, allowing them to see clearly in darkness, often aided by a reflective layer. • **Deep-sea fish:** Species such as anglerfish and lanternfish have adapted eyes that detect minimal light in deep ocean environments, enabling effective hunting. • **Fireflies:** These insects utilise bioluminescence to produce visible light for communication in dark surroundings. • **Scorpions:** Scorpions fluoresce under ultraviolet light, enhancing visibility in dark habitats and assisting in prey detection. **3.b Identify experts & connect to communities of biologists and naturalists.** **Societies** • **Society for Integrative and Comparative Biology (SICB)**: This organisation provides a platform for networking with biologists specialising in evolutionary adaptations and sensory biology, facilitating connections with experts who can offer insights into low-light vision adaptations. • **American Association for the Advancement of Science (AAAS)**: This organisation promotes collaboration among scientists and engineers. Their conferences and forums can provide opportunities to engage with leading researchers in optics and visual systems. • **Society for Photographic Science and Technology (SPST)**: This society focuses on the scientific aspects of photography and imaging technology, offering access to experts who can share knowledge on improving image clarity in low-light environments. • **The International Society for Optical Engineering (SPIE)**: It connects professionals in the optics and photonics fields, making it a valuable resource for networking with experts in imaging technologies and sensory systems inspired by nature.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core features of the product** • **Enhanced light absorption:** Moth eyes have microstructured surfaces that maximise light capture, particularly in low-light conditions. This principle can be applied to improve the sensitivity and performance of our imaging system in dim environments.

- **Minimised reflection:** The design of moth eyes reduces light reflection, allowing for clearer vision. Our system can emulate this feature to decrease glare and enhance image clarity in various lighting scenarios.
- **High sensitivity in low light:** Moth eyes are adapted to detect even the smallest amounts of light. Incorporating similar mechanisms will enable our system to achieve high resolution and sensitivity in dark conditions.
- **Environmental adaptability:** Moths can adjust their visual capabilities based on changing light conditions. Designing our imaging system to adapt to varying illumination levels will enhance its functionality across different environments.

Keywords

Light absorption, minimised reflection, high sensitivity, and environmental adaptability.

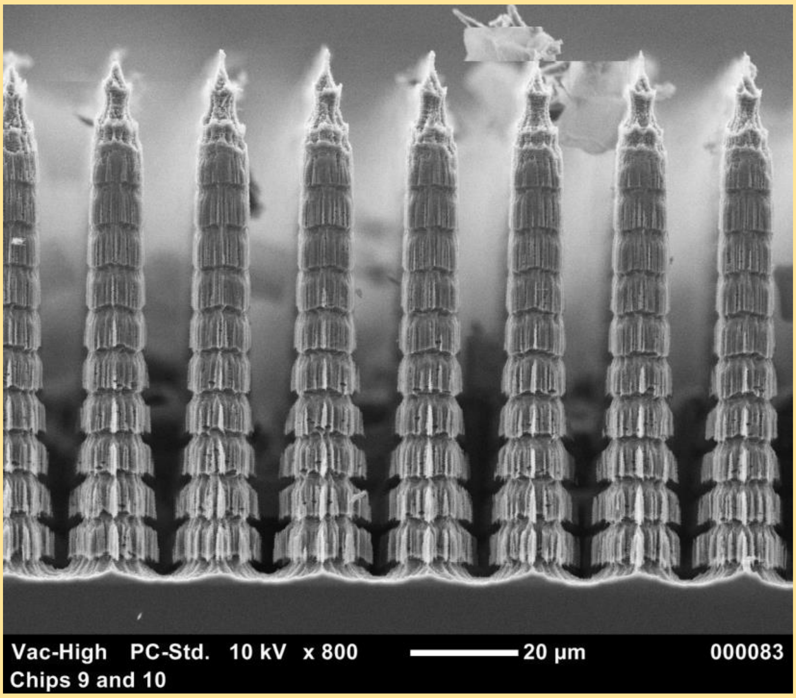

Figure 1. Moth's Eye Inspires Critical Component on SOFIA's Newest Instrument

Source: https://www.nasa.gov/centers-and-facilities/ames/moths-eye-inspires-critical-component-on-sofias-newest-instrument/

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Our product will feature a system designed for long-distance transmission and signal clarity, drawing inspiration from the exceptional communication abilities of dolphins. Adaptive frequency modulation will be used in the design to minimise energy consumption and guarantee efficient communication over

	long underwater distances. To improve the clarity of transmitted signals in complex acoustic environments, sophisticated algorithms will be used to filter out background noise. Furthermore, targeted communication will be possible thanks to focused sound projection technology, which will also lower interference and increase transmission efficiency. This novel strategy will guarantee dependable performance in a range of underwater conditions, enabling smooth interactions in deep-sea environments.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** Drawing inspiration from natural phenomena, such as moth eyes for increasing light absorption and reducing reflection, nocturnal animals for high sensitivity, fireflies for bioluminescence, and dolphins for focused sound projection, the design aims to improve sensitivity and clarity in low-light imaging systems. Adaptability to changing lighting conditions, glare reduction, high-resolution performance in low light, and effective light capture are essential features. Proposed ideas include using micro-patterned coatings to improve light capture, implementing advanced sensors mimicking nocturnal retinas, developing anti-glare coatings, creating systems with dynamic lighting adjustments, integrating bioluminescent elements for extra illumination, designing a modular system for customisation, employing machine learning for optimising settings, incorporating multi-spectral imaging, enhancing user interfaces for manual and automated controls. The goal of this comprehensive approach is to develop practical low-light imaging solutions that meet human needs. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features:** • Enhanced light absorption. • Minimised reflection. • High sensitivity in low light. • Adaptive technology. • Modular design. **Context** • Suitable for night-time photography, wildlife observation, underwater exploration, and other scenarios where low-light conditions present challenges. • Target users include photographers, researchers, and rescue teams who require reliable imaging capabilities in dark or poorly lit environments. **Constraints**

	• **Environmental limitations:** The design must perform effectively in diverse conditions, including underwater environments, various depths, and changing light levels. • **Technical feasibility:** Ensure that the innovative technologies can be integrated into a compact, lightweight design that remains practical for users. • **Cost considerations:** Balance the incorporation of advanced features with affordability to make the technology accessible to a broader range of users. • **Energy efficiency:** Optimise power consumption to ensure the system can operate for extended periods, especially in remote settings where power sources are limited.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The proposed design concepts, inspired by moth-eye technology, align well with the criteria of enhancing sensitivity and clarity in low-light imaging systems. Features such as micro-structured coatings for light absorption and anti-reflective surfaces for glare reduction are technically feasible, supported by advancements in material science and existing sensor technologies. Additionally, adaptive technology for automatic adjustments and modular design for customizability enhance usability while addressing market diversity. These concepts prioritise sustainability and energy efficiency, making them compatible with environmental goals. The growing demand for advanced imaging solutions in photography, wildlife observation, and rescue operations suggests a promising business model, provided that cost management and production efficiency are effectively addressed. Overall, the concepts are viable and present strong potential for success in the market. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** To create a viable low-light imaging system inspired by moth-eye technology, it's crucial to refine previous steps based on evaluation insights. First, research advancements in micro-structured coatings for effective light absorption and explore anti-reflective technologies to ensure clarity. Identify optimal sensor technologies that balance sensitivity, size, and energy efficiency, while simplifying the integration of adaptive features for user-friendliness. Finally, iterate on the design by creating prototypes and testing them with users to refine functionality, ensuring that the final product meets user needs and market demands for success.

Additional resources:

https://techcrunch.com/2016/12/20/moth-eyes-inspired-the-design-of-this-hypersensitive-camera/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Polar-bear-inspired material

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How can the hollow, heat-trapping structure of polar bear fur inspire the development of lightweight, highly efficient insulation for extreme cold environments? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. **Key functions of the design** • **Heat retention:** The design must trap heat effectively to maintain warmth in cold conditions. • **Lightweight structure:** The insulation should be low in weight to facilitate mobility and ease of use. • **Durability and adaptability**: The material should withstand harsh environments while retaining its insulating properties over time. **2.c Flip the question. Consider opposite functions.** How does insulation that traps too much heat lead to discomfort and overheating in moderately cold environments? The hollow structure of polar bear fur traps air, creating an insulating layer that minimises heat loss in extreme cold. This allows polar bears to retain warmth efficiently without needing thick, heavy fur. Insulation without this type of air-trapping structure, however, might fail to retain heat effectively, leaving the wearer vulnerable to cold. For instance, insulation made from solid, dense materials might lack sufficient air pockets, increasing bulk without providing adequate warmth. In this sense, to maximise thermal efficiency in cold environments, insulation design should incorporate hollow, air-trapping features inspired by polar bear fur.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.**

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	Natural models • **Polar bear fur**: Known for its hollow, translucent hairs, polar bear fur is an excellent model for trapping warmth and reducing heat loss. • **Arctic fox fur**: Thick and layered to provide insulation in subzero temperatures, the Arctic fox's coat demonstrates the function of multi-layered insulation. • **Bird down feathers**: The structure of down feathers, which trap air close to the body, serves as another model for lightweight, efficient thermal insulation. **3.b Identify experts & connect to communities of biologists and naturalists.** To deepen connections with experts and communities relevant to polar bear-inspired insulation, we should consider a diverse range of professionals and organisations across fields like zoology, bioengineering, environmental science, and sustainable design.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** Polar bear fur has evolved to provide exceptional insulation and adaptability in extreme Arctic conditions. The core functions of this biological strategy revolve around heat retention, lightweight structure, and durability. Here are the main elements: • **Hollow hair structure:** Each hair is hollow, trapping air within and creating a thermal barrier that minimises heat loss. • **Translucent fur with reflective properties**: The translucent fur allows sunlight to penetrate down to the bear's black skin, which absorbs heat efficiently, creating a secondary source of warmth. • **Dense fur layering for protection**: The fur has two layers—a dense undercoat and a longer outer layer. This layering provides added insulation and shields the bear from extreme cold and wind. • **Water Resistance**: The fur repels water, helping keep the bear dry and preserving body heat even after swimming in frigid waters. **Keywords** Hollow hair structure, translucent fur, layered insulation, water resistance.

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	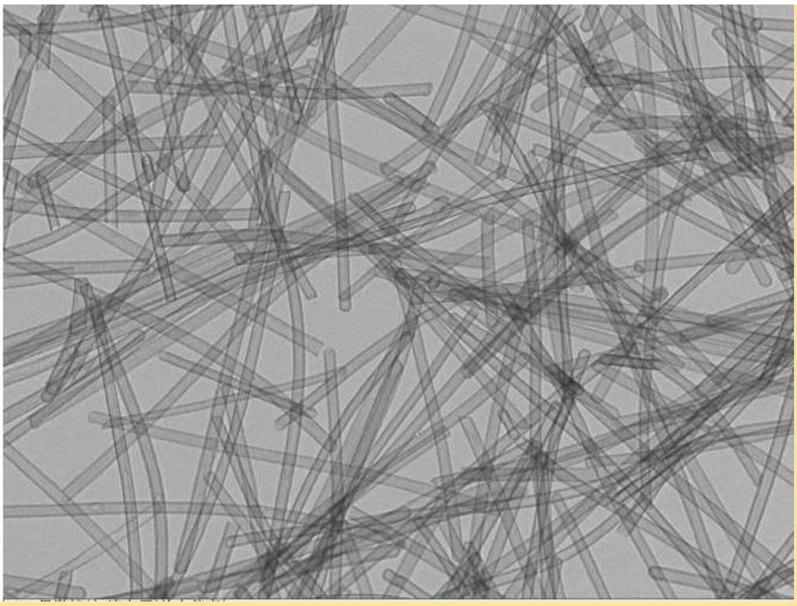 Figure 1. Electron microscopy of the hollow bioinspired carbon tube aerogel. Source: https://phys.org/news/2019-06-polar-bear-inspired-material-insulation.html **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** To translate lessons from nature into effective design strategies, focus on maximising thermal efficiency by developing materials that trap heat and reduce energy use, ensuring comfortable living spaces. Optimise light reflection with surfaces that minimise heat absorption, enhancing energy efficiency and reducing the need for cooling. Incorporate multi-functional textures that provide benefits like improved insulation and aesthetic appeal, and design materials with adaptive properties that change characteristics based on environmental conditions to maintain comfort in varying climates. Implementing these strategies in residential, commercial, and public buildings can significantly enhance energy efficiency and the overall quality of life for occupants.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** To create effective natural-inspired design strategies, key concepts such as maximising thermal efficiency through innovative materials that trap heat and reduce energy consumption, as well as optimising light reflection with surfaces that minimise heat absorption, must be prioritised. Furthermore, experimenting with multipurpose textures can improve both functionality and appearance, and materials with adaptive qualities enable real-time adaptation to changing environmental conditions, guaranteeing comfort in a range of climates. Researching new composite materials, developing modular insulation panels, and designing building facades with reflective coatings are some ideas for future research. These tactics will be strengthened by incorporating smart technology, making use of recycled and sustainable materials, and placing a strong emphasis on user-centred design.

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	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution. **Features** • Thermal efficiency. • Light reflection. • Multi-functional textures. • Adaptive properties. **Context** • Implementation in residential, commercial, and public buildings for enhanced energy efficiency and comfort. • Use of materials in furniture and wall coverings to enhance user comfort and aesthetics. • Focus on environmentally friendly materials and processes in construction and design. **Constraints:** • **Material availability:** Limitations regarding the sourcing of innovative materials and their costs. • **Regulatory standards:** Compliance with building codes and energy efficiency regulations. • **User preferences:** Consideration of varying comfort needs and aesthetic choices among different user groups. • **Climate variability:** Adaptability to different environmental conditions and regions.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The most effective way to evaluate whether the proposed design concepts meet the design challenges and constraints is to assess them against the following parameters: thermal efficiency, light reflection, adaptability to environmental changes, and aesthetic appeal. The designs should enhance energy efficiency and user comfort while promoting sustainability and minimising environmental impact. All materials utilised must be non-toxic, environmentally friendly, and sustainable, meeting performance standards for various applications, including residential and commercial settings. In terms of compatibility with Earth's systems, using traditional materials may raise concerns regarding pollution and waste. Ideally, the design concepts should incorporate renewable or recyclable materials to reduce their ecological footprint and support sustainable resource management.

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	Regarding the feasibility of the technical and business model, the success of the modular insulation panels and reflective building facades depends on their performance and material innovation. There is a growing market demand for energy-efficient building solutions, but consumers increasingly prioritise sustainability. Consequently, a successful business model must highlight eco-friendly practices while balancing performance and cost-effectiveness across the various concepts. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** After identifying modular insulation panels and reflective building facades as our design concepts, we focused on their potential to enhance thermal efficiency and energy conservation. Key strategies revolved around using advanced, eco-friendly materials and innovative coatings to improve performance and durability. By integrating smart adaptive materials with cost-effective sensors for real-time environmental monitoring and developing multi-functional wall coverings from sustainable textiles, we successfully translated these insights into a cohesive design approach that prioritises usability, comfort, and sustainability while meeting modern energy efficiency standards.

Additional resources:

https://phys.org/news/2019-06-polar-bear-inspired-material-insulation.html

https://projectscot.com/2020/07/engineer-creates-insulation-inspired-by-polar-bear-fur/

https://www.sciencedirect.com/science/article/abs/pii/S2213138822002570

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: The Beetles That Drink Water From Air

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do beetles in arid environments extract water from the air to survive in extreme conditions? **2.b Ask yourself what your design wants to do.** **Key functions of the design:** • **Water collection**: Efficiently capture moisture from fog or humid air. • **Water transportation**: Channel collected water for storage or use. • **Energy efficiency**: Use passive methods to harvest water without relying on external energy sources. **Biological contexts** • **Moisture collection**: Hydrophilic bumps condense water vapour into droplets. • **Water transportation**: Hydrophobic grooves direct water toward a central collection point. • **Energy efficiency**: Passive condensation driven by natural airflow and humidity. **2.c Flip the question. Consider opposite functions.** How do organisms in nature passively capture, transport, and store water in arid environments?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Passive water harvesting in arid conditions **Natural models** • **Namib desert beetle:** Uses a combination of hydrophilic bumps and hydrophobic grooves to collect water. • **Cacti:** Use ridges and spines to capture and channel dew and fog to their roots.

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	• **Lichen and moss:** Absorb moisture directly from the air using capillary action.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions:**
	  ○ MIT's Fog Harvesting Lab: Focuses on water collection technologies inspired by natural processes.
	  ○ University of Oxford's Zoology Department: Studies biomimetic adaptations of desert organisms.
	• **Professional communities**
	  ○ Biomimicry Institute: Connects innovators and researchers studying natural water-harvesting solutions.
	  ○ International Water Association: Offers research on sustainable water management practices.
	Connect to communities
	• **Online forums and groups**
	  ○ ResearchGate: Engage with material scientists and biomimicry experts studying water-harvesting surfaces.
	  ○ LinkedIn Groups: Join discussions on sustainable technologies and biomimetic design.
	• **Local organisations and events**
	  ○ **Water management conferences:** Learn about advancements in fog collection and water efficiency.
	  ○ **Biomimicry workshops:** Network with professionals working on bioinspired water solutions.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords** **1. Water collection** • **Keywords:** Condensation, moisture capture, fog harvesting. • **Natural model:** Namib desert beetle. • **Function:** Attract and condense water vapour into droplets. **2. Water transportation** • **Keywords:** Channelling, directional flow, hydrophobic Grooves • **Natural model:** Beetle shell grooves, cactus ridges • Function: Funnel collected water to a central storage or usage point.

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	3. Energy efficiency • **Keywords:** Passive Process, Sustainability, No External Energy • **Natural model:** Passive Water Collection by Beetles • **Function:** Harvest water without relying on energy-intensive methods. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Water collection** • Design strategy: Use materials with a combination of water-attracting and water-repelling properties to condense and collect water from air. **Water transportation** • Design strategy: Incorporate grooves or channels to efficiently guide collected water to a storage area. **Energy efficiency** • Design Strategy: Design systems that passively harvest water using environmental conditions like wind and humidity.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Water collection** • Develop fog nets with hydrophilic and hydrophobic materials for improved water capture. • Create building facades that mimic beetle shells to collect water in urban environments. **2. Water transportation** • Integrate channels into surfaces to direct collected water to reservoirs. • Design self-cleaning grooves to maintain efficiency over time. **3. Energy efficiency** • Use passive cooling techniques to enhance condensation in hot, arid climates. • Design systems that work without relying on electricity, ideal for remote locations. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **1. Features** • **Water collection**

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	○ Superhydrophilic bumps to condense water. ○ Hydrophobic channels for efficient water droplet formation. • **Water transportation** ○ Grooves that guide water toward reservoirs. ○ Self-cleaning coatings to maintain functionality. • **Energy efficiency** ○ Passive condensation processes. ○ Integration of natural airflow to enhance water capture. **2. Context** • **Target users** ○ Communities in arid regions need sustainable water solutions. ○ Industries looking for eco-friendly water harvesting systems. • **Applications** ○ Water collection systems for homes and buildings. ○ Portable fog-catching devices for agriculture or personal use. **3. Constraints** • **Technical limitations** ○ Balancing durability and efficiency in water-harvesting materials. ○ Adapting designs for varying humidity levels. • **Cost considerations** ○ Ensuring affordability for low-income communities. ○ Scaling up production without environmental harm. • **Environmental impact** ○ Using sustainable and biodegradable materials. ○ Minimising ecological disruption during deployment.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The water-harvesting solution inspired by beetles aligns well with the design challenge by addressing sustainability, passive functionality, and efficiency. Key technical challenges include ensuring durability and adapting designs to varying environmental conditions. The business model can leverage partnerships with NGOs and governments focused on water access in arid regions. 6.b Revise and revisit previous steps as necessary to generate a viable solution. **Refinements include**

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	• Testing different material combinations to optimise water collection and transportation. • Developing modular designs for easy installation and scalability. • Incorporating feedback from target communities to ensure usability and relevance. By refining these aspects, the beetle-inspired water-harvesting system can provide a sustainable and accessible solution for water-scarce environments, improving lives and conserving resources globally.

Additional resources:

https://biomimicry.org/

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Solution: name of the solution

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.
How do bones repair themselves when damaged with minimal external intervention?
2.b Ask yourself what your design wants to do.
Key Functions of the design
• Self-healing: Detect and repair cracks in concrete structures without requiring human intervention.
• Structural integrity: Restore strength and prevent further damage or collapse.
• Sustainability: Reduce the need for frequent maintenance and material replacement.
Biological contexts
• Damage detection: Mimic the chemical signalling used by bone cells to identify cracks.
• Scaffold formation: Use embedded agents that form a structure to support repairs.
• Mineral deposition: Incorporate materials that replicate bone's mineralisation process.
2.c Flip the question. Consider opposite functions.
How do organisms in nature self-repair while maintaining their functionality and efficiency?</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution.
Function
Passive self-repair to restore structural integrity.
Natural models
• Bones: Repair fractures using a three-step process of signalling, scaffold formation, and mineral deposition.</td></tr>
</table>

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	• **Tree bark:** Heals itself by sealing wounds with new layers, preventing further damage.
	• **Seashells:** Rebuild damaged areas by layering calcium carbonate.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions**
	  ○ Harvard Wyss Institute: Researches biomimetic materials inspired by natural processes.
	  ○ Delft University of Technology: Specialises in self-healing concrete and sustainable construction materials.
	• **Professional communities**
	  ○ American Concrete Institute (ACI): Discusses advances in concrete technology.
	  ○ Biomimicry Institute: Connects experts working on self-healing materials inspired by nature.
	Connect to communities
	• **Online forums and groups**
	  ○ **ResearchGate:** Engage with materials scientists and biomimicry researchers.
	  ○ **LinkedIn groups:** Join discussions on innovative materials and sustainability.
	• **Local organisations and events**
	  ○ **Construction technology conferences:** Explore the latest developments in concrete solutions.
	  ○ **Biomimicry workshops:** Network with experts in bioinspired design.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords:** **1. Self-healing** • **Keywords:** Repair, Passive, Detection. • **Natural model:** Bones. • **Function:** Automatically detect and repair cracks to restore structural strength. **2. Scaffold formation** • **Keywords:** Support, framework, reinforcement.

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	• **Natural model:** Fibrous framework in bones. • **Function:** Create a temporary structure for repairing the damage. **3. Mineral deposition** • **Keywords:** Strength, durability, restoration. • **Natural Model:** Calcium and phosphate deposition in bones. • **Function:** Fill cracks with durable material to restore functionality. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Self-healing** • **Design strategy:** Embed materials in concrete that can detect damage and initiate the repair process automatically. **Scaffold formation** • **Design strategy:** Include agents that create a temporary structure within cracks, allowing the repair material to solidify. **Mineral deposition** • **Design strategy:** Utilise minerals or bacteria that deposit durable compounds to effectively fill and seal cracks.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Self-healing mechanism** • Embed capsules filled with repair agents (e.g., healing bacteria or chemicals) in the concrete mix. • Use smart sensors to detect damage and trigger the release of repair agents. **2. Scaffold formation** • Incorporate biodegradable polymers that expand to form a framework inside cracks. • Use chemical agents that solidify when exposed to moisture. **3. Mineral deposition** • Utilise calcium carbonate-producing bacteria to fill cracks. • Include chemical compounds that mimic the mineralization process of bones.

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	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Self-healing mechanism**
	  ○ Repair capsules or embedded bacteria that activate upon cracking.
	• **Scaffold formation**
	  ○ Fibrous agents that create a temporary structure.
	• **Mineral deposition**
	  ○ Use of durable mineral compounds like calcium carbonate.
	2. Context
	• **Target users**
	  ○ Construction companies seeking durable, low-maintenance materials.
	  ○ Municipalities aiming to extend the lifespan of public infrastructure.
	• **Applications**
	  ○ Bridges, roads, and buildings are prone to wear and tear.
	  ○ Remote or hazardous areas where repairs are challenging.
	3. Constraints
	• **Technical limitations:**
	  ○ Ensuring the uniform distribution of repair agents in concrete.
	  ○ Achieving long-term durability and reusability of the self-healing mechanism.
	• **Cost considerations**
	  ○ Balancing affordability with advanced functionality.
	• **Environmental impact**
	  ○ Using sustainable and biodegradable materials.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The self-healing concrete inspired by bones aligns well with the challenge by addressing sustainability, durability, and reduced maintenance. The main technical challenge lies in ensuring long-term functionality and cost-effectiveness. The business model could focus on partnerships with construction companies and governments, emphasizing the cost savings and environmental benefits of self-healing materials.

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	6.b Revise and revisit previous steps as necessary to generate a viable solution. **Refinements include** • Testing and optimising the distribution of self-healing agents to maximise effectiveness. • Exploring eco-friendly and cost-effective materials for capsules and scaffolds. • Prototyping and field testing in diverse environments to ensure reliability. By refining these aspects, the self-healing concrete solution can revolutionize construction, providing sustainable, durable, and cost-effective materials for modern infrastructure.

Additional resources:

https://biomimicry.org/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: name of the solution

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do mussels attach securely to surfaces in dynamic and wet environments, maintaining functionality despite external stresses? **2.b Ask yourself what your design wants to do.** **Key Functions of the Design:** • **Strong Adhesion**: Create filters with enhanced adhesive properties to attach securely to surfaces in wet or harsh environments. • **Durability**: Ensure filters maintain their functionality over long periods and under varying environmental conditions. • **Sustainability**: Use eco-friendly materials and processes to minimize environmental impact. **Biological contexts:** • **Adhesion mechanism**: Mimic the protein-based glue that mussels use to stick to wet, slippery surfaces. • **Resilience**: Replicate mussels' ability to withstand waves, currents, and temperature fluctuations. • **Selective permeability**: Leverage the controlled permeability seen in mussel byssal threads for efficient filtration. **2.c Flip the question. Consider opposite functions.** How do organisms in nature adhere to and maintain stability on wet and dynamic surfaces while performing essential functions?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Strong adhesion and durability in wet environments. **Natural models** • **Mussels**: Use protein-based adhesives that form robust bonds in wet, saline environments.

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	• **Barnacles**: Create calcified glue-like substances for permanent attachment to surfaces.
	• **Lotus Leaves**: While not adhesive, they exhibit water-repellent properties that can inspire anti-clogging features for filters.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions**
	  ○ MIT Bioinspired Materials Lab: Focuses on bioadhesives and sustainable material development.
	  ○ University of California, Santa Barbara (UCSB): Known for studies on mussel adhesion and protein biochemistry.
	• **Professional communities**
	  ○ American Society of Mechanical Engineers (ASME): Hosts discussions on biomimicry in materials engineering.
	  ○ Adhesion Society: Focuses on the science of adhesives and surface interactions.
	Connect to communities
	• **Online forums and groups**
	  ○ **ResearchGate:** Engage with biomaterials scientists and environmental engineers.
	  ○ **Biomimicry Institute's AskNature Platform:** Collaborate with biomimicry experts.
	• **Local Organisations and Events**
	  ○ **Biomimicry conferences:** Explore innovative applications of bioinspired materials.
	  ○ **Environmental sustainability workshops:** Network with stakeholders interested in eco-friendly solutions.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords** **1. Adhesion** • **Keywords:** Wet, robust, protein-based. • **Natural Model:** Mussels. • **Function:** Achieve strong adhesion in wet conditions using bioinspired glues. **2. Durability**

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	• **Keywords:** Resilience, stability, longevity. • **Natural model:** Mussel byssal threads. • **Function:** Maintain structural integrity over time, resisting environmental stressors. **3. Selective permeability** • **Keywords:** Filtration, controlled, efficient. • **Natural model:** Mussels' filter-feeding mechanism. • **Function:** Filter particles selectively while ensuring water flow. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Adhesion** • **Design strategy:** Use mussel-inspired protein glues that bond effectively in wet environments. **Durability:** • **Design strategy:** Incorporate flexible, resilient materials that withstand dynamic forces and environmental fluctuations. **Selective permeability** • **Design strategy:** Design filters with pore structures that mimic natural filtration mechanisms.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Adhesion mechanism** • Develop bioadhesive coatings for filters to ensure secure attachment in dynamic or wet conditions. • Use dopamine-mimicking polymers to create strong, water-resistant bonds. **2. Durable materials** • Create filters using hybrid materials that combine toughness with elasticity. • Design coatings resistant to corrosion, temperature fluctuations, and biological fouling. **3. Selective filtration** • Employ nanostructured membranes inspired by mussel filtration for enhanced performance.

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	• Include self-cleaning mechanisms to reduce maintenance requirements.
	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Adhesion**
	  ○ Mussel-inspired bioadhesive coatings.
	  ○ Water-activated bonding agents.
	• **Durability:** Resilient materials resistant to environmental stress.
	  ○ Resilient materials resistant to environmental stress.
	  ○ Hybrid designs for flexibility and strength.
	• **Filtration Efficiency:** Selective permeability for specific particle sizes.
	  ○ Selective permeability for specific particle sizes.
	  ○ Self-cleaning or anti-clogging features.
	2. Context
	• **Target users**
	  ○ Industrial facilities need robust filtration systems for wastewater.
	  ○ Municipal water treatment plants in humid or aquatic environments.
	• **Applications**
	  ○ Water purification in urban and industrial settings.
	  ○ Aquaculture systems requiring debris filtration.
	3. Constraints
	• **Technical limitations**
	  ○ Developing cost-effective bioadhesives at scale.
	  ○ Ensuring long-term durability of bioinspired materials.
	• **Cost considerations**
	  ○ Balancing material affordability with advanced functionality.
	  ○ Reducing costs for large-scale filtration applications.
	• **Environmental impact**
	  ○ Using biodegradable or recyclable materials.
	  ○ Minimising ecological disruption during production or disposal.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with**

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	Earth's systems. Assess the feasibility of both the technical and business models. The mussel-inspired adhesive filters align well with the challenge by combining strong adhesion, durability, and efficient filtration. The concept is environmentally friendly and innovative, but requires further optimisation to balance performance with cost and scalability. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Refinements Include** ● **Enhance adhesion:** Refine the adhesive formula to ensure strong and reversible bonding. ● **Optimise durability:** Test hybrid materials for flexibility and resilience in diverse conditions. ● **Improve efficiency:** Incorporate nanostructures and self-cleaning properties to boost filtration performance. By refining these aspects, mussel-inspired adhesive filters can become a revolutionary solution for water treatment and industrial filtration, combining natural efficiency with sustainable innovation.

Additional resources:

https://biomimicry.org/

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: name of the solution

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How does nacre (mother of pearl) in abalone shells create a strong yet lightweight and flexible material? **2.b Ask yourself what your design wants to do.** **Key Functions of the design:** • **Strength and durability**: Develop materials that can withstand high stress without breaking. • **Lightweight structure**: Create materials that are strong yet not overly dense. • **Flexibility**: Introduce a degree of malleability to prevent catastrophic failure. **Biological contexts** • **Layered construction**: Mimic the alternating hard-soft layers of nacre. • **Stress dissipation**: Emulate the energy-absorbing properties of nacre's organic matrix. • **Adaptability**: Use hierarchical design to achieve multifunctional material properties. **2.c Flip the question. Consider opposite functions.** How do organisms in nature create lightweight, strong, and flexible structures that withstand high stress?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Durable and lightweight material construction. **Natural models** • **Nacre in abalone shells:** Layered construction of calcium carbonate and organic polymers for strength and flexibility. • **Spider silk**: Strong, lightweight, and flexible fibres that absorb stress effectively.

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	• **Human bones**: Hierarchical structure combining hard mineral layers and soft collagen for strength and resilience.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions:**
	  ○ Harvard Wyss Institute: Research on biomimetic materials.
	  ○ MIT Material Science Lab: Studies on advanced composites inspired by natural materials.
	• **Professional communities**
	  ○ Materials Research Society (MRS): Focused on advancements in material science.
	  ○ Biomimicry Institute: Promotes nature-inspired solutions.
	Connect to communities
	• **Online forums and groups**
	  ○ ResearchGate: Engage with researchers studying advanced composite materials.
	  ○ LinkedIn Groups: Network with professionals in sustainable materials.
	• **Local organisations and events**
	  ○ **Materials science conferences:** Attend presentations on bioinspired materials.
	  ○ **Workshops by biomimicry organisations:** Learn from nature-inspired material innovators.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords:** **1. Strength and durability** • **Keywords:** Toughness, Resilience, Stress Resistance • **Natural model:** Nacre • **Function:** Prevent crack propagation and ensure durability under stress. **2. Lightweight structure** • **Keywords:** Efficiency, low density, structural optimisation. • **Natural model:** Nacre, spider silk. • **Function:** Combine strength and lightness for versatile applications. **3. Flexibility**

	• **Keywords:** Adaptability, malleability, crack prevention. • **Natural Model:** Nacre, bones. • **Function:** Dissipate stress through layered, flexible structures. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Strength and durability** • **Design strategy:** Develop materials with alternating hard and soft layers to absorb stress and prevent cracks from spreading. **Lightweight structure** • **Design strategy:** Use low-density materials arranged in optimised patterns for strength without added weight. **Flexibility** • **Design strategy:** Incorporate flexible components or microstructures to enhance material adaptability and resistance to catastrophic failure.

Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs."
	https://toolbox.biomimicry.org/methods/emulate/
	5.a List your key information and explore as many ideas as possible.
	1. Strength and durability
	• Composite materials with hard-soft layering inspired by nacre.
	• Self-healing properties to repair minor cracks automatically.
	2. Lightweight structure
	• Use 3D printing to replicate nacre's hierarchical structure.
	• Incorporate hollow or honeycomb patterns for added lightness.
	3. Flexibility
	• Design flexible interfaces between layers to dissipate stress.
	• Use bioinspired polymers to introduce malleability.
	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Strength and durability**
	  ○ Layered composite materials.
	  ○ Crack-resistant structures with energy dissipation.
	• **Lightweight structure**

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	○ 3D-printed, low-density materials. ○ Optimised structural patterns, such as honeycombs. • **Flexibility** ○ Flexible, bioinspired polymers. ○ Adaptive interfaces between layers. **2. Context** • **Target users** ○ Aerospace engineers seek strong, lightweight materials. ○ Construction companies need durable composites. • **Applications** ○ Protective coatings for vehicles and machinery. ○ Building materials in high-stress environments. **3. Constraints** • **Technical limitations** ○ Achieving consistent layering and bonding at scale. ○ Balancing flexibility with long-term durability. • **Cost considerations** ○ Developing affordable, scalable manufacturing techniques. • **Environmental impact** ○ Using eco-friendly and recyclable materials.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The nacre-inspired material design aligns with the goals of strength, lightness, and flexibility, addressing the needs of industries such as construction and aerospace. Technical challenges include achieving uniform layer deposition and scalability. The business model can target industries prioritizing high-performance, sustainable materials, with potential applications in protective gear, vehicles, and infrastructure. 6.b Revise and revisit previous steps as necessary to generate a viable solution. **Refinements include** • Developing advanced manufacturing techniques, such as nanotechnology or additive manufacturing, to replicate nacre's layered structure. • Testing materials under diverse stress conditions to ensure durability and adaptability.

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	• Exploring biodegradable or recyclable components to align with environmental goals. By addressing these refinements, the nacre-inspired material can become a versatile solution, providing strong, lightweight, and flexible alternatives to conventional materials while reducing environmental impact.

Additional resources:

https://biomimicry.org/

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Solution: name of the solution

BIOMIMICRY DESIGN	Description
Step 2 – Biologize	**2.a Ask yourself how nature can solve this.** How does shark skin reduce drag in water, thereby improving speed and efficiency? **2.b Ask yourself what your design wants to do.** **Key functions of the design** • **Drag reduction**: Enhance fluid dynamics to reduce energy consumption. • **Anti-biofouling**: Prevent the accumulation of microorganisms and debris on surfaces. • **Efficiency**: Improve speed or fuel efficiency in fluid environments like water or air. **Biological contexts** • **Streamlining**: Mimic the dermal denticles' ability to reduce turbulence. • **Fouling resistance**: Prevent adherence of biological organisms to surfaces. • **Energy savings**: Reduce the energy required for motion in fluids. **2.c Flip the question. Consider opposite functions.** How do organisms in nature move efficiently through fluid environments while avoiding drag and fouling?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Drag reduction and anti-fouling in fluid environments. **Natural models** • **Shark skin**: Dermal denticles streamline flow and resist fouling. • **Dolphin skin**: Smooth and flexible, it reduces turbulence and drag. • **Lotus leaf**: Hydrophobic surface resists adhesion, reducing fouling.

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	3.b Identify experts & connect to communities of biologists and naturalists. **Experts** ● **Universities and research institutions** ○ University of California, San Diego (UCSD): Research on bioinspired materials and fluid dynamics. ○ Fraunhofer Institute: Studies biomimetic surfaces for drag reduction. ● **Professional communities** ○ Biomimicry Institute: A hub for nature-inspired solutions and materials research. ○ American Institute of Aeronautics and Astronautics (AIAA): Focuses on fluid dynamics and aerospace innovations. **Connect to communities** ● **Online forums and groups** ○ ResearchGate: Network with experts in hydrodynamics and biomimetic materials. ○ LinkedIn Groups: Join discussions on marine technology and bioinspired designs. ● Local organisations and events ○ **Maritime conferences:** Learn about marine engineering and innovative ship designs. ○ **Workshops on biomimicry:** Explore applications of shark skin-inspired technologies.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords** **1. Drag reduction** ● **Keywords:** Streamlining, turbulence control, hydrodynamics. ● **Natural model:** Shark skin (dermal denticles). ● **Function:** Reduce drag by optimising fluid flow. **2. Anti-biofouling** ● **Keywords:** Adhesion resistance, cleanliness, longevity. ● **Natural model:** Shark skin, lotus leaf. ● **Function:** Prevent microorganism buildup to maintain efficiency. **3. Energy efficiency**

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	• **Keywords:** Optimisation, conservation, sustainability. • **Natural model:** Shark skin. • **Function:** Save energy during movement by reducing resistance. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Drag reduction** • **Design strategy:** Develop surfaces with micro-structured patterns that streamline fluid flow, reducing turbulence and resistance. **Anti-biofouling** • **Design strategy:** Incorporate non-adhesive textures that resist biological buildup without harmful chemicals. **Energy efficiency** • **Design strategy:** Optimise fluid-facing surfaces to reduce energy consumption in vehicles, ships, or machinery operating in water or air.

Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs."
	https://toolbox.biomimicry.org/methods/emulate/
	5.a List your key information and explore as many ideas as possible.
	1. Drag reduction
	• Develop a coating for ships and submarines with micro-textured surfaces.
	• Design aircraft surfaces that optimise airflow using similar textures.
	2. Anti-biofouling
	• Create non-toxic coatings for marine vessels to resist organism buildup.
	• Apply the concept to medical devices to prevent bacterial adhesion.
	3. Energy efficiency
	• Use shark skin-inspired designs for wind turbine blades.
	• Apply in piping systems to minimise resistance and improve flow efficiency.
	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Drag reduction**
	  ○ Micro-patterned coatings for water or air vehicles.
	  ○ Enhanced hydrodynamic designs for sportswear or swimwear.

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	• **Anti-biofouling**
	  ◦ Self-cleaning surfaces for marine vessels and underwater equipment.
	  ◦ Bacteria-resistant coatings for medical applications.
	• **Energy efficiency**
	  ◦ Shark-inspired designs for propellers, turbines, or fans.
	  ◦ Flow-optimised designs for fluid transport systems.
	2. Context
	• **Target users**
	  ◦ Shipbuilding and maritime industries.
	  ◦ Aerospace and automotive sectors for fuel efficiency.
	• **Applications**
	  ◦ Marine vessels, aircraft, medical devices, and piping systems.
	3. Constraints
	• **Technical limitations**
	  ◦ Precision manufacturing is required for micro-patterned surfaces.
	  ◦ Durability of coatings in extreme conditions.
	• **Cost considerations**
	  ◦ High initial costs for R&D and manufacturing.
	• **Environmental impact**
	  ◦ Ensure materials are non-toxic and environmentally sustainable.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** Shark skin-inspired designs effectively address drag reduction, anti-biofouling, and energy efficiency challenges. The technology is highly compatible with industries seeking sustainable solutions, such as shipping and renewable energy. Challenges include scaling up production and ensuring durability under diverse conditions. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Refinements include** • Experimenting with new materials and manufacturing techniques for scalable, cost-effective micro-structured surfaces.

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	• Conducting extensive testing in real-world environments, such as ships at sea or aircraft in flight. • Exploring secondary applications, such as self-cleaning surfaces for solar panels or heat exchangers. By addressing these refinements, shark skin-inspired technology can offer a transformative solution to improve fluid dynamics, reduce energy consumption, and enhance sustainability across multiple industries.

Additional resources:

https://biomimicry.org/

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BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do spiders create lightweight yet incredibly strong silk fibers for survival? **2.b Ask yourself what your design wants to do.** **Key Functions of the Design:** • **Strength**: Develop lightweight materials with high tensile strength for structural and industrial use. • **Elasticity**: Ensure flexibility and durability under stress to prevent breakage. • **Material efficiency**: Mimic spider silk's resource-efficient production process for sustainability. **Biological contexts** • **Strength and elasticity**: Emulate the silk's dual-phase molecular structure. • **Energy efficiency**: Produce fibres at room temperature using environmentally friendly methods. • **Self-assembly**: Replicate the self-organising nature of spider silk proteins during spinning. **2.c Flip the question. Consider opposite functions.** How do organisms create strong and flexible materials while minimising energy and resource use?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Lightweight, strong, and flexible materials. **Natural models** • **Spider silk**: Combines strength and elasticity in a lightweight structure. • **Silkworm silk**: Produced efficiently by caterpillars for protective cocoons.

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	• **Tendon and ligaments**: Human connective tissues that balance tensile strength and elasticity.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions**
	  ○ University of Cambridge's Department of Materials Science: Focuses on bioinspired materials.
	  ○ Wyss Institute for Biologically Inspired Engineering: Explores nature-inspired fibres.
	• **Professional communities**
	  ○ American Materials Research Society (MRS): Offers insights into bio-based fibres.
	  ○ Biomimicry Institute: Promotes research on nature-inspired designs.
	Connect to communities
	• **Online forums and groups**
	  ○ ResearchGate: Collaborate with experts in biopolymers and sustainable materials.
	  ○ LinkedIn Groups: Discussions on bioinspired materials and industrial applications.
	• **Local organisations and events**
	  ○ **Materials science seminars:** Learn about advancements in high-strength fibres.
	  ○ **Biomimicry conferences:** Network with experts in bio-inspired technologies.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords:** **1. Strength** • **Keywords:** Tensile, durable, lightweight. • **Natural model:** Spider silk. • **Function:** Achieve exceptional strength-to-weight ratio for structural use. **2. Elasticity** • **Keywords:** Flexibility, resilience, adaptability. • **Natural model:** Spider silk. • **Function:** Maintain performance under varying stresses without breaking.

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	3. Material efficiency • **Keywords:** Sustainability, energy efficiency, minimal waste. • **Natural model:** Spider silk production. • **Function:** Create fibres using low-energy, resource-efficient processes. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Strength** • **Design strategy:** Develop materials with molecular structures that combine toughness and lightweight properties, similar to spider silk. **Elasticity** • **Design strategy:** Integrate flexibility into high-strength materials to improve resilience and adaptability under stress. **Material efficiency** • **Design strategy:** Produce fibres using sustainable processes that mimic the low-energy, ambient-condition manufacturing of spider silk.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Strength** • Use bioinspired polymer fibres for construction, aerospace, and protective gear. • Create lightweight ropes and cables with enhanced load-bearing capacity. **2. Elasticity** • Design medical sutures and implants that mimic the flexibility and strength of spider silk. • Develop textiles that stretch without tearing, improving wearability and durability. **3. Material efficiency** • Explore synthetic spider silk production using genetically engineered microorganisms. • Develop scalable manufacturing methods for eco-friendly fibre production.

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	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Strength**
	  ○ High-strength polymer-based ropes, cables, and construction materials.
	  ○ Bulletproof vests and impact-resistant gear.
	• **Elasticity**
	  ○ Flexible textiles for sportswear and medical applications.
	  ○ Stretchable materials for robotics and wearable tech.
	• **Material efficiency**
	  ○ Scalable microbial silk production.
	  ○ Eco-friendly processes for sustainable manufacturing.
	2. Context
	• **Target users**
	  ○ Construction and aerospace industries.
	  ○ Medical professionals for sutures and implants.
	• **Applications**
	  ○ Protective gear, textiles, and lightweight structural components.
	3. Constraints
	• **Technical limitations**
	  ○ Challenges in replicating the exact molecular structure of spider silk.
	  ○ Scaling synthetic production to industrial levels.
	• **Cost considerations**
	  ○ High initial R&D costs for bioinspired fibre production.
	• **Environmental impact**
	  ○ Ensuring that materials and processes are sustainable and biodegradable.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** Spider silk-inspired materials meet key challenges such as balancing strength, elasticity, and sustainability. The design is suitable for diverse industries, including construction, aerospace, and healthcare. Major challenges include scaling production and ensuring cost-effectiveness.

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	6.b Revise and revisit previous steps as necessary to generate a viable solution. **Refinements include** • Improving synthetic production methods using genetically engineered bacteria or yeast to mimic spider silk proteins. • Collaborating with material science experts to optimise the strength and flexibility of bioinspired fibres. • Testing prototypes in varied applications, such as ropes, textiles, and medical sutures, to validate performance and scalability. By addressing these refinements, spider silk-inspired fibres can revolutionise industries with lightweight, durable, and eco-friendly materials, ensuring sustainability and innovation in high-strength applications.

Additional resources:

https://biomimicry.org/

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<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.
How does the lotus plant maintain clean and water-repellent surfaces despite living in muddy and aquatic environments?
2.b Ask yourself what your design wants to do.
Key functions of the design
• Self-cleaning: Enable surfaces to repel dirt and water.
• Water resistance: Prevent water absorption to protect the material's integrity.
• Sustainability: Use eco-friendly methods and materials to replicate the lotus effect.
Biological contexts
• Micro-texture design: Mimic the microscopic roughness and nanostructures of lotus leaves that repel water.
• Hydrophobic coating: Replicate the waxy coating that enhances water repellence.
• Self-cleaning mechanism: Utilise the rolling motion of water droplets to carry away dirt and contaminants.
2.c Flip the question. Consider opposite functions.
How do organisms in nature maintain clean and water-repellent surfaces in challenging environments?</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution.
Function
Passive water repellence and self-cleaning in natural environments.
Natural models
• Lotus leaves: Micro- and nanostructures create superhydrophobic surfaces that repel water and dirt.
• Butterfly wings: Hydrophobic scales allow them to stay dry and clean during flight in humid conditions.</td></tr>
</table>

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	• **Water striders:** Legs coated with nanostructures enable them to repel water and float on its surface.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions**
	  ○ **MIT:** Researches superhydrophobic and self-cleaning materials inspired by nature.
	  ○ **Max Planck Institute for Polymer Research:** Focuses on biomimetic surfaces and nanotechnology.
	• **Professional communities**
	  ○ **Biomimicry Institute:** Facilitates connections to experts working on nature-inspired designs.
	  ○ **Society of Coatings Technology**: Discusses advancements in hydrophobic coatings.
	Connect to communities
	• **Online forums and groups**
	  ○ **ResearchGate:** Engage with material scientists and biomimicry researchers.
	  ○ **LinkedIn groups:** Participate in discussions on advanced coatings and sustainability.
	• **Local organisations and events**
	  ○ **Materials science conferences:** Network with innovators in nanotechnology and surface design.
	  ○ **Biomimicry workshops:** Collaborate with experts exploring the lotus effect and related applications.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Core functions and keywords** **1. Micro-texture design** • **Keywords:** Nano-structures, hydrophobic, roughness. • **Natural model:** Lotus leaf. • **Function:** Use micro- and nanostructures to create superhydrophobic surfaces. **2. Hydrophobic coating** • **Keywords:** Wax layer, water repellence, durability. • **Natural Model:** Waxy surface of lotus leaves.

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	• **Function:** Prevent water from adhering by applying a hydrophobic layer. **3. Self-cleaning mechanism** • **Keywords:** Water droplets, dirt removal, rolling action. • **Natural Model:** Lotus leaf surface. • **Function:** Use water droplets to pick up and carry away dirt particles. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Micro-texture design** • **Design strategy:** Create surfaces with microscopic and nanoscopic roughness to repel water and dirt. **Hydrophobic coating** • **Design strategy:** Develop thin, durable hydrophobic coatings inspired by the lotus leaf. **Self-cleaning mechanism** • **Design strategy:** Design surfaces that leverage water droplets to clean themselves.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Micro-texture design** • Develop materials with micro-scale surface patterns inspired by lotus leaves for industrial and consumer applications. • Create road pavements or outdoor tiles with micro-textures to reduce slipping hazards during rain. **2. Hydrophobic coating** • Manufacture hydrophobic coatings for glass surfaces like car windshields, building facades, and solar panels to repel water and dirt. • Apply hydrophobic coatings to industrial equipment used in marine and wet environments to prevent corrosion and rust. **3. Self-cleaning mechanism** • Create self-cleaning paint for homes and industrial facilities, reducing maintenance costs and environmental impact.

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- Develop self-cleaning food packaging to enhance hygiene and prolong freshness.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

1. Features

- **Self-cleaning**
  - Micro-textured surfaces for dirt and water repellence.
  - Hydrophobic coatings that mimic the lotus leaf.
- **Water resistance**
  - Durable materials for outdoor and marine use.
  - UV-resistant coatings to maintain performance over time.
- **Sustainability**
  - Use of biodegradable and eco-friendly materials.
  - Manufacturing methods with minimal environmental impact.

2. Context

- **Target users**
  - Architects and builders seeking self-cleaning windows and surfaces.
  - Outdoor gear manufacturers need durable, water-resistant fabrics.
- **Applications**
  - Construction (windows, facades).
  - Transportation (self-cleaning car windows, anti-corrosion coatings).
  - Renewable energy (dust-resistant solar panels).

3. Constraints

- **Technical challenges**
  - Scaling up manufacturing processes for micro- and nano-textured surfaces.
  - Ensuring long-term durability of hydrophobic coatings.
- **Cost considerations**
  - Reducing costs for bio-inspired materials and manufacturing methods.
- **Environmental impact**
  - Avoiding harmful chemicals in coatings.
  - Ensuring biodegradability and recyclability of materials.

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Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The lotus effect-inspired solution addresses challenges of cleanliness, water repellence, and sustainability effectively. It offers applications in diverse industries, but scalability and durability remain key challenges. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Refinements include** • **Enhance durability:** Develop UV-resistant and wear-resistant hydrophobic materials for extended use. • **Optimise scalability:** Improve fabrication techniques for cost-effective production of micro- and nano-textures. • **Focus on sustainability:** Use biodegradable and non-toxic materials for coatings. By addressing these refinements, the lotus effect-inspired solution can revolutionise industries by providing innovative, sustainable, and highly functional water-repellent and self-cleaning technologies.

Additional resources:

https://biomimicry.org/

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BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How does the electric eel generate and store energy efficiently to produce high-voltage electric discharges? **2.b Ask yourself what your design wants to do.** **Key functions of the design** • **Energy storage**: Store electrical energy compactly and efficiently. • **Energy generation**: Generate high-output electrical discharges when needed. • **Sustainability**: Use eco-friendly materials and processes to reduce environmental impact. **Biological contexts** • **Energy generation**: Mimic the electric eel's ability to generate electricity through specialised cells (electrocytes). • **Scalable storage**: Replicate the stacking of electrocytes to create voltage gradients. • **Energy efficiency**: Adapt the efficient conversion of chemical to electrical energy seen in eels. **2.c Flip the question. Consider opposite functions.** How do organisms in nature generate and store electrical energy while maintaining compactness, efficiency, and functionality?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Efficient generation and storage of electrical energy in a compact form. **Natural models** • **Electric eels**: Use electrocytes arranged in series to generate significant voltage outputs. • **Electric rays**: Generate electricity through specialised electric organs for defence and predation.

	• **Mitochondria**: Cellular powerhouses that efficiently convert energy through chemical gradients.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions**
	  ○ **California Institute of Technology (Caltech):** Researches bioelectrical systems for energy applications.
	  ○ **University of Michigan:** Specialises in bioinspired energy systems, including electric eel-inspired batteries.
	• **Professional communities**
	  ○ **Electrochemical Society (ECS):** Focuses on the development of advanced energy storage solutions.
	  ○ **Biomimicry Institute:** Offers a network of experts working on bioinspired designs.
	Connect to communities
	• **Online forums and groups**
	  ○ **ResearchGate:** Engage with researchers studying bioelectricity and energy systems.
	  ○ **LinkedIn Groups:** Join discussions on bioinspired energy solutions and sustainability.
	• **Local organizations and events**
	  ○ **Energy innovation conferences:** Present opportunities to network with renewable energy experts.
	  ○ **Biomimicry workshops:** Connect with experts working on nature-inspired energy technologies.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Core functions and keywords** **1. Energy generation** • **Keywords:** Electrocytes, discharge, voltage gradient. • **Natural model:** Electric eel. • **Function:** Generate high-voltage electric discharges using stacks of specialised cells. **2. Energy storage** • **Keywords:** Compact, efficient, layered. • **Natural model:** Electrocyte stacks.

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	• **Function:** Store electrical energy using layers of cells to maximise voltage output. 3. Energy conversion • **Keywords:** Chemical to electrical, gradient, efficiency. • **Natural model:** Electric organ. • **Function:** Convert chemical energy into electrical energy with minimal energy loss. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Energy generation** • **Design strategy:** Use stacked energy cells inspired by electrocytes to generate high-voltage outputs. **Energy storage** • **Design strategy:** Mimic the layered arrangement of electrocytes to create scalable, compact energy storage. **Energy conversion** • **Design strategy:** Utilise biomimetic mechanisms to convert stored energy into electrical output efficiently.
Step 5 – Emulate	“Emulation is an exploratory process that strives to capture a “recipe” or “blueprint” in nature’s example that can be modelled in our own designs.” https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Energy generation** • Create bio-inspired electrocytes using conductive polymers or nanomaterials. • Develop layers that mimic the eel’s voltage gradient to produce high-energy outputs. **2. Energy storage** • Use flexible, lightweight materials to create compact and portable energy storage devices. • Incorporate stacked cells that replicate the eel’s electrocyte arrangement for scalability. **3. Energy conversion** • Employ ion gradients and exchange membranes to efficiently convert stored energy into electrical discharge.

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	• Use systems inspired by biological energy transfer (e.g., ATP synthesis in mitochondria).
	
	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	
	1. Features
	• **Energy generation**
	  ○ High-voltage cells inspired by electrocytes.
	  ○ Gradient-based energy conversion systems.
	• **Energy storage**
	  ○ Flexible, scalable designs for compact storage.
	  ○ Lightweight materials for portability.
	• **Sustainability**
	  ○ Biodegradable and eco-friendly materials.
	  ○ Renewable energy integration for self-charging systems.
	
	2. Context
	• **Target users**
	  ○ Consumer electronics manufacturers are looking for sustainable battery solutions.
	  ○ Renewable energy companies need efficient energy storage.
	• **Applications**
	  ○ Wearable devices and portable electronics.
	  ○ Grid-scale storage for solar and wind energy.
	
	3. Constraints
	• **Technical challenges**
	  ○ Developing materials that replicate electrocyte functionality.
	  ○ Ensuring scalability for larger energy storage applications.
	• **Cost considerations**
	  ○ Reducing costs for the mass production of bio-inspired materials.
	  ○ Balancing affordability with advanced functionality.
	• **Environmental impact**
	  ○ Minimising resource-intensive manufacturing processes.
	  ○ Ensuring end-of-life recyclability or biodegradability.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.**

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Electric eel-inspired energy storage systems offer a promising solution for sustainable, compact, and efficient energy storage. While the concept aligns with modern energy demands, challenges remain in scalability and cost-effectiveness.

6.b Revise and revisit previous steps as necessary to generate a viable solution.

Refinements include

- **Enhance energy generation:** Develop advanced materials that mimic electrocyte gradients for higher efficiency.
- **Optimise storage:** Create modular designs that allow for scalability and customisation.
- **Improve sustainability:** Focus on biodegradable and recyclable materials to reduce environmental impact.

By refining these aspects, electric eel-inspired energy storage systems can revolutionise energy solutions, offering efficient and eco-friendly options for modern and future needs.

Additional resources:

https://biomimicry.org/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: name of the solution

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do animal limbs effectively absorb impact and reduce stress during motion, ensuring durability and flexibility in challenging environments? **2.b Ask yourself what your design wants to do.** **Key functions of the design** • **Shock absorption**: Dissipate energy to reduce stress on the structure during impacts. • **Durability**: Withstand repetitive use without degradation. • **Flexibility**: Adapt to varying levels of impact while maintaining stability. **Biological contexts** • **Shock absorption**: Mimic the elastic and viscoelastic properties found in animal joints and tendons. • **Energy dissipation**: Use layered or composite structures inspired by the microarchitecture of animal limbs. • **Flexibility and stability**: Model designs on the dynamic adaptability of cartilage and muscle systems. **2.c Flip the question. Consider opposite functions.** How do organisms in nature absorb shock, dissipate energy, and maintain stability under repeated or extreme impacts?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Passive energy absorption and structural protection against repeated stress. **Natural models** • **Kangaroo tendons**: Store and release energy efficiently during hopping, minimizing strain. • **Woodpecker skull**: Absorbs high-impact forces while protecting the brain using layered bone and cartilage.

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	• **Elephant feet**: Utilise a spongy fat pad for shock absorption to support heavy loads.
	
	3.b Identify experts & connect to communities of biologists and naturalists.
	
	Experts
	
	• **Universities and research institutions**
	  ○ **Harvard University, Wyss Institute:** Focuses on bioinspired soft robotics and materials.
	  ○ **Stanford Biomechanics Laboratory:** Studies impact resistance in natural and synthetic systems.
	
	• Professional Communities:
	  ○ **Society for Experimental Mechanics:** Discusses advances in material resilience inspired by biology.
	  ○ **Biomimicry Institute:** Connects innovators with experts studying biomechanical solutions.
	
	Connect to Communities:
	
	• **Online forums and groups**
	  ○ **ResearchGate:** Collaborate with biomechanics researchers and materials scientists.
	  ○ **LinkedIn groups:** Engage with professionals in impact-resilient material design.
	
	• **Local organisations and events**
	  ○ **Materials science conferences:** Showcase advancements in shock-absorbing technologies.
	  ○ **Biomimicry workshops:** Explore bioinspired solutions for energy dissipation.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Core functions and keywords** **1. Shock absorption** • **Keywords:** Elasticity, energy dissipation, impact resistance. • **Natural model:** Kangaroo tendons. • **Function:** Store and release energy efficiently, reducing strain on the structure. **2. Layered structures** • **Keywords:** Composite layers, flexibility, adaptability. • **Natural model:** Woodpecker skull.

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	• **Function:** Use layered materials to distribute and dissipate forces effectively. **3. Fat pads and cushions** • **Keywords:** Compression, load support, resilience. • **Natural model:** Elephant feet. • **Function:** Use soft yet durable materials to cushion impacts and support heavy loads. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Shock absorption** • **Design strategy:** Incorporate viscoelastic materials that mimic the elasticity of tendons to absorb energy and reduce stress. **Layered structures:** • **Design strategy:** Use composite materials with alternating stiff and flexible layers to enhance impact resistance. **Cushioning systems:** • **Design strategy:** Develop soft, compressible pads that adapt to varying loads and recover quickly.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Shock absorption** • Utilise bioinspired elastic polymers in sports equipment to mitigate impact injuries. • Develop shock-absorbing soles for footwear to enhance comfort and durability. **2. Layered structures** • Design and manufacture helmets and protective gear utilising layered composites to dissipate forces during impacts. • Design automotive bumpers with alternating stiff and flexible layers to enhance crash resistance. **3. Cushioning systems** • Develop furniture and vehicle seats with spongy, adaptive cushions to improve ergonomics.

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	• Use compressible padding in prosthetics and medical devices to enhance comfort and functionality.
	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Shock absorption**
	  ○ Elastic materials for energy dissipation.
	  ○ Viscoelastic polymers for repetitive impacts.
	• **Layered structures**
	  ○ Composite layers for durability and flexibility.
	  ○ Alternating stiff and soft layers to enhance impact resistance.
	• **Cushioning systems**
	  ○ Compressible pads for comfort and load distribution.
	  ○ Adaptive materials for ergonomic support.
	2. Context
	• **Target users**
	  ○ Athletes and sports gear manufacturers for injury prevention equipment.
	  ○ Automotive and aerospace industries for crash-resistant materials.
	• **Applications**
	  ○ Protective gear (helmets, body armour).
	  ○ Footwear, seats, and ergonomic furniture.
	3. Constraints
	• **Technical challenges**
	  ○ Balancing elasticity and durability in synthetic materials.
	  ○ Ensuring scalability and cost-effectiveness in manufacturing.
	• **Cost considerations**
	  ○ Reducing production costs without compromising quality.
	• **Environmental impact**
	  ○ Using eco-friendly materials and processes.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The shock absorption solution inspired by animal limbs effectively addresses energy dissipation, durability, and adaptability. Applications range from sports

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	gear to industrial and medical devices. Challenges include achieving scalability and balancing cost with performance. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Refinements include** • **Enhance durability:** Use advanced polymers and composites to improve material longevity. • **Optimise scalability:** Develop efficient manufacturing techniques for layered and viscoelastic materials. • **Focus on sustainability:** Incorporate biodegradable and recyclable components. By refining these aspects, the solution inspired by animal limb shock absorption can revolutionise safety, comfort, and impact resistance across various industries.

Additional resources:

https://biomimicry.org/

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Solution: name of the solution

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do whales efficiently filter tiny food particles from large volumes of water using baleen structures? **2.b Ask yourself what your design wants to do.** **Key functions of the design** • **Filtration**: Separate desired materials (e.g., small particles) from larger volumes of fluid or other substances. • **Energy Efficiency**: Achieve filtration passively, without requiring external energy input. • **Durability**: Maintain functionality under repetitive or prolonged use. **Biological contexts** • **Sieve-like structure**: Mimic the overlapping keratin bristles in whale baleen to create a flexible yet durable filtration system. • **Selective capture**: Design for efficient retention of small particles while allowing fluids to pass freely. • **Low energy usage**: Use passive flow dynamics, leveraging natural currents or gravity for filtration. **2.c Flip the question. Consider opposite functions.** How do organisms in nature efficiently and sustainably filter small particles without complex machinery?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Function** Passive, efficient, and selective filtration. **Natural models** • **Whale baleen**: Keratin bristles create a flexible, semi-permeable barrier for filtering krill and plankton from water. • **Mangrove roots**: Trap sediments while allowing water to flow, aiding in natural filtration.

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	• **Spiderwebs**: Capture fine particles like dust and pollen with intricate, overlapping fibre patterns.
	3.b Identify experts & connect to communities of biologists and naturalists.
	Experts
	• **Universities and research institutions**
	  ○ **Woods Hole Oceanographic Institution:** Studies marine biology, including whale feeding mechanisms.
	  ○ **National Institute for Materials Science (NIMS):** Focuses on bioinspired materials, including filtration systems.
	• **Professional Communities:**
	  ○ **American Filtration Society:** Explores advances in filtration technologies inspired by nature.
	  ○ **Biomimicry Institute:** Connects innovators to resources on bioinspired design.
	Connect to communities
	• **Online forums and groups**
	  ○ **ResearchGate:** Collaborate with marine biologists and materials scientists working on filtration technologies.
	  ○ **LinkedIn groups:** Discuss sustainable filtration systems with industry professionals.
	• **Local organisations and events**
	  ○ **Ocean conservation conferences:** Learn about whale biology and bioinspired technologies.
	  ○ **Materials science workshops:** Explore applications of sieve-like structures in industrial design.

Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions and keywords** **1. Sieve-like structure** • **Keywords:** Filtration, keratin, flexibility. • **Natural model:** Whale baleen. • **Function:** Use a layered, fibrous structure to trap small particles while allowing fluids to pass through. **2. Selective capture** • **Keywords:** Particle retention, efficiency, size differentiation. • **Natural Model:** Baleen bristle arrangement.

	• **Function:** Retain particles of specific sizes while maximising the throughput of water or other fluids. **3. Energy efficiency** • **Keywords:** Passive filtration, flow dynamics, sustainability. • **Natural Model:** Baleen-driven water flow. • **Function:** Leverage natural currents or gravity to achieve filtration without active energy input. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** **Sieve-like structure** • **Design strategy:** Use flexible, overlapping fibres to create a semi-permeable barrier for filtration systems. **Selective capture** • **Design strategy:** Optimise spacing and alignment of fibres to target specific particle sizes for retention. **Energy efficiency** • **Design strategy:** Design systems to operate passively, relying on gravity, flow dynamics, or natural pressure gradients.
Step 5 – Emulate	"Emulation is an exploratory process that strives to capture a "recipe" or "blueprint" in nature's example that can be modelled in our own designs." https://toolbox.biomimicry.org/methods/emulate/ **5.a List your key information and explore as many ideas as possible.** **1. Sieve-like structure** • Develop filters for industrial use, such as wastewater treatment or food production, using flexible fibre arrangements. • Create personal water filtration devices inspired by baleen structures for outdoor or emergency use. **2. Selective capture** • Design air filters that trap fine pollutants while allowing clean air to flow efficiently. • Develop sieves for microplastic removal in water bodies, targeting particles of specific sizes. **3. Energy efficiency** • Build passive filtration systems for rural or off-grid communities, eliminating the need for electricity.

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	• Integrate filtration into drainage systems, using gravity-driven water flow for debris capture.
	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
	1. Features
	• **Filtration**
	    o Flexible fibre arrangements for particle capture.
	    o Durable, lightweight materials for extended use.
	• **Selective capture**
	    o Adjustable spacing for targeting specific particle sizes.
	    o Multi-layered systems for improved filtration efficiency.
	• **Energy efficiency**
	    o Passive flow systems require no external energy.
	    o Self-cleaning mechanisms to reduce maintenance.
	2. Context
	• **Target Users**
	    o Industries needing eco-friendly and efficient filtration systems.
	    o Outdoor enthusiasts requiring portable water filters.
	• **Applications**
	    o Industrial (wastewater treatment, food processing).
	    o Consumer (water filters, air purifiers).
	    o Environmental (microplastic removal, pollution mitigation).
	3. Constraints:
	• **Technical challenges**
	    o Balancing filtration efficiency with fluid throughput.
	    o Ensuring material durability in varying conditions.
	• **Cost considerations**
	    o Reducing costs for large-scale production.
	    o Making filters affordable for low-income communities.
	• **Environmental impact**
	    o Using sustainable, biodegradable materials.
	    o Minimising ecological disruption during manufacturing.

Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with**

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	Earth's systems. Assess the feasibility of both the technical and business models. The baleen-inspired filtration solution addresses critical challenges in particle retention, energy efficiency, and sustainability. Its applications span the industrial, consumer, and environmental fields, but challenges such as scalability and material durability remain. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Refinements include** • **Enhance durability:** Develop advanced polymers or natural fibres that mimic baleen's flexibility and resilience. • **Optimise scalability:** Improve manufacturing techniques to produce layered, sieve-like structures efficiently and affordably. • **Focus on sustainability:** Use recyclable or biodegradable materials in filter designs. By addressing these refinements, the baleen-inspired filtration system can offer innovative, eco-friendly solutions for a wide range of filtration needs across various industries and environments.

Additional resources:

https://biomimicry.org/

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Nature Noise Barriers

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do natural systems manage noise in their environments? • How do forests dampen sound through layered vegetation? • How do animals like owls use soft feathers to minimise sound during flight? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to do. • The design aims to passively absorb or deflect urban noise, inspired by nature's strategies for sound management. **2.c Flip the question. Consider opposite functions.** • Instead of solely reducing noise, consider how natural systems use sound barriers to maintain quiet zones or protect sensitive areas.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Forests and dense vegetation create natural sound buffers. • Owl feathers absorb sound through soft, fringed edges. • Seashells and caves use shape and structure to deflect and dampen noise. **3.b Identify experts & connect to communities of biologists and naturalists.** • Acoustic ecologists and bioacoustics researchers. • Engage with biomimicry design communities and urban planning groups focused on noise reduction.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core elements**

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	• Layered structures, soft surfaces, and strategic shapes to diffuse sound waves. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • Use multi-layered green walls with dense foliage. • Incorporate soft, porous materials inspired by animal adaptations. • Design urban structures with curved forms to scatter sound.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Key features** • Passive sound absorption. • Modular green designs. • integration with urban landscapes. **Ideas** • Living sound barriers are constructed from layers of vegetation. • Acoustic panels mimicking the appearance of owl feathers for quiet zones. • Curved, sound-reflecting structures inspired by seashells. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** • **Features:** Sound absorption, sustainability. • **Context:** High-traffic urban areas, public spaces. • **Constraints:** Space limitations, budget.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Criteria** • Noise reduction. • Environmental integration. • Low maintenance. **Feasibility** Moderate cost but scalable and eco-friendly over time. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Test solutions in urban pilot projects and gather feedback to refine designs.

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Additional resources:

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Cactus Water Storage and Distribution Systems

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • Desert plants like cacti and succulents have evolved to store water in their tissues and minimise evaporation. • Some animals, like the Namib desert beetle, can capture water from fog through structures on their bodies. • Certain plants, like the agave, have deep roots that access water below the surface and are adapted to dry climates. **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to do. • Reduce water usage in urban landscapes without compromising aesthetics or plant health. • Promote self-sustaining, drought-tolerant plantings and systems that minimise the need for irrigation. **2.c Flip the question. Consider opposite functions.** • How do plants store and conserve water? vs. How can plants actively capture and conserve atmospheric moisture? • How do animals adapt to extreme dryness? vs. How can animals help us develop systems for water harvesting in urban spaces?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Research plants such as the desert rose, which thrives in dry environments and stores water efficiently. • Study animals like the Namib desert beetle, which collects water from fog and condensation. • Explore plant and animal adaptations in arid ecosystems for insights into water retention strategies. **3.b Identify experts & connect to communities of biologists and naturalists.**

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	• Contact botanists, ecologists, and biologists specializing in desert ecosystems and water conservation. • Engage with communities working on sustainable landscaping, urban ecology, and water-efficient systems.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** • Water storage through specialised tissues and deep-root systems. • Collection of atmospheric water using natural structures (e.g., water-harvesting surface textures). • Drought resistance and the ability to conserve water over extended periods. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • Design landscaping with native and drought-tolerant plants that require minimal water input. • Integrate fog-collection or water-harvesting surfaces, inspired by the Namib beetle’s body structures, to collect atmospheric moisture for irrigation. • Use deep-rooted plants that naturally access groundwater, reducing the need for surface irrigation.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Drought-resistant plant species. • Rainwater and fog collection surfaces. • Smart irrigation systems that mimic the natural water retention and storage found in ecosystems. **5.b Organise your ideas into categories that include features, context, constraints, etc., and select the design concepts that best fit your solution.** **Features** • Use of native, drought-tolerant plants. • Water-harvesting structures. • Efficient irrigation systems that mimic natural water cycles. **Context** • Urban parks, streetscapes, and residential areas. • Locations with water scarcity or limited access to irrigation resources.

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	Constraints • Initial installation costs for water-harvesting systems. • Maintenance requirements for specialized irrigation solutions.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems.** • Assess the feasibility of implementing water-harvesting structures in an urban setting. • Assess the degree to which native plant species can adapt to local urban environments. • Check compatibility with local regulations for water usage and sustainability goals. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** • Refine water collection technologies based on climate data and local water availability. • Adjust plant selection based on regional preferences and environmental factors.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Nature recycling system

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do animals, insects, or microorganisms sort and process materials in their natural environment? • How do ecosystems break down organic matter and recycle nutrients efficiently? **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to do. • The design should create an efficient and self-sustaining waste sorting and recycling system inspired by natural processes. • The system must identify different types of waste, sort them accordingly, and facilitate the recycling process with minimal human intervention. **2.c Flip the question. Consider opposite functions.** • How do animals store or protect valuable resources in nature? (versus: how do they process waste?) • How do ecosystems maintain balance and recycle energy in their habitats? (versus: how do ecosystems generate waste?)
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • In nature, fungi break down organic matter and recycle nutrients in soil. • Ants and termites efficiently sort and transport materials within their colonies. • Microorganisms in composting systems work together to decompose waste and create fertile soil. **3.b Identify experts and connect to communities of biologists and naturalists.** • Consult with ecologists and environmental engineers specialising in waste management or natural recycling processes.

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	• Reach out to experts studying ecosystems and the breakdown of organic matter, such as those researching composting and waste decomposition.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Biological strategy** Efficient waste sorting and decomposition inspired by ants, fungi, and microorganisms. **Core functions** • **Material sorting:** Similar to how ants organise waste and food in their nests. • **Decomposition and recycling:** Inspired by fungi breaking down organic material into nutrients. • **Collaboration:** Microorganisms work together to efficiently decompose waste and enrich the soil. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • The design strategy would create an automated system that sorts different types of waste (organic, recyclable, non-recyclable) using sensors and mechanical sorting methods, mimicking the precision of ants in organizing resources. • The system would integrate microbial processes that accelerate waste decomposition, similar to natural composting, making use of waste to generate energy or organic products like fertilisers.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Automated sorting of waste by type and material. • Microbial waste processing systems (similar to composting or natural recycling). • Reusable materials recovery system to recycle plastic, metals, and organic waste. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.** **Categories** • **Functionality:** Automated waste sorting, recycling, and organic decomposition. • **Sustainability:** Integration of microbial processes to reduce landfill waste and generate organic products.

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	• **Feasibility:** Implementation of AI and sensors for sorting, while maintaining low energy consumption.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** • The design addresses the challenge by automating waste sorting and integrating natural recycling processes. • It aligns with sustainable practices, reducing the amount of waste sent to landfills and minimising human labour. **Feasibility** High initial costs for automation, but long-term savings and environmental benefits make it a worthwhile investment. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** • Reassess the cost-benefit analysis for large-scale implementation and find ways to reduce initial costs. • Explore partnerships with local municipalities and environmental organisations to pilot the solution.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Cactus Water Storage and Distribution Systems

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** Cacti are excellent models for efficient water collection and storage. Their unique structure allows them to capture moisture from the air and funnel it into their roots, even in arid conditions. **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish. The design should be capable of capturing and storing water from rainfall or humidity in urban settings, minimising water loss and optimising storage for later use during dry periods. 2.c Flip the question. Consider opposite functions. • How do plants deal with water scarcity? vs. How can we store excess water to prevent flooding during heavy rains?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • The structure of cactus spines and ridges allows them to channel water directly into their roots, preventing evaporation and maximising water capture. Similar methods could be applied to urban architecture to create efficient rainwater harvesting systems. **3.b Identify experts & connect to communities of biologists and naturalists.** • Engage with experts in plant physiology and sustainable water management to understand how cactus adaptations can be translated into urban water systems.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** The cactus uses its unique shape and surface texture to funnel moisture toward its roots. These adaptations can be mimicked in urban water systems to collect, store, and utilise water in a sustainable way. 4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

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	Urban infrastructure could be designed with surfaces that collect and channel water efficiently, using materials that mimic the texture and shape of cactus spines. For example, rooftops could be equipped with features that capture rainwater and direct it to storage tanks or green spaces for later use.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Water collection through surface textures. • Passive water harvesting systems in buildings. • Using cactus-inspired ridges or spines to channel rainwater into storage systems. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.** • **Features:** Efficient water capture, storage, and minimal evaporation. • **Context:** Urban settings with varying rainfall patterns. • **Constraints:** Space limitations, installation costs, and integration with existing infrastructure.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Design alignment** • The water collection system inspired by cactus structures is aligned to improve urban water management by offering efficient water capture and storage, especially in areas prone to drought and flooding. • The solution could contribute to more sustainable urban environments by reducing water wastage and minimising flood risk through efficient rainwater harvesting. **Compatibility with Earth's systems** • The design mimics natural water collection methods, which are inherently sustainable. The use of biomimicry to replicate cactus-like features ensures the solution works harmoniously with Earth's natural water cycles, rather than disrupting them. • This system would promote water conservation, reduce reliance on traditional water infrastructure, and work with nature rather than against it. **Feasibility of the technical model** • **Pros:** The technology for creating water collection surfaces that mimic cactus structures is feasible and can be integrated into existing buildings or urban infrastructure with proper design. • **Cons:** The initial costs of installing these systems may be high, and retrofitting older buildings might present challenges. However, the long-

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	term benefits of reduced water consumption and flooding could outweigh these costs. **Feasibility of the business model** ● Given the rising interest in sustainability and climate resilience, there is a growing market for solutions like this. Partnerships with urban planners, municipalities, and eco-conscious builders could support the adoption of these systems. However, the initial investment could be a barrier for widespread implementation. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Revisions to consider** ● Further exploration of cost-effective materials or scalable solutions to minimise initial costs. ● Consideration of modular designs that can be adapted to different urban settings, making it easier to integrate the system into existing infrastructure.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Termite mounds which regulate temperature and humidity

<table>
<tr><th>BIOMIMICY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.

Nature solves cooling challenges through various biological strategies. For instance, termites construct mounds with intricate internal structures that effectively regulate temperature and humidity despite extreme external conditions. These mounds stay cool in high temperatures due to their natural ventilation system.

2.b Ask yourself what your design wants to do.

Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to accomplish.

The design wants to reduce the energy consumption required for cooling systems in industrial plants by replicating nature's strategies for passive cooling. Specifically, it aims to optimise internal temperature control without relying on energy-intensive air conditioning or refrigeration systems.

2.c Flip the question. Consider opposite functions.
How can nature help maintain heat or keep processes warm without excessive energy?
How can we prevent overcooling while still ensuring optimal conditions in an industrial setting?</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution.
The termite mound is a well-known natural model for passive cooling, utilising the natural flow of air and its structural design to maintain a stable internal temperature.
Other potential models might include the cooling strategies of certain desert plants or the skin of animals like elephants, which regulates body temperature through highly effective circulation mechanisms.
3.b Identify experts & connect to communities of biologists and naturalists.
Experts in bioclimatic architecture, such as those involved in passive cooling technologies, can provide valuable insights into the most effective biomimetic applications.
Naturalists specialising in desert ecosystems or those who study thermoregulation in animals may also offer valuable perspectives.</td></tr>
</table>

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Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** The cactus uses its unique shape and surface texture to funnel moisture toward its roots. These adaptations can be mimicked in urban water systems to collect, store, and sustainably utilise water. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Urban infrastructure could be designed with surfaces that collect and channel water efficiently, using materials that mimic the texture and shape of cactus spines. For example, rooftops could be equipped with features that capture rainwater and direct it to storage tanks or green spaces for later use.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Key information** • Passive ventilation systems. • Heat-absorbing materials. • Self-regulating temperature control. • Sustainable cooling technologies. **Ideas** • Design factory spaces with passive ventilation systems similar to termite mounds. • Use eco-friendly materials such as natural stone or clay that have high thermal mass for buildings. • Implement a sensor-driven system to regulate airflow and internal temperatures automatically. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.** **Categories** • **Features:** Passive cooling, self-regulating temperature, use of natural materials • **Context:** Industrial factories, energy-intensive manufacturing processes • **Constraints:** Cost of initial installation, integration into existing buildings • **Selected design concept:** A hybrid solution combining passive ventilation and thermal mass, with an automated system for airflow management.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in terms of their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.**

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	Design alignment The design solution directly addresses the challenge of reducing energy consumption in industrial cooling by utilising nature-inspired methods for temperature regulation, thereby reducing reliance on energy-intensive air conditioning systems. **Compatibility with Earth's systems:** The solution is highly compatible with Earth's systems, utilising natural materials and passive cooling strategies, thereby reducing the environmental impact of industrial cooling processes. **Feasibility of the technical model:** The technology is feasible, as passive cooling systems and heat-absorbing materials already exist. However, initial costs for installing such systems can be high, and retrofitting older factories may be challenging. **Feasibility of the business model:** The business model is viable, especially in the long term. Energy savings from reduced cooling costs and the growing demand for sustainable solutions will likely make the system profitable over time. Governments and environmental organizations may offer subsidies or grants for such initiatives. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** **Revisions to consider** • Further research into low-cost materials for heat regulation that can be used in the initial stages of the design. • Explore modular designs that allow companies to integrate the system gradually, reducing the financial burden of full implementation.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Nature Precision Irrigation System

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** Nature's ecosystems use water efficiently through various mechanisms, such as the distribution of water via plant root systems and rainwater absorption techniques of certain plants. For example, plants like the cactus store water and use it strategically, while moss absorbs and retains moisture efficiently. **2.b Ask yourself what your design wants to do.** Determine the key functions of your design and identify contexts in nature. Functions can refer to the role played by an organism's adaptations or behaviours that enable it to survive. They can also refer to something your design solution needs to do. The design needs to ensure that water is distributed precisely and efficiently across agricultural fields, minimizing waste and ensuring that each plant receives the appropriate amount of hydration based on its needs and the surrounding environment. **2.c Flip the question. Consider opposite functions.** Instead of focusing on how water can be added to the soil, consider how plants manage to reduce water loss through transpiration. How do plants prevent water from evaporating too quickly or ensure that moisture is stored where it's needed most?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Examine how desert plants, such as succulents and cacti, store water and release it gradually. Additionally, the root systems of **forest trees** have evolved to absorb moisture deeply from the soil and distribute it efficiently to different parts of the plant. • Study how **mosses and ferns** retain water, which could inspire new approaches to storing and distributing moisture. **3.b Identify experts & connect to communities of biologists and naturalists.** • Engage with **plant biologists** who specialise in water storage mechanisms in plants. • Connect with experts in **precision agriculture** and **hydrology** to gain insights into existing water-saving technologies and challenges in irrigation.

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Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** • **Cacti** store water in their tissues, which can be used gradually over time. • **Mosses** can absorb and hold water in a way that prevents excessive evaporation. • **Tree roots** create a deep and wide network that allows the plant to access moisture over a larger area, even in dry conditions. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • Design an **irrigation system** inspired by the way **cacti** store water, using **smart moisture sensors** and **smart valves** to release water slowly and efficiently as needed. • Incorporate **micro-irrigation techniques**, similar to how moss absorbs and retains water, to ensure that water is delivered directly to the plant roots without unnecessary evaporation. • Design an irrigation network that mimics the **root systems** of trees, ensuring water can be accessed deeply and efficiently, reaching the furthest roots.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Smart irrigation system with real-time moisture monitoring. • Self-regulating systems that adjust water flow based on weather conditions and plant needs. • Low-pressure drip irrigation to minimise evaporation and runoff. • Water storage tanks that slowly release moisture according to the plant's needs, mimicking the water storage capabilities of cacti. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.** **Key features** • Smart moisture sensors. • Drip irrigation system for targeted water distribution. • Adaptive watering schedules based on weather patterns. **Context** • Implemented in dry or drought-prone areas with agriculture dependent on irrigation. • Supports sustainable farming practices. **Constraints**

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	• High initial installation costs for the advanced system. • Technical support is required for system maintenance.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems.** The system aligns with the challenge by offering a solution to water waste and ensuring that crops receive the right amount of hydration. **Compatibility with Earth's systems** The system uses natural principles of water conservation and storage, and it minimises environmental impact by reducing water waste and promoting sustainable farming practices. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** • Ensure the system is scalable for large fields and affordable for small-scale farmers. • Consider solar-powered or low-energy options for running the irrigation system in regions with limited access to electricity.

Additional resources:

https://biomimicry.org/

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Resilient structure of Palm trees

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** **Biological model** Palm trees are highly flexible and resilient structures that can withstand extreme winds in tropical storms and hurricanes. Their long, slender trunks and aerodynamic fronds allow them to bend without breaking, dispersing wind forces efficiently. Additionally, their deep and expansive root systems provide a strong anchor in loose or sandy soils.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Solution overview** Design resilient buildings inspired by the structural properties of palm trees, integrating flexibility, aerodynamic design, and deep anchoring systems. The solution aims to create energy-efficient, weather-resistant structures that can withstand high winds and extreme weather events. **Key features of the design** **Aerodynamic building shape** • The building's shape mimics the streamlined fronds of a palm tree, reducing wind resistance and pressure on the structure. • Rounded or tapered edges can redirect wind flow, minimizing potential damage. **Flexible structural materials** • Use flexible building materials, such as high-strength composites or carbon fibre, inspired by the pliability of palm trunks. • The building can sway and dissipate energy during high winds without sustaining structural damage. **Deep anchoring foundations** • Employ deep foundation systems inspired by palm tree root structures, ensuring stability even in loose or sandy soil. • Include adjustable foundations for areas with seismic activity, adding multi-hazard resilience. **Lightweight and modular components**

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	• Modular, lightweight components reduce overall structural load while maintaining strength, similar to the lightweight composition of palm fronds. • These components can be prefabricated, lowering construction costs and timelines. **Energy efficiency features** • Incorporate natural ventilation designs inspired by the spacing of palm fronds, which allow airflow while providing shade. • Integrate rooftop solar panels and rainwater harvesting systems for sustainable resource use.
Step 4 – Abstract	**4. Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Applications** • Coastal buildings in hurricane-prone regions. • Modular housing units for disaster relief. • Skyscrapers in urban areas face extreme weather events. **Expected outcomes** • Improved safety and durability of buildings in extreme weather. • Reduction in repair and rebuilding costs after disasters. • Promotion of sustainable and adaptive architectural designs. **Partner involvement** • **Architectural firms:** Designing biomimetic building prototypes. • **Engineering companies:** Testing flexible materials and anchoring systems. • **Government agencies:** Providing funding and subsidies for resilient building initiatives.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Smart irrigation system with real-time soil moisture monitoring, inspired by the sensitivity of plant roots to water levels. • Self-regulating systems that adjust water flow based on weather conditions, mimicking the behaviour of moss and cacti in adapting to water availability. • Low-pressure drip irrigation systems to reduce evaporation and minimise water runoff, similar to how desert plants minimise water loss.

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	• Water storage tanks that mimic the water retention abilities of cacti, gradually releasing moisture to plants based on their needs. • Root-inspired underground water distribution systems to ensure even hydration across the soil. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Key features** • **Smart moisture sensors:** Monitor soil conditions in real-time to regulate irrigation. • **Drip irrigation system:** Ensures targeted and efficient water distribution. • **Adaptive watering schedules:** Use weather data to determine optimal irrigation timing and frequency. • **Water storage solutions:** Tanks designed to replicate cacti water retention capabilities. **Context** • Designed for agricultural fields in drought-prone or arid regions. • Supports sustainable farming practices by reducing water waste and ensuring resource efficiency. • Constraints • High initial costs for advanced technology and installation. • Training is required for farmers to use and maintain the system. • Limited scalability in areas with poor access to technology or electricity.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The solution addresses the challenge by reducing water waste and ensuring crops receive adequate hydration. **Alignment with criteria** • Reduces water usage. • Enhances crop yields through precise and efficient hydration. • Supports sustainable agriculture by mimicking natural water conservation principles. **Compatibility with Earth's systems**

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	• Uses biomimetic principles that align with natural water management and conservation strategies. • Minimises environmental impact by reducing runoff, evaporation, and water waste. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** • **Scalability:** Develop modular systems for small-scale and large-scale farms to make the solution more accessible. • **Affordability:** Explore options for subsidies, partnerships, and affordable versions for smallholder farmers. • **Energy efficiency:** Integrate solar power or other renewable energy sources to run the irrigation system in remote areas. • **Maintenance:** Develop a user-friendly interface and provide technical support or training programs for farmers.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Nature efficient insulation and thermal regulation

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** **Biological model** The natural world offers a variety of examples of efficient insulation and thermal regulation, one of the most well-known being the structure of animal burrows. For instance, the **European rabbit burrow** maintains a relatively stable temperature, even during extreme seasonal temperature changes, due to the insulating properties of the surrounding soil. Another example is the **polar bear's fur**, which provides excellent thermal insulation against freezing temperatures through a combination of dense underfur and hollow guard hairs that trap air.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Solution overview** Design a building insulation system inspired by natural thermal regulation mechanisms, such as those found in animal burrows and polar bear fur. The goal is to develop an insulation material that enhances energy efficiency by using natural and biodegradable materials, offering thermal stability without reliance on synthetic or non-biodegradable alternatives. **Key features of the design** • **Biodegradable insulation materials:** The use of cellulose-based materials, hempcrete, or mycelium (fungal roots) as natural insulation, which mimic the insulating properties of soil in animal burrows or the thermal regulation in polar bear fur. • **Multi-layered insulation:** Like the layers of fur in polar bears, insulation can involve several layers with varying densities and structures to trap heat in colder climates or allow ventilation in warmer climates. • **Thermal mass and airflow regulation:** Building components that integrate passive heating and cooling, inspired by burrows, where the thermal mass of the walls regulates internal temperatures while allowing for airflow and preventing overheating. • **Natural ventilation systems:** Including air channels and vents inspired by animal burrows, which allow for the natural flow of warm and cool air to enhance temperature regulation without the use of mechanical systems.

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Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Applications** • **Residential homes in extreme climates:** Buildings in hot or cold climates where energy use for heating or cooling is high can benefit from better natural insulation. • **Public and commercial buildings:** Schools, hospitals, and offices are looking to reduce energy consumption and create healthier, more sustainable environments. • **Eco-friendly construction projects:** Homes built with sustainable materials, aiming for green building certifications such as LEED. **Expected outcomes** • Reduced energy consumption for heating and cooling, lowering both operational costs and environmental impact. • Improved indoor comfort by stabilising internal temperatures year-round. • Increased adoption of sustainable, biodegradable materials in the construction industry. **Partner involvement** • **Material manufacturers:** Supply and develop sustainable, biodegradable insulation materials, such as mycelium, hempcrete, and cellulose. • **Architectural firms:** Design buildings that incorporate these new insulation materials and passive thermal regulation systems. • **Government agencies:** Provide support and incentives for green building solutions and sustainable construction practices.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • **Natural insulation materials:** Mycelium, hempcrete, cellulose, and wool-based insulation materials. • **Layered insulation systems:** Multiple layers of materials with varying thermal properties to create a multi-functional insulating system, similar to polar bear fur or burrow structures. • **Passive temperature regulation:** Incorporate systems to balance temperature fluctuations without mechanical interventions, inspired by natural systems like animal burrows or hibernation chambers. • **Ventilation channels:** Incorporate passive airflow channels that regulate temperatures naturally, without the need for energy-intensive HVAC systems.

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	5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution. **Category** / **Features** Materials: Biodegradable materials, such as hempcrete, cellulose, and mycelium, are used for insulation. Insulation System: A multi-layered insulation system inspired by the fur of polar bears and their burrows. Thermal Regulation: Utilisation of natural ventilation channels for regulating airflow and temperature. Energy Efficiency: Integrating natural heat regulation to reduce reliance on artificial heating or cooling systems. **Context** • This solution is suitable for regions experiencing extreme climates, particularly those where energy use for heating or cooling is a concern. • The design also supports the adoption of eco-friendly materials in the building industry, contributing to sustainable architecture. **Constraints** • The cost of eco-friendly materials may be initially higher, though long-term savings in energy costs could offset the upfront investment. • Scaling the solution for large buildings or urban environments may require adjustments to traditional construction techniques.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment with the challenge** This design offers a natural solution to the challenge by using biomimicry to reduce energy consumption for heating and cooling. By mimicking the insulation properties of animal burrows and polar bear fur, the solution directly addresses the need for improved insulation. **Compatibility with Earth's systems**

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	The use of biodegradable, natural materials aligns with Earth's systems, reducing waste and minimising the environmental footprint of buildings. This passive temperature regulation system also minimises the need for external energy inputs, thereby reducing the building's carbon footprint. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** • **Scalability:** Explore modular insulation options that can be adapted for different building sizes, from small homes to large commercial buildings. • **Affordability:** Investigate mass production of biodegradable materials to lower costs, and consider subsidies or incentives for the adoption of sustainable materials in construction. • **Maintenance:** Ensure that the passive ventilation systems are easy to maintain and adaptable to different climate conditions. Additionally, provide support for installing insulation materials in existing buildings, not just new construction.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Natural filtration systems for purify water

BIOMIMICY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** **Biological model** Natural filtration systems, such as wetlands, utilise plants, microorganisms, and natural processes to clean and purify water. Wetlands filter out pollutants by using plant roots to absorb nutrients and contaminants, while microorganisms break down organic matter. The slow movement of water through wetland soil also helps trap particles and reduce the release of pollutants. Additionally, biofiltration in soils and riverbeds effectively removes toxins through natural biochemical processes.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** **Solution overview** Design a wastewater treatment system based on the principles of natural filtration, utilising plants, microorganisms, and biofilter systems to purify water. The solution aims to reduce chemical use and energy consumption while maintaining effective filtration and purifying capabilities. **Key features of the design** • **Plant-based biofilters:** Utilise the root systems of plants like reeds or cattails, which are known to absorb contaminants and purify water, creating a natural filtration system. • **Microbial biofilm layers:** Incorporate layers of natural microorganisms that can break down organic contaminants and convert harmful compounds into less toxic substances. • **Layered filtration media:** Use natural materials such as gravel, sand, and activated carbon, which mimic the filtration process of riverbeds and soil, to physically and chemically filter out pollutants. • **Slow water movement:** Implement a system that slows down water flow, allowing for extended filtration time, similar to the natural filtration in wetlands, where water passes through different substrates and interacts with microorganisms.

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Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Applications** • Small-scale municipal and community wastewater treatment plants. • Decentralised or rural wastewater management systems. • Eco-villages, agricultural wastewater treatment, or stormwater filtration systems. • Urban water reclamation and reuse systems. **Expected outcomes** • Reduced reliance on energy-intensive chemical treatment processes. • Effective reduction of pollutants, such as nitrogen, phosphorus, and organic matter. • Improved water quality for reuse or discharge into natural water sources. • Increased sustainability and cost-efficiency for wastewater treatment operations. **Partner involvement** • **Environmental engineers:** Designing the system and integrating biological elements into existing infrastructure. • **Municipalities and government agencies:** Supporting pilot projects, providing funding, and implementing systems. • **Agricultural and eco-community developers:** Applying systems in rural or decentralized locations.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Floating wetland systems for wastewater treatment in lagoons or ponds. • Microbial fuel cells combined with biofiltration to enhance water purification. • Constructed wetlands with varying depths and plant types to treat different contaminants. • Modular biofiltration units that can be scaled based on the size of the community or facility. 5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

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	Key features • Modular biofilter units that integrate plant-based filtration. • Incorporation of microbial layers for enhanced breakdown of organic matter. • Low-maintenance, gravity-powered filtration system for small-scale communities. **Context** • Suitable for rural and urban locations where conventional wastewater treatment is difficult or costly to implement. • Can be scaled for large or small facilities, depending on the size of the community or wastewater volume. **Constraints** • Slower treatment process compared to conventional chemical treatments. • Initial setup costs for constructing biofilter systems. • Challenges in maintaining optimal plant and microbial health for long-term functionality.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in relation to their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** The system addresses the challenge by offering a sustainable, low-energy, and chemical-free alternative to traditional wastewater treatment methods. It mimics natural filtration processes, which are effective at purifying water, reducing pollutants, and maintaining a balanced ecosystem. **Alignment with criteria** • Minimises energy consumption and environmental impact. • Relies on natural processes for water purification, reducing reliance on synthetic chemicals. • Scalable and adaptable to various community sizes and environmental conditions. **Compatibility with Earth's systems** • The solution aligns with ecological principles by using natural filtration methods that work in harmony with the environment. • Enhances biodiversity by incorporating plant life and microorganisms into the system, thereby helping to preserve and promote ecological health.

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	6.b Revise and revisit previous steps as necessary to generate a viable solution. • **Scalability:** Design modular systems that can be adapted to different-sized communities or industrial applications. • **Cost-effectiveness:** Explore options for government subsidies, grants, or partnerships to lower initial installation costs. • **Sustainability:** Use locally sourced materials and native plants to reduce costs and improve system resilience.

Additional resources:

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

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Solution: Nature's natural air purification systems

<table>
<tr><th>BIOMIMICY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.

Biological model

The solution draws inspiration from nature's natural air purification systems. Specifically, plants like spider plants and peace lilies have been shown to filter indoor air by absorbing harmful chemicals and particulates through their leaves and roots. Additionally, particular species of moss and algae can capture fine particulates in the air. At the same time, some trees, like the silver birch and urban ash, are known to absorb carbon dioxide and other air pollutants through their leaves and bark.</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution.

Solution overview

Design a natural air filtration system based on plant systems that will be implemented in urban areas to reduce pollution levels and improve air quality. The system would incorporate plants known for their air-purifying properties, along with other natural materials like moss or algae, strategically placed in urban spaces.

Key features of the design
Green walls and green roofs: Utilise a variety of air-purifying plants in vertical gardens and rooftop gardens to naturally filter the air, absorbing pollutants and providing shade to mitigate heat island effects.
Moss mats and algae panels: Install moss mats and algae panels in high-traffic areas, such as alongside roads, to trap delicate particulate matter and convert CO2 into oxygen.
Tree planting initiatives: Plant trees with proven air-purifying properties along roads, in parks, and urban squares to absorb pollutants directly from the air.
Expected outcomes
Reduction in urban air pollutants (e.g., PM2.5, NOx).
Improvement in public health due to cleaner air.
Increased green space in urban environments, which also improves mental well-being.</td></tr>
</table>

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Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram or drawing and/or find images that can inform the design.** **Applications** • Urban areas with high levels of air pollution. • Parks, public squares, and along major roadways. • Green roofs and walls for commercial buildings and public infrastructure. **Expected outcomes** • Enhanced urban air quality. • Reduction in respiratory diseases among residents. • Contribution to urban sustainability through natural filtration. **Partner involvement** • **Urban planners and municipal governments**: Support the integration of green air filtration solutions in city planning and funding. • **Landscape architects and horticulturists**: Design and select plants and materials that are suitable for effective filtration. • **Environmental agencies**: Monitor the effectiveness and impact of the air filtration systems on air quality and public health.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** • Green walls made of a variety of air-purifying plants, such as spider plants and peace lilies, which absorb indoor pollutants. • Moss panels that collect and filter fine particles in the air. • Vertical gardens that not only purify air but also add aesthetic value and encourage biodiversity. • Tree planting initiatives featuring trees that absorb carbon dioxide and other pollutants, such as silver birch or urban ash. • Algae-based filters that capture carbon and particulates from the air. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Key features** • Air-purifying plant systems (green walls, moss, algae, and trees). • Modular and scalable for different urban settings (parks, roadsides, rooftops). • Low-energy, sustainable technology with minimal maintenance needs.

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	Context • Target urban areas with high levels of pollution. • Focus on cost-effective solutions that can be implemented in dense urban environments and on infrastructure like roads, buildings, and parks. **Constraints** • **Maintenance:** Requires regular care for plant systems and potential replanting. • **Cost:** Initial setup costs for infrastructure and plant systems may be high; however, there are long-term benefits in terms of health and energy savings. • **Space:** Availability of suitable spaces for large-scale installations (e.g., rooftops or parks).
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment with challenge** The natural air filtration system directly addresses the challenge of improving urban air quality while reducing environmental impact. By utilising plants and other natural materials, the solution reduces pollutants in a sustainable, energy-efficient manner, without relying on synthetic or high-energy filtration systems. The solution also promotes the natural regulation of air quality, similar to how ecosystems maintain balance through the roles of plants in absorbing CO2, particulates, and other air pollutants. **Compatibility with Earth's systems** The design aligns with Earth's systems by mimicking natural processes such as photosynthesis, plant transpiration, and natural filtration. Plants naturally absorb CO2 and pollutants, while also providing oxygen and reducing the heat island effect. This solution supports a circular and restorative approach to urban planning, reducing reliance on artificial systems and integrating biological processes into the urban environment. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** • **Scalability:** To make the design more scalable, further research could focus on optimizing the plant species selection based on their effectiveness in air filtration in different climate zones and pollution types. Modular green walls and rooftop gardens can be designed for easy installation and maintenance across various urban environments, from residential buildings to public parks. The solution can also be adapted for use in smaller, more affordable setups, such as portable moss mats or DIY kits for individual households or community spaces.

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	• **Affordability:** A phased approach could be adopted, starting with pilot projects in specific areas (e.g., heavily polluted neighbourhoods or business districts) and scaling up as results are observed. Partnerships with governments or environmental organisations could help offset initial costs. Additionally, exploring government incentives or subsidies for green infrastructure could make the solution more affordable. • **Maintenance and longevity:** To address the maintenance concerns, the system can be designed with low-maintenance plants and materials that require minimal care. Additionally, automated irrigation or watering systems could be integrated to reduce the time and labour involved in upkeep. Regular monitoring systems could track the effectiveness of the filtration and alert city managers to any areas needing attention. • **Energy efficiency:** Since the design is based on natural processes, it requires little to no additional energy input, making it highly sustainable. However, for larger installations, integrating renewable energy sources (e.g., solar panels for automated irrigation systems) could further enhance energy efficiency and reduce the environmental footprint.

Additional resources:

https://biomimicry.org/

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Solution: Gecko-Inspired Adhesives

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do geckos adhere to surfaces without using glue or residue? • How do natural systems create temporary adhesion that is reusable? **2.b Ask yourself what your design wants to do.** • Achieve reversible adhesion. • Stick securely to various surfaces, even under different environmental conditions. • Leave no residue when removed. **2.c Flip the question. Consider opposite functions.** • How do geckos adhere to surfaces?. • How do natural systems ensure things do not stick to them (e.g., lotus leaves repelling water)?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Research the adhesive properties of gecko toepads, focusing on Van der Waals forces. • Study other animals with adhesive capabilities, such as tree frogs and insects like beetles. • Review scientific literature on bio adhesion and reversible adhesives. **3.b Identify experts & connect to communities of biologists and naturalists.** • Connect with biologists specializing in animal biomechanics. • Collaborate with materials scientists researching bio-inspired adhesives. • Engage with biomimicry communities like the Biomimicry Institute..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** Adhesion, reversibility, self-cleaning.

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	Key elements Microstructures on gecko toes use Van der Waals forces to stick to surfaces without leaving residue. These structures maintain adhesion even on dusty surfaces.  Michel Pierfitte, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Develop surfaces or materials with microscopic structures that can adhere to smooth or uneven surfaces without glue or residue. Ensure reusability and durability for consumer or industrial applications.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Microstructures mimic gecko toe pads to create adhesion without glue. **Ideas** Develop reusable, residue-free tape for household, medical, or industrial applications. Create climbing gear with enhanced grip. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** Adhesion via microstructures, durability, and reusability. **Context** Indoor and outdoor applications, non-toxic materials. **Constraints** Material costs, surface compatibility, and wear over time.

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	Idea selected A reusable adhesive strip for household use.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) in terms of their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Strong alignment with the challenge to create reusable, residue-free adhesives. Meets sustainability goals by eliminating the use of chemical adhesives. **Feasibility** Technically feasible with current material science advancements. However, scalability and cost need to be evaluated for mass production. **Compatibility with the Earth's systems** Made from biodegradable or recyclable materials to minimise environmental impact. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Explore alternate materials that maintain adhesion but reduce manufacturing costs. Revisit microstructure designs to enhance durability for repeated use.

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=vS0TuIPoeBs – "The Stickiest *Non-Sticky* Substance"

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Solution: Termite-Inspired Ventilation Systems

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do termites regulate the temperature and airflow inside their mounds? • How do natural systems manage heat without external energy sources? **2.b Ask yourself what your design wants to do.** • Passively regulate temperature. • Optimize airflow for cooling or heating. • Mimic nature's energy-efficient climate control systems. **2.c Flip the question. Consider opposite functions.** • How do termites control internal temperatures?. • How do natural systems trap heat or prevent airflow?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study termite mounds and their passive cooling mechanisms. • Explore natural ventilation systems in other animals, such as prairie dog burrows. • Research academic papers on thermoregulation in social insects. **3.b Identify experts & connect to communities of biologists and naturalists.** • Consult entomologists studying termites and their ecological roles. • Network with sustainable architecture and engineering researchers. • Partner with environmental scientists familiar with ecosystem thermodynamics..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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	 Source: https://flickr.com/photos/48539981@N03/29383903862 **Core functions** Passive cooling, airflow regulation. **Key elements** Termite mounds use a network of vents and chambers to maintain stable internal temperatures, even in extreme climates. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design ventilation systems that regulate air movement and temperature using a network of interconnected pathways, reducing reliance on energy-intensive cooling systems.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Passive airflow control using a network of channels. **Ideas** Design energy-efficient HVAC systems for large buildings. Create low-cost cooling systems for arid regions. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** Natural cooling, passive system, sustainable materials. **Context** Hot climates, areas with limited electricity.

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	Constraints Building regulations, scalability for different structures. **Idea selected** Passive cooling system for schools in hot climates.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Effectively meets goals for passive cooling in hot climates, reducing reliance on energy-intensive HVAC systems. **Feasibility** Requires integration into existing architectural designs, which may add initial cost. Long-term savings from energy efficiency enhance viability. **Compatibility with the Earth's systems** Reduces carbon footprint and aligns with sustainable urban development. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Test ventilation designs in different building types. Collaborate with architects to refine designs for cost-effective implementation.

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=qP8DSdfoiZw – A video on How Termite mounds Cool Itself | Biomemetic architecture: Zimbabwe Eastgate center

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

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Solution: Humpback Whale Flipper-Inspired Wind Turbines

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do humpback whales use their flippers to move efficiently through water? • How do natural systems optimize fluid dynamics to maximize energy transfer? **2.b Ask yourself what your design wants to do.** • Reduce drag and improve efficiency. • Minimize turbulence and vibration. • Capture more energy with the same effort. **2.c Flip the question. Consider opposite functions.** • How do whale flippers enhance movement efficiency?. • How do natural systems resist movement or create drag (e.g., certain seeds designed to stay in one place)?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Research humpback whale flipper structures and tubercles. • Study fluid dynamics in marine animals with optimized movement, like dolphins. • Review scientific papers on aerodynamics in nature. **3.b Identify experts & connect to communities of biologists and naturalists.** • Connect with marine biologists focusing on cetacean anatomy and behaviour. • Work with mechanical and aerospace engineers researching biomimetic applications. • Engage with oceanography institutes and biofluid mechanics specialists..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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	Core functions Enhanced fluid dynamics, reduced drag, increased lift. **Key elements** Tubercles (bumps) on humpback whale flippers streamline movement through water, improving energy efficiency.  Source: Humpback Whale Flipper-Inspired Wind Turbines, AI generated by Canva **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Create aerodynamic structures with strategically placed ridges or contours to reduce drag and improve performance in wind or water flow applications.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Tubercles reduce drag and improve lift. **Ideas** Modify turbine blades to improve efficiency in low-wind areas. Explore similar concepts for boat propellers or drones. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** Drag reduction, aerodynamic efficiency. **Context** Renewable energy sector, offshore and onshore settings. **Constraints**

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	Manufacturing costs and durability in extreme weather. **Selected concept** Turbine blades optimized for low-wind environments.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Meets the goal of increasing efficiency in low-wind environments, improving renewable energy output. **Feasibility** Technically feasible with existing turbine manufacturing technologies; however, it may require investment in retrofitting existing turbines. **Compatibility with the Earth's systems** Reduces dependency on fossil fuels and integrates seamlessly into sustainable energy initiatives. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Refine blade designs for cost-effective retrofitting. Test durability in extreme weather conditions to ensure long-term performance

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=1eDYTzEYrkM – A Short video by Stephen Dewar, Philip Watts & Frank Fish - Turbines and fans inspired by whales (SHORT)

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Solution: Firefly-Inspired LED Efficiency

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do fireflies produce bright light without generating heat? • How do natural systems manage energy efficiency in bioluminescence? **2.b Ask yourself what your design wants to do.** • Maximize light output while minimizing energy use. • Avoid heat loss during energy conversion. • Produce light in an eco-friendly way. **2.c Flip the question. Consider opposite functions.** • How do fireflies maximize light efficiency? • How do natural systems suppress or absorb light (e.g., nocturnal animals avoiding detection)?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study the microstructures in firefly lanterns that enhance light emission. • Research bioluminescence in other organisms, such as jellyfish or deep-sea fish. • Explore literature on bio-inspired optics and photonics. **3.b Identify experts & connect to communities of biologists and naturalists.** • Collaborate with entomologists studying light-producing insects. • Partner with optical engineers and nanotechnology researchers. • Network with lighting design professionals and bioengineering experts..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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	 Source: Firefly-Inspired LED AI generated by Canva **Core functions** Optimized light emission, energy efficiency. **Key elements** The microstructures on firefly lanterns prevent internal reflection and maximize light output. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Develop lighting solutions with surface textures or materials that reduce energy loss and enhance brightness. Focus on optimizing angles and reflectivity.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Microstructures optimize light output. **Ideas** Improve brightness in energy-efficient LEDs for homes and vehicles. Create outdoor lighting systems with minimal energy loss. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** Enhanced brightness, reduced energy loss. **Context** Urban lighting, energy-saving devices. **Constraints** Integration with existing lighting systems, cost efficiency.

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	Selected concept High-efficiency LED bulbs for public lighting.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Enhances brightness and reduces energy consumption, addressing the needs of urban and residential lighting. **Feasibility** Integration with current LED production processes is achievable. Costs are competitive with conventional LEDs. **Compatibility with the Earth's systems** Reduces energy use, aligning with global sustainability targets. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Conduct user testing to refine the balance between brightness and efficiency. xplore partnerships with manufacturers to scale production.

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=_7qrfCpMhjc - "How fireflies inspired energy-efficient lights - BBC World Service, 30 Animals podcast"

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Solution: Moth Eye-Inspired Anti-Reflective Coatings

BIOMIMICRY DESIGN	Description
Step 2 – Biologize	**2.a Ask yourself how nature can solve this.** • How do moth eyes minimize light reflection? • How do natural systems reduce glare to enhance visibility? **2.b Ask yourself what your design wants to do.** • Reduce reflection and glare on surfaces. • Maximize light absorption for better performance. • Enhance visibility under various lighting conditions. **2.c Flip the question. Consider opposite functions.** • How do moth eyes reduce reflection? • How do natural systems amplify reflection or scatter light (e.g., iridescent butterfly wings)?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study moth eye nanostructures that reduce reflection. • Explore anti-reflective adaptations in other animals, such as nocturnal predators. • Review academic research on bio-inspired anti-glare materials. **3.b Identify experts & connect to communities of biologists and naturalists.** • Connect with entomologists researching nocturnal insects. • Collaborate with material scientists developing nanostructured coatings. • Engage with physicists specializing in light manipulation..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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	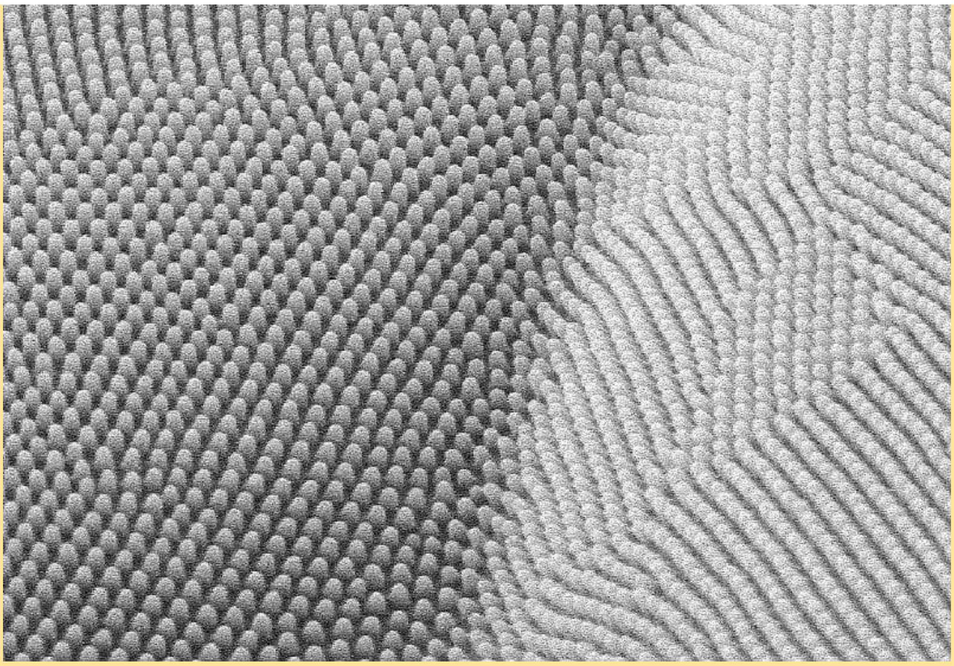 Source: https://asknature.org/strategy/eyes-are-anti-reflective/ **Core functions** Reflection reduction, improved visibility. **Key elements** Moth eyes have nanoscale structures that minimize glare and reflection, allowing them to see clearly in low light. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design surfaces with nano-patterned coatings to minimize reflection and enhance clarity in optical devices, displays, or solar panels.
Step 5 – Emulate	5.a List your key information and explore as many ideas as possible. **Features**: Non-patterned surfaces minimize reflection. **Ideas** Apply coatings to reduce glare on smartphone screens and improve the efficiency of solar panels by minimizing reflection. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.** **Features** Glare reduction, improved light absorption. **Context**

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	Consumer electronics, renewable energy. **Constraint** Manufacturing scalability and wear resistance. **Idea selected** Anti-reflective coating for solar panels in high-sun regions.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Effectively addresses glare reduction and light absorption for electronics and solar panels. **Feasibility** Nano-patterned coating production is technically feasible but requires scaling to reduce costs. **Compatibility with the Earth's systems** Enhances solar energy efficiency, contributing to renewable energy goals. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Optimise coating for durability and cost. Explore secondary applications, such as automotive glass or eyewear

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=JvnD-A_dkmY - "Moth-eye-inspired Sub-wavelength antireflective structures for solar cells"

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Kingfisher-Inspired Bullet Trains

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How does the kingfisher's beak move through water with minimal disturbance?. • How do natural systems reduce noise during high-speed movement?. **2.b Ask yourself what your design wants to do.** • Minimize noise and aerodynamic drag. • Maintain stability at high speeds. • Reduce energy loss during motion. **2.c Flip the question. Consider opposite functions.** • How does the kingfisher reduce disturbance during movement?. • How do natural systems maximize turbulence or create noise (e.g., how some predators create splashes to confuse prey)?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study the aerodynamic properties of the kingfisher's beak. • Explore other birds with efficient diving techniques, like gannets. • Review research on fluid mechanics and aerodynamics in bird anatomy. **3.b Identify experts & connect to communities of biologists and naturalists.** • Collaborate with ornithologists studying avian biomechanics. • Work with transport engineers focusing on noise reduction and aerodynamics. • Engage with design consultants for high-speed train systems..
Step 4 – Abstract	4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.

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	 Source: https://www.flickr.com/photos/lipkee/505129764/ **Core functions** Noise reduction and streamlined movement. **Key elements** The pointed beak of the kingfisher reduces the shockwave created when diving into water, enabling silent and efficient motion. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design transportation systems with tapered shapes to minimize noise and energy loss, thereby enhancing efficiency in high-speed travel or underwater vehicles.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Streamlined shape reduces noise and energy consumption. **Ideas** Design quiet and efficient high-speed trains. Adapt the concept for airplanes or underwater vessels. **5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.** **Features**: Noise reduction, energy efficiency.

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	Context High-speed transportation systems, urban settings. **Constraints** Aerodynamic testing, manufacturing costs. **Selected concept** Noise-optimized bullet trains for urban areas.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Reduces noise pollution and energy consumption for urban high-speed trains, while improving passenger comfort. **Feasibility** Aerodynamic improvements are technically feasible but may require redesign of train exteriors. **Compatibility with the Earth's systems** Supports sustainable transportation goals by reducing energy use and emissions. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Conduct wind-tunnel testing to refine the nose shape. Collaborate with engineers to integrate aerodynamic features without compromising safety.

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=F_fZroQxD_g - "A kingfisher helped reshape Japan's bullet train - BBC World Service, 30 Animals podcast"

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Spider Silk-Inspired Synthetic Fibers

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do spiders create strong, lightweight silk? • How do natural systems combine strength and flexibility in materials? **2.b Ask yourself what your design wants to do.** • Provide strength and elasticity in one material. • Be lightweight and durable. • Adapt to different uses, such as medical sutures or protective gear. **2.c Flip the question. Consider opposite functions.** • How do spiders make their silk so strong? • How do natural systems produce weak fibres (e.g., cobwebs designed to break easily)?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study the molecular composition and structure of spider silk. • Research other natural fibres, such as silkworm silk or mussel threads. • Explore academic papers on bio-inspired materials and tensile strength. **3.b Identify experts & connect to communities of biologists and naturalists.** • Connect with arachnologists specializing in spider silk production. • Collaborate with textile engineers and materials scientists. • Engage with biomaterials research labs and startups.
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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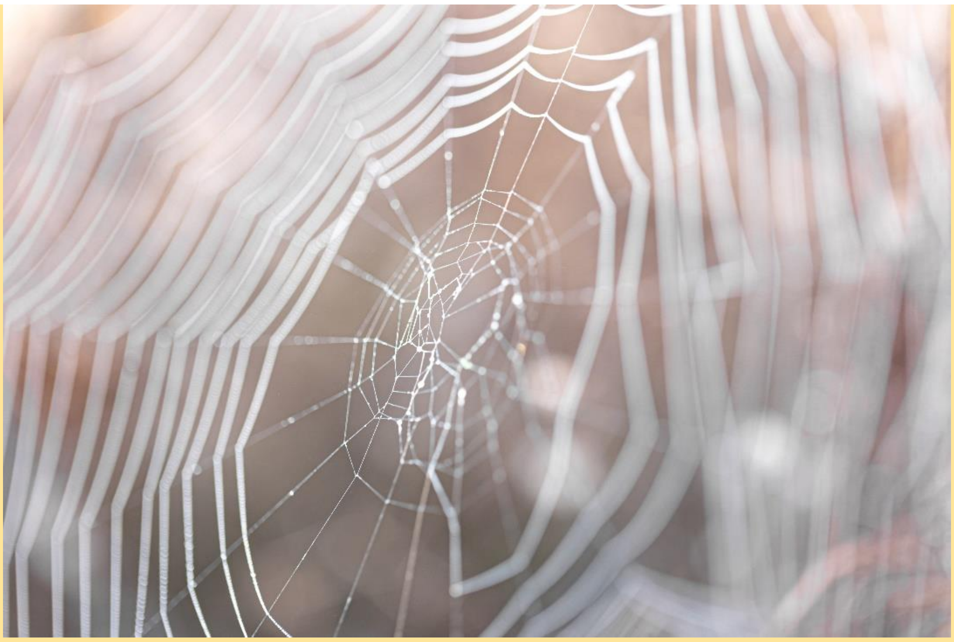

Source: https://www.freepik.com/free-photo/natural-abstract-background-with-cobwebs-sunlight_18857742.htm#fromView=search&page=1&position=9&uuid=08af6ed4-64b0-4e9b-a7b1-f7f92169bcdd

Core functions

Strength, elasticity, light weight.

Key elements

Spider silk is a protein-based fibre with a unique molecular structure that combines high tensile strength and flexibility.

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Develop lightweight, strong, and flexible materials for use in construction, safety gear, or medical applications, focusing on molecular alignment for durability.

Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

Features

High strength and elasticity, lightweight.

Ideas

Develop lightweight cables for construction. Create medical sutures that are both strong and flexible.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution.

Features

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	Strength, flexibility, and biocompatibility. **Context** Construction, medical, and sports equipment. **Constraints** Synthetic production costs and environmental sustainability. **Selected concept** Biodegradable surgical sutures for medical use.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Meets goals for strong, lightweight materials in medical and construction applications. **Feasibility** The synthetic production of spider silk proteins is advancing, but it requires scaling up for widespread use. **Compatibility with the Earth's systems** Use biodegradable or sustainable inputs to reduce environmental impact. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Experiment with alternative biopolymers to reduce costs. xplore hybrid materials to enhance functionality

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=cTF3Hy5w8lo - "A Spider Inspired Solution to Sustainable Fashion | Turning Liquid Into Thread=The Future of Design?"

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LET'S MIMIC SOLUTIONS

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Solution: Boxfish-Inspired Car Design

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How does the boxfish move efficiently through water despite its boxy shape?. • How do natural systems balance stability and low drag in their forms?. **2.b Ask yourself what your design wants to do.** • Reduce drag and fuel consumption. • Maintain stability and manoeuvrability. • Ensure safety and efficiency in design. **2.c Flip the question. Consider opposite functions.** • How does the boxfish reduce drag while maintaining stability?. • How do natural systems create instability or drag when needed (e.g., fish flaring fins to slow down)?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study the hydrodynamic shape of the boxfish and its unique carapace structure. • Research other aquatic animals with stable yet low-drag shapes. • Review literature on bio-inspired automotive design. **3.b Identify experts & connect to communities of biologists and naturalists.** • Partner with marine biologists specializing in fish morphology. • Work with automotive designers and engineers in biomimicry projects. • Collaborate with hydrodynamics experts in industrial applications..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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	 Source: https://www.inaturalist.org/photos/339539534 **Core functions** Stability, low drag. **Key elements** The boxfish has a streamlined body shape that balances drag reduction with stability, enabling efficient movement in water. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design vehicles or structures with rounded, streamlined shapes for improved stability and efficiency in fluid or air movement.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Streamlined body balances drag reduction and stability. **Ideas** Design compact cars with improved fuel efficiency. Use the shape for underwater 5.b Organise your ideas into categories that include the features, the context, the constraints, etc., and select the design concepts that best fit your solution. **Features** Low drag, high stability. **Context** Urban transportation, underwater exploration.

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	Constraints Consumer preferences, regulatory requirements. **Selected concept** Fuel-efficient city car with a streamlined design.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Streamlined design reduces drag and improves fuel efficiency in urban vehicles. **Feasibility** Car manufacturing processes can incorporate this design with minimal adjustments. However, consumer acceptance needs to be tested. **Compatibility with the Earth's systems** Reduces fuel consumption and aligns with green transportation initiatives. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Test prototypes in real-world driving conditions to gather consumer feedback and refine both aesthetics and functionality.

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=5tFqlhATUZs – “Mercedes-Benz bionic car”

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Namib Desert Beetle-Inspired Water Harvesting

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How does the Namib Desert beetle collect water from fog? • How do natural systems capture moisture from the air in arid environments? **2.b Ask yourself what your design wants to do.** • Capture and channel water efficiently. • Work in dry, low-humidity environments. • Be sustainable and adaptable to various climates. **2.c Flip the question. Consider opposite functions.** • How does the Namib beetle harvest water? • How do natural systems prevent moisture loss (e.g., cacti with water-retentive structures)?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study the water collection strategies of the Namib Desert beetle. • Explore other organisms in arid environments, such as cacti or lizards. • Review research on fog-harvesting mechanisms in nature. **3.b Identify experts & connect to communities of biologists and naturalists.** • Collaborate with entomologists studying desert beetles and their adaptations. • Work with environmental engineers focusing on water scarcity solutions. • Engage with sustainability researchers and desert ecologists..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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Source: Namib Desert Beetle-Inspired Water Harvesting AI created by Canva

Core functions

Water collection, survival in arid environments.

Key elements

The Namib Desert beetle has hydrophilic (water-attracting) bumps on its back that capture moisture from fog, channelling it to its mouth.

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Create materials or structures with moisture-attracting surfaces for water collection in dry areas, integrating passive systems for water harvesting

Step 5 – Emulate

5.a List your key information and explore as many ideas as possible.

Features

Hydrophilic bumps capture water from the air.

Ideas

Develop portable water-harvesting devices for arid regions and integrate them into buildings for passive water collection.

5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Features

Passive water collection, moisture condensation.

Context

Desert environments, drought-prone areas.

Constraints

Durability and cost of large-scale implementation.

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	Idea selected A rooftop system for water harvesting in dry regions.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Captures water passively, addressing water scarcity in arid regions. **Feasibility** Effective for small-scale applications; scalability for community use requires additional research. **Compatibility with the Earth's systems** Operates passively without energy input, reducing environmental impact. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Test prototypes in diverse climate conditions. Explore integration with existing water infrastructure

Additional resources:

https://biomimicry.org/

https://www.youtube.com/watch?v=TmyfqjXOf7M&t=25s – "Can Namib Desert Beetles Help Us Solve Our Drought Problems? | Think Like a Tree"

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A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Pinecone-Inspired Building Materials

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** • How do pinecones respond to changes in humidity? • How do natural systems regulate moisture or open/close mechanisms? **2.b Ask yourself what your design wants to do.** • Adapt to environmental moisture levels. • Control ventilation passively without external energy. • Enhance energy efficiency in buildings. **2.c Flip the question. Consider opposite functions.** • How do pinecones react to humidity changes? • How do natural systems resist environmental changes or remain unaffected by moisture (e.g., desert plants with waxy coatings)?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Study the hygroscopic properties of pinecones and their response to moisture. • Research other natural materials with adaptive responses to humidity. • Explore scientific papers on passive design inspired by plant mechanisms. **3.b Identify experts & connect to communities of biologists and naturalists.** • Partner with botanists studying seed dispersal and plant structures. • Collaborate with architects and civil engineers focused on sustainable design. • Engage with biomimicry networks and adaptive material researchers..
Step 4 – Abstract	**4.a Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.**

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	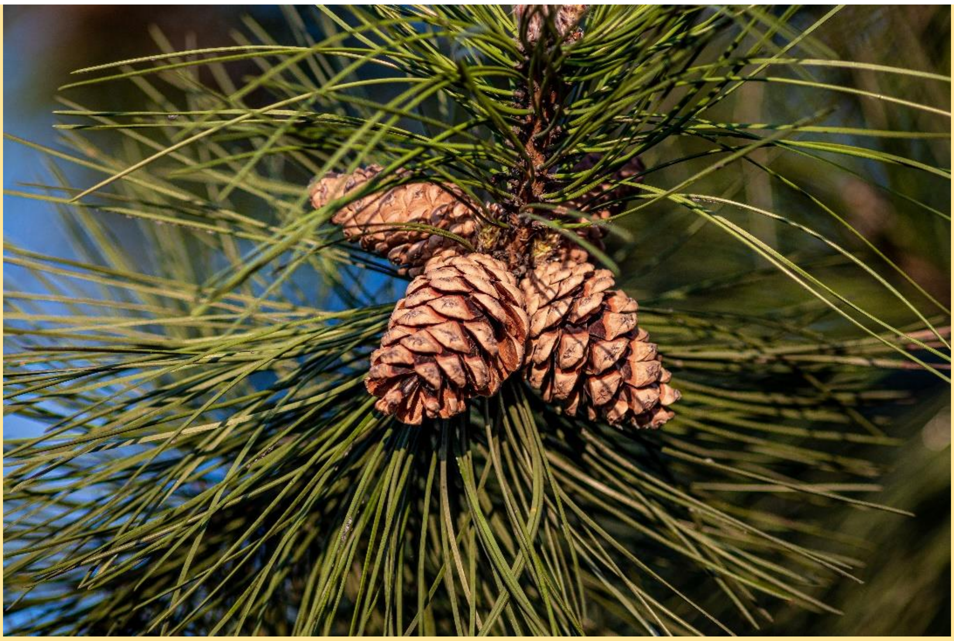 Source: https://www.freepik.com/free-photo/closeup-shot-pine-cones-hanging-tree_12859335.htm#fromView=search&page=1&position=6&uuid=93831a35-4f6b-47a0-b085-c080801f1261 **Core functions** Responsive material behaviour, moisture adaptation. **Key elements** Pinecones open or close their scales in response to humidity levels, utilising their structure to regulate seed dispersal. **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design building materials or structures that adjust to humidity changes, improving ventilation and reducing the need for mechanical systems in climate control.
Step 5 – Emulate	**5.a List your key information and explore as many ideas as possible.** **Features** Materials adapt to changes in humidity for natural ventilation. **Ideas** Develop smart building facades that open or close automatically based on weather conditions. Use for greenhouses or climate-sensitive buildings **5.b Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.** **Features** Responsive material, natural humidity control.

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	Context Green architecture and energy-efficient construction. **Constraints** Material cost and durability under varying conditions. **Selected concept** Humidity-responsive building panels for greenhouses.
Step 6 – Evaluate	**6.a Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment** Responsive materials naturally manage humidity, reducing energy consumption in climate-sensitive buildings. **Feasibility** Material development is achievable but requires testing for long-term durability. **Compatibility with the Earth's systems** Low-energy and sustainable material aligns with green building initiatives. **6.b Revise and revisit previous steps as necessary to generate a viable solution.** Conduct field tests in various climates. Collaborate with architects to refine integration into building designs.

Additional resources:

https://biomimicry.org/

https://youtube.com/shorts/3o6ZeiqpA8g?si=dUHuQroWoqAH-TUK -

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Passive cooling system inspired by desert beetles

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do beetles, such as the Namib Desert beetle, survive in extremely hot environments with little water? **Context** These beetles manage heat and water loss using unique physical adaptations. The Namib beetle, for instance, uses a combination of hydrophilic bumps and hydrophobic channels on its back to collect and funnel water from morning fog. Additionally, some beetles regulate body temperature through reflective shell coatings, behavioural shading, or microstructural surface adaptations that minimise heat absorption. **2.b Ask yourself: What do I want my design to do?** • Regulate temperature passively using natural principles. • Collect moisture or disperse heat in buildings or electronics. • Minimise or eliminate the need for energy-consuming cooling systems. **2.c Flip the question. Consider opposite functions.** How do desert beetles avoid overheating during the hottest parts of the day? How do organisms retain or conserve moisture and avoid water loss?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Namib Desert beetle (stenocara gracilipes):** Uses surface structures to harvest water from fog and manage heat. • **Fennec fox:** Has large ears to dissipate heat. • **Saharan silver ant:** Reflects sunlight with unique triangular hairs. • **Cactus and agave:** Use self-shading and reflective surfaces to reduce water loss and overheating. • **Termites:** Engineer mounds to passively regulate temperature. **3.b Identify experts & connect to communities of biologists and naturalists.**

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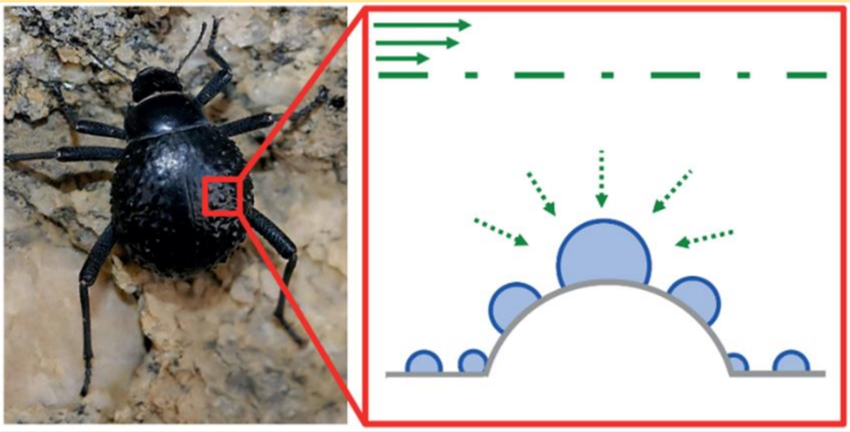
	• Entomologists specializing in desert insect adaptations. • Materials scientists and engineers researching bioinspired passive cooling surfaces. • Architecture and biomimicry communities (e.g., Biomimicry Institute, AskNature.org). • Climate-responsive architecture experts and thermal dynamics researchers..
Step 4 – Abstract	**4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** Passive cooling, moisture collection, surface temperature control. **Key elements** • **Micro- and nano-scale surface patterning**: Alternating hydrophilic and hydrophobic zones. • **Heat-reflective surfaces**: Structural colours or coatings that reduce solar absorption. • **Behavioural/ structural shielding**: Orientation and surface textures to reduce heat intake.  Image retrieved from Researchgate **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** • Design **building materials** or **coatings** that mimic beetle shell patterns to collect dew or reflect heat. • Create **roofing panels** with textured surfaces to channel condensation or reflect infrared light. • Develop **ventilated facade systems** with beetle-inspired microstructures for enhanced evaporative cooling.

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- Use **surface geometry** to enhance convective cooling and radiation emission, reducing heat buildup..

Step 5 – Emulate

5.1 List your key information and explore as many ideas as possible.

Key concepts

- Hydrophilic/hydrophobic surface engineering.
- Passive water harvesting and cooling.
- Reflective and textured material coatings.
- Directional water transport systems.

Ideas

- Self-cooling building claddings.
- Fog-harvesting walls for arid regions.
- Beetle-inspired textiles for thermoregulating clothing.
- Passive cooling covers for electronics or outdoor units.
- Beetle-shell inspired car paints or roof coatings to reduce internal heat gain.

5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context	Features	Constraints
Buildings in hot/arid zones	Passive dew collection, heat reflection, and cooling	Scaling surface texture, durability
Electronics	Overheat reduction using surface structuring	Miniaturization, material compatibility
Textiles	Thermoregulation and moisture control	Comfort, washability, and affordability
Urban furniture/shelters	Self-cooling benches or shaded walkways	Weather resistance, vandal-proofing

Idea selected

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	A building facade system that mimics the Namib beetle's shell to cool and collect water in hot, arid climates passively. This system uses micro-textured panels to direct condensed fog or dew toward storage and ventilation units.
Step 6 – Evaluate	**6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.** **Alignment with criteria** • Meets goals for low-energy cooling and water conservation. • Inspired directly by an organism that thrives in extreme heat and water scarcity. • Can integrate with sustainable architecture or green building certification systems. **Feasibility** • **Technical**: Material science supports fabrication of micro-structured surfaces; fog-harvesting has proven viability. • **Economic**: Initial R&D investment is moderate; long-term savings in energy/water costs are high. • **Environmental**: Promotes sustainable cooling with no emissions or refrigerants. Materials should aim for recyclability. **6.2 Revise and revisit previous steps as necessary to generate a viable solution.** • **Prototype testing:** Evaluate surface textures in lab-controlled heat and humidity conditions. • **Iterate materials:** Improve hydrophobic/hydrophilic contrast for fog collection. • **Optimise shape:** Refine geometry for different climatic contexts (e.g., vertical vs. horizontal installations). .

Additional resources:

AskNature on Namib Beetle Water Harvesting

https://biomimicry.org/

https://www.sciencedirect.com/science/article/abs/pii/S1364032118302302

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3930861/

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Manta ray-inspired underwater propulsion

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do manta rays achieve manoeuvrable underwater propulsion? **Context** Manta rays and similar marine animals propel themselves using undulating fin movements, generating thrust with minimal turbulence. Their flexible, wing-like pectoral fins allow silent, stable, and energy-efficient gliding through water. **2.b Ask yourself: What do I want my design to do?** • Propel efficiently and quietly through water. • Replace or supplement traditional thrusters. • Enable agile, bioinspired underwater movement. **2.c Flip the question. Consider opposite functions.** • How do traditional propeller systems cause inefficiencies and noise?. • How can flexible, soft-bodied movement reduce wear, noise, and turbulence?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Manta rays:** Large surface area fins with oscillatory motion. • **Stingrays and eagle rays:** Use dynamic wing-like propulsion. • **Cephalopods (like squids and octopuses):** Use jet propulsion and body undulation. • **Fish (e.g., tuna, eels):** Offer contrasting caudal propulsion models. **3.b Identify experts & connect to communities of biologists and naturalists.** • Marine biologists specialising in locomotion. • Engineers in biomimetic robotics and soft robotics. • Research institutions like MIT's Biomimetic Robotics Lab..

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<td>Step 4 – Abstract</td>
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4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.

Core functions

Silent propulsion, manoeuvrability, energy efficiency.

Key elements

- Oscillating fin-based thrust instead of rotary propellers.
- Flexibility in body and fins for adaptive movement.
- Streamlined, drag-reducing body shape.
- Smooth energy transfer along the fin's surface.

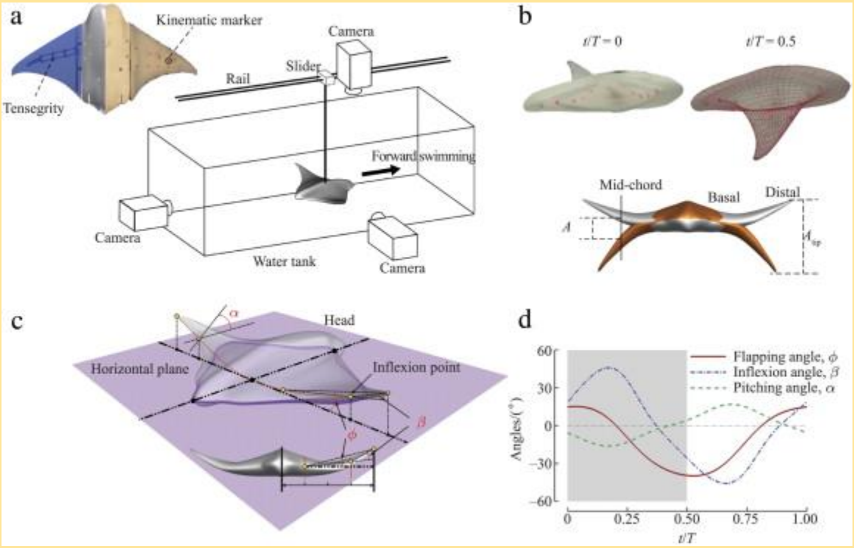

Image retrieved from [Sciencedirect]

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Create soft-robotic fin systems that oscillate like manta ray pectoral fins to propel underwater vehicles silently and efficiently. Use flexible polymers or smart materials controlled by precision actuators to replicate natural wave propagation.

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<td>Step 5 – Emulate</td>
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5.1 List your key information and explore as many ideas as possible.

Ideas

- Underwater drones with lateral fin propulsion.
- Autonomous exploration bots with ray-like movement.
- Rescue or inspection devices that move silently around coral reefs or infrastructure.

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	5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.
Step 6 – Evaluate	**6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.**

Context	Features	Constraints
Underwater Drones	Silent gliding, high manoeuvrability	Cost, waterproofing actuators
Environmental Surveys	Low disturbance to marine life	Data collection integration
Military/Stealth Ops	Minimal acoustic signature	Complex control systems
Coral Reef Monitoring	Precise control and obstacle avoidance	Size restrictions, low-energy systems

Idea selected

An autonomous underwater glider with manta-inspired lateral fin propulsion, designed for quiet marine surveys and exploration.

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

Alignment

- Matches goals for sustainable, efficient, and low-noise propulsion.
- Bioinspired movement enables operation in ecologically sensitive zones.

Technical feasibility

- Advances in soft robotics make flexible propulsion viable.
- Control systems for undulatory motion are improving.

Business model

- Strong potential in marine research, defence, and aquaculture.
- Eco-tourism and underwater photography may benefit from silent propulsion systems.

Earth compatibility

- Low energy consumption.
- Reduced mechanical pollution and marine disruption.
- Biodegradable or recyclable construction materials can enhance sustainability.

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	6.2 Revise and revisit previous steps as necessary to generate a viable solution. • Test materials for durability and energy efficiency. • Optimise actuator placement for smoother fin wave propagation. • Expand to modular designs for variable depth and speed use.

Additional resources:

https://asknature.org

https://biomimicry.org/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Bio-inspired self-healing concrete

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do biological organisms heal themselves after injury? Nature responds to damage through **autonomous repair mechanisms**, like: • **Human bones** regenerating fractures via mineral deposition. • **Skin** closes wounds through cellular signalling. • **Plants** seal bark wounds with resins. **Natural model** **Bacteria-activated healing**, as seen in some microbial interactions, where calcite-producing bacteria fill voids in living systems. **2.b Ask yourself: What do I want my design to do?** • Heal microcracks in concrete automatically. • Respond to water or air infiltration by activating the healing process. • Extend the operational life of buildings and bridges. **2.c Flip the question. Consider opposite functions.** • Instead of preventing cracks entirely, how can we enable materials to respond intelligently to damage?. • How can we mimic life's ability to regenerate in an inorganic material?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Bones:** Mineralisation processes fill cracks over time. • **Trees:** Bark regenerates after injury using internal fluid and sap. • **Bacteria:** Spore-forming bacteria activate under moisture to produce limestone, sealing gaps.

	3.b Identify experts & connect to communities of biologists and naturalists. • Microbiologists researching calcifying bacteria. • Civil engineers focused on smart materials. • Biomimicry institutes and material scientists..
Step 4 – Abstract	**4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** Autonomous repair, moisture activation, mineralisation. **Key elements** • Triggered by environmental cues (e.g. moisture). • Microorganisms or microcapsules release binding agents. • Fills microcracks before they propagate.

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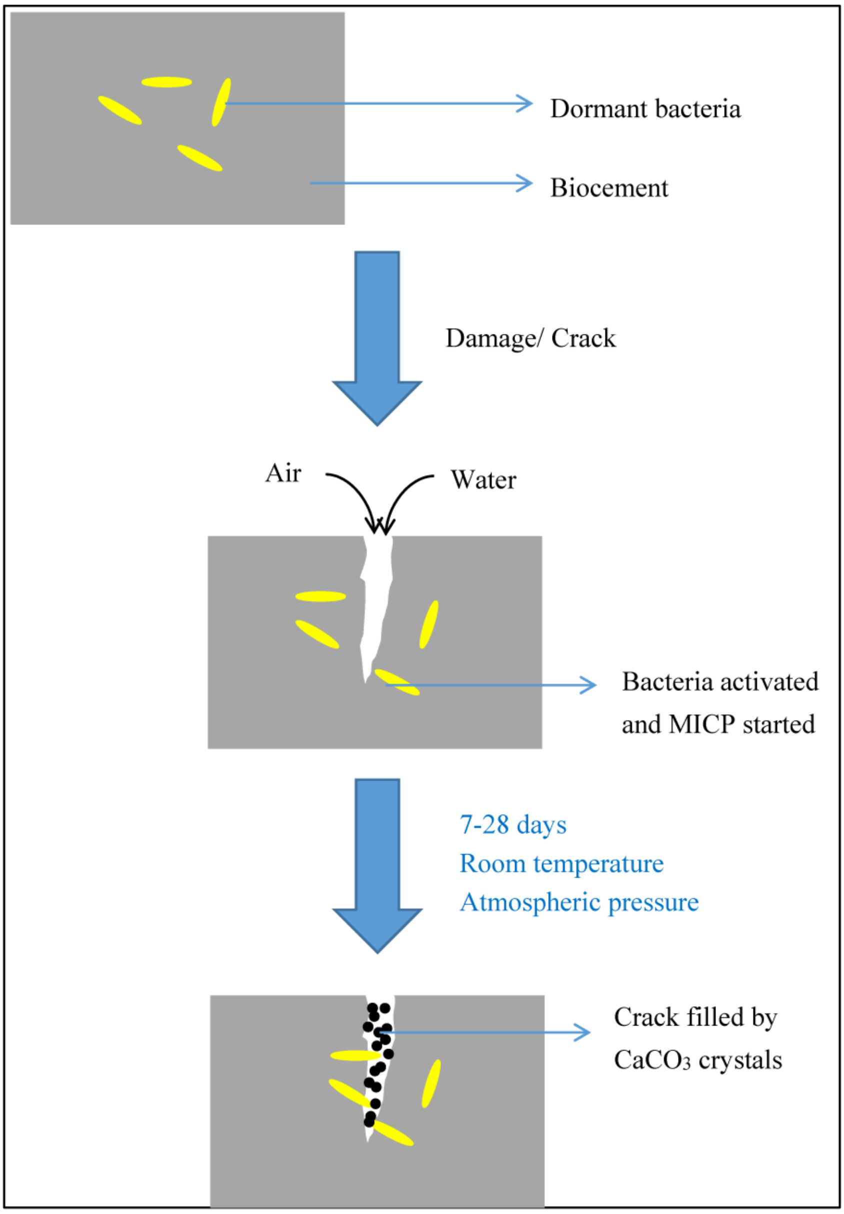

Image retrieved from MDPI

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Develop concrete embedded with capsules or spore-forming bacteria that release calcite or binding polymers when cracks form and moisture enters, effectively healing the structure before significant damage occurs.

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Step 5 – Emulate

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5.1 List your key information and explore as many ideas as possible.

Key ideas

- Bacteria-activated concrete.

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- Microencapsulated healing agents.
- Sensors that detect crack formation and trigger healing.
- Integration with modular building components.

5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context	Features	Constraints
Infrastructure (bridges, roads)	Water-activated healing, microbially driven	Exposure to contaminants, temperature cycles
High-rise buildings	Long-term integrity, smart structure potential	Certification hurdles, embedded systems cost
Military bunkers	Damage resistance, lower visibility of maintenance	Harsh conditions, chemical compatibility
Housing in remote areas	Minimal maintenance, long lifespan	Lack of skilled labour, limited monitoring tools

Idea selected

Bacteria-based self-healing concrete that activates upon crack formation and contact with moisture, sealing gaps with calcium carbonate deposits.

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Criteria fit

- Passive, automatic healing.
- Increases structural resilience.
- Reduces material waste over time.

Feasibility

- Technically viable (already in prototype/commercial trial phase).

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	• Cost-effective over the long term compared to traditional repairs. • Environmentally positive due to reduced reconstruction needs. **Earth compatibility** • Aligns with circular economy principles. • Bacteria are naturally occurring and environmentally benign. • Can reduce carbon emissions from concrete production by extending the lifecycle. **6.2 Revise and revisit previous steps as necessary to generate a viable solution.** • Test bacterial survivability over decades. • Adapt for extreme climates or saltwater environments. • Explore hybrid systems (e.g., bacterial + chemical capsules). .

Additional resources:

https://asknature.org

https://biomimicry.org/

https://www.mdpi.com/1996-1944/13/21/4993

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Shark-skin inspired anti-fouling surfaces

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do organisms in nature, such as sharks, manage to prevent the accumulation of microorganisms and other unwanted organisms on their surfaces without relying on chemical defences or constant cleaning? Sharks avoid biofouling without the use of secretions or chemicals. Their skin is covered in microscopic riblet structures (dermal denticles) that create a rough, flowing surface, preventing microorganisms from settling. **2.b What do I want my design to do?** • Prevent adhesion of algae, bacteria, and barnacles. • Work passively- no toxins or active cleaning. • Be applicable in dynamic environments (e.g., moving ships). **2.c Flip the question** • Instead of using chemical deterrents, how can we design surfaces that inherently prevent fouling?. • How can texture alone discourage colonisation?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Shark skin:** Ribbed texture prevents attachment. • **Dolphin skin:** Constantly regenerating and low-friction. • **Lotus leaves:** Superhydrophobic and self-cleaning. • **Fish scales:** Flexible and protective. **3.b Identify experts & connect to communities of biologists and naturalists.** • Marine biologists and biomaterials scientists. • Naval engineers and green coating developers. • Biomimicry communities like Biomimicry 3.8..

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<td>Step 4 – Abstract</td>
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4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.

Core functions

Anti-adhesion, self-cleaning, passive biofouling resistance.

Key elements

- Micro/nanoscale riblet patterns.
- Directional flow channels.
- Surface hardness and elasticity balance.

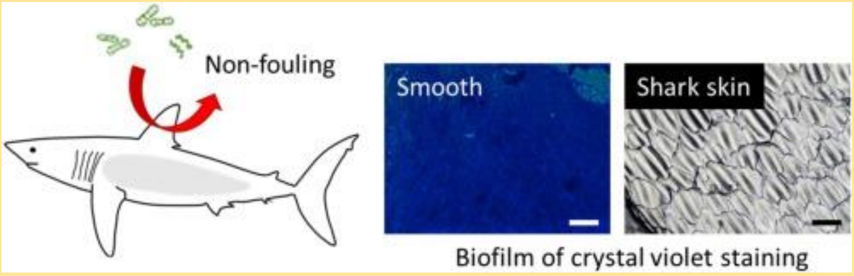

Image retrieved from Elsevier

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Develop coatings or films with micropatterned surfaces that mimic shark skin to disrupt microbial adhesion. Use 3D-printing, embossing, or nanoimprint lithography to scale production. Ensure application to boats, medical devices, and even architectural surfaces.

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<tr>
<td>Step 5 – Emulate</td>
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5.1 List your key information and explore as many ideas as possible.

Key ideas

- Shark-skin textured wraps for ships.
- Micro-patterned hospital equipment coatings.
- Anti-biofilm surfaces in wastewater pipes.
- Paints with embedded riblet patterns.

5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context	Features	Constraints

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Marine vessels	Riblet-patterned hull coatings, drag reduction	UV wear, considerable surface coverage cost
Medical devices	Anti-bacterial textured coatings	Biocompatibility, cleaning protocols
Water infrastructure	Fouling-resistant pipe interiors	Flow dynamics, installation complexity
Architecture (e.g. pools)	Algae-preventing tiles or coatings	Aesthetic compatibility, weathering

Idea selected

Flexible shark-skin inspired surface wrap for boats and underwater infrastructure that prevents fouling without leaching chemicals.

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Criteria fit

- Passive resistance to fouling.
- No chemicals involved.
- Scalable to large surfaces.

Feasibility

- Technologically viable with modern microfabrication.
- Costs more than paint but is offset by durability and environmental safety.

Earth compatibility

- Zero toxicity.
- Enhances ocean health.
- Recyclable substrate materials possible.

6.2 Revise and revisit previous steps as necessary to generate a viable solution.

- Improve durability for high-abrasion areas.
- Explore hybrid solutions: texture + non-toxic repellents.
- Test performance in various marine environments..

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Additional resources:

https://asknature.org

https://biomimicry.org/

https://www.sciencedirect.com/science/article/abs/pii/S0927776519308823

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Forest-Inspired Urban Air Filtration

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do forest ecosystems purify the air by capturing and breaking down airborne pollutants through physical and biochemical processes involving leaves, bark, and microbes? **2.b What do I want my design to do?** • Remove air pollutants passively using forest-mimicking surfaces. • Function in dense urban environments. • Improve human health and biodiversity. **2.c Flip the question** • Instead of using mechanical filtration systems, how can we design **architectural elements that act like trees**?. • What natural systems remove air contaminants without noise or electricity?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Forests:** Leaves capture dust; bark and soil bacteria break down pollutants. • **Mosses and lichens:** Absorb heavy metals and fine particles. • Epiphytes (e.g., ferns): Grow vertically and filter air. • **Soil microbiomes:** Transform harmful gases into nutrients. **3.b Identify experts & connect to communities of biologists and naturalists.** • Ecologists and botanists studying urban vegetation. • Environmental engineers. • Green infrastructure and living wall designers. .
Step 4 – Abstract	**4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram/ drawing and/ or find images that can inform the design.**

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Core functions

Particulate capture, gaseous absorption, passive chemical transformation.

Key elements

- Dense leaf structures and porous surfaces.
- Microbial action in roots and biofilms.
- Vertical layering and varied textures.

Image retrieved from Mymodernmet

Retrieved from Whatdesigncando

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	4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective. Design vertical green walls, modular moss panels, or biofilters for urban use. Integrate airflow-maximising forms, surface textures, and plants or biofilms that passively filter and degrade pollutants.
Step 5 – Emulate	**5.1 List your key information and explore as many ideas as possible.** **Key ideas** • Living facades with diverse plant species. • Air-cleaning kiosks or bus stops with moss columns. • Urban furniture with embedded biofiltration modules. • Rooftop or roadside "mini-forests" with layered canopy design. **5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.**

Context	Features	Constraints
Building facades	Vertical green walls with air-purifying plants	Irrigation, structural support
Public transportation	Moss-filter bus stops or station panels	Exposure to vandalism, seasonal variation
Urban plazas/parks	Tree-like structures with filtering capabilities	Space usage, maintenance
School zones/hospitals	Bio-reactive walls or air-cleaning outdoor furniture	Cost, integration with existing structures

	Idea selected Modular forest-inspired green wall system using moss and microbe-rich substrates for passive urban air purification.
Step 6 – Evaluate	**6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** **Criteria fit** • Passive resistance to fouling.

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	• No chemicals involved. • Scalable to large surfaces. **Feasibility** • Technologically viable with modern microfabrication. • Costs more than paints but is offset by durability and environmental safety. **Compatibility with the Earth's systems** • Zero toxicity. • Enhances ocean health. • Recyclable substrate materials possible. **6.2 Revise and revisit previous steps as necessary to generate a viable solution.** • Customise plant/moss species for regional air pollutants. • Embed sensors to track air quality and plant health. • Combine with educational or aesthetic functions.

Additional resources:

- https://asknature.org
- https://biomimicry.org/
- https://mymodernmet.com/briiv-air-filter/
- https://www.whatdesigncando.com/stories/vertical-forests-reduce-energy-use-improve-urban-air-quality/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Owl Feather-Inspired Acoustic Panels

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do owls achieve near-silent flight through physical adaptations in their feathers that scatter and absorb sound, enabling them to hunt without alerting their prey? **2.b What do I want my design to do?** • Reduce unwanted environmental and indoor noise using passive physical mechanisms. • Be installable in buildings, vehicles, or infrastructure. • Improve soundscapes without adding electronic systems. **2.c Flip the question** • Instead of blocking or cancelling sound electronically, how can we **disperse or absorb sound like owls** do?. • What textures or microstructures passively dampen sound in nature?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Owl feathers:** Fringe-like structures on the leading and trailing wing edges scatter air turbulence and suppress sound. • **Pine trees or bamboo:** Absorb and diffuse wind-generated sound through flexible, porous canopies. • **Mosses and ferns:** Soft, layered structures that absorb vibration and noise. **3.b Identify experts & connect to communities of biologists and naturalists.** • Ornithologists studying owl morphology. • Acoustic engineers and biomimicry researchers. • Soundscape design consultants and environmental psychologists..

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Step 4 – Abstract

4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram/ drawing and/ or find images that can inform the design.

Core functions

Sound absorption, turbulence diffusion, vibration damping.

Key elements

- Serrated edges and porous feather texture.
- Irregular surface topography.
- Directional sound scattering.

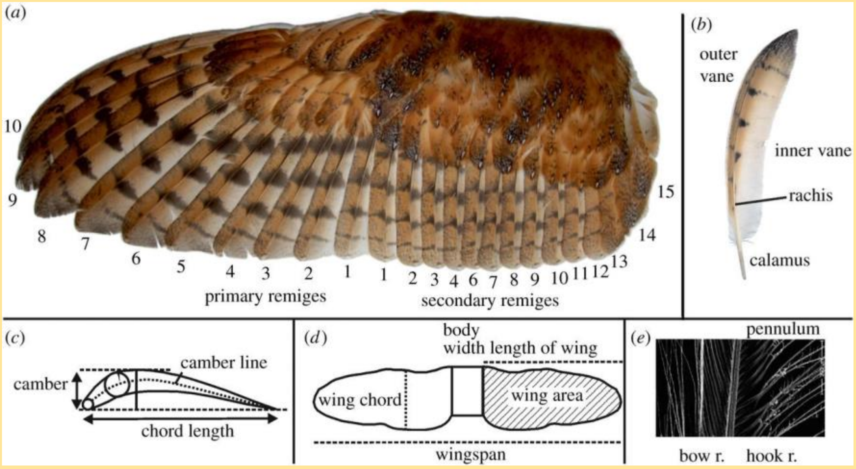

Image retrieved from [Royal Society Publishing]

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Design acoustic panels and baffles with microstructured or fringed surfaces that replicate the appearance of owl feathers. These could be created using sound-absorbent composite materials, arranged in curved or layered geometries that reflect and trap sound waves in indoor or outdoor settings.

Step 5 – Emulate

5.1 List your key information and explore as many ideas as possible.

Key ideas

Lightweight ceiling panels with micro-grooved, fringe-like textures.

- Outdoor noise barriers shaped like feather arrays.
- Public seating or partitions using vibration-dampening soft textures.
- Modular acoustic panels for classrooms or coworking spaces.

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	5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context	Features	Constraints
Urban housing developments	Facade panels inspired by owl feathers to absorb traffic and industrial noise, improving resident comfort	Weather resistance, integration into building codes, and cost of biomimetic materials
Schools and public libraries	Interior ceiling and wall panels with microstructured surfaces to diffuse and absorb sound, promoting a quiet learning environment	Fire safety certification, aesthetic requirements, cleaning/maintenance
Public transport infrastructure (train stations, subways)	Curved owl-feather-mimic baffles to dampen high-frequency sounds from engines and PA systems	High foot traffic durability, installation logistics, vibration resistance
Open office workspaces	Lightweight hanging partitions and wall systems based on owl wing fringe patterns to reduce human speech noise	Installation flexibility, material costs, compatibility with existing office layouts

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

Criteria fit

- Effectively meets the goal of passive noise reduction.
- Inspired directly by owl wing morphology.
- Scalable to multiple architectural contexts.

Feasibility

- Technically viable with today's manufacturing (CNC, 3D printing, moulded polymers).
- Low energy use compared to active noise control.

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	• Can be integrated into aesthetic design. **Earth compatibility** • Panels made of biodegradable or recycled fibres are eco-friendly. • Reduces acoustic pollution without increasing energy load. **6.2 Revise and revisit previous steps as necessary to generate a viable solution.** • Tailor panel surface texture to specific frequency ranges (e.g. traffic vs. human speech). • Test for fire safety, mould resistance, and indoor air quality compatibility. • Explore partnerships with interior design brands or urban furniture producers..

Additional resources:

https://asknature.org

https://biomimicry.org/

https://mymodernmet.com/briiv-air-filter/

https://royalsocietypublishing.org/doi/10.1098/rsfs.2016.0078

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Lotus Leaf & Penguin Feather-Inspired Anti-Icing Surfaces

<table>
<tr><th>BIOMIMICRY DESIGN</th><th>Description</th></tr>
<tr><td>Step 2 – Biologise</td><td>2.a Ask yourself how nature can solve this.

How do lotus leaves and penguin feathers prevent water from sticking and freezing on their surfaces by using microscopic textures and surface chemistry that repel moisture and limit ice adhesion?

2.b What do I want my design to do?
Passively prevent or reduce ice accumulation.
Avoid the use of electricity or chemicals.
Be scalable and adaptable to different surface materials.
2.c Flip the question
Instead of removing ice after it forms, how can we stop it from forming or sticking in the first place?.
How can we mimic natural strategies for moisture repellence and thermal insulation?.</td></tr>
<tr><td>Step 3 – Discover</td><td>3.a Search for natural models that match the same functions and context as your design solution.
Lotus leaf: Superhydrophobic micro/nano structures that cause water to bead up and roll off, preventing freezing.
Penguin feathers: The overlapping barbs trap air, reducing contact with water and limiting freezing, while promoting rapid drying.
Butterfly wings and springtail skin: Repel moisture through patterned scales and roughness.
3.b Identify experts & connect to communities of biologists and naturalists.
Surface engineering researchers in anti-icing technologies.
Biologists studying cold-climate adaptations.
Materials science and textile innovation labs..</td></tr>
</table>

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Step 4 – Abstract

4.1 Summarize the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.

Core function

Super hydrophobicity, low thermal conductivity, and moisture repellence.

Key elements

- Hierarchical roughness at micro- and nano-scales.
- Wax-like surface coatings in nature.
- Air-trapping structures that insulate or shed moisture quickly.

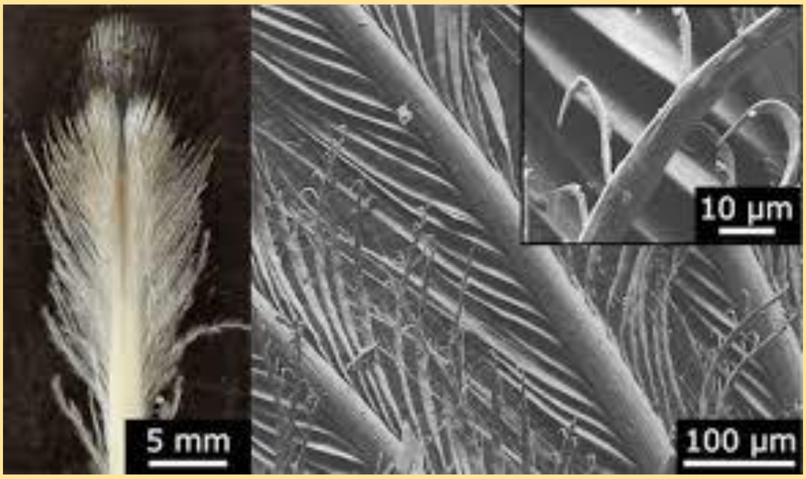

Image retrieved from [DownToEarth]

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Create coatings or surface treatments that mimic lotus leaf microstructures and penguin feather arrangements. Incorporate air-

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trapping patterns, low surface energy materials, or 3D-textured films for use on infrastructure or vehicles exposed to cold.

Step 5 – Emulate

5.1 List your key information and explore as many ideas as possible.

Key ideas

- Transparent, anti-icing window films for cars and aircraft.
- Protective coatings for wind turbine blades in snowy regions.
- Penguin-inspired fibre coatings for extreme-weather clothing.
- Anti-icing road reflectors or rail infrastructure panels.

5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context	Features	Constraints
Aircraft wings/windows	Transparent, hydrophobic textured coatings	UV resistance, aerodynamic tolerance, and optical clarity
Wind turbine blades	Textured surfaces with ice-repelling grooves	Durability under wind and rain erosion
Cold-weather clothing	Lightweight fibres with air-trapping, moisture-wicking design	Breathability, manufacturing cost, comfort
Urban infrastructure (rails, roads)	Ice-resistant panels or tiles inspired by the lotus leaf texture	Impact resistance, installation feasibility

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

Criteria fit

- Passive, nature-based solution that eliminates toxic chemicals and reduces energy use.
- Inspired directly by two robust, field-tested natural models (lotus + penguin).

Feasibility

- Laboratory success in creating superhydrophobic coatings.
- Requires durability testing for mechanical wear, UV exposure, and dirt accumulation.

Compatibility with the Earth's systems

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	• Avoids polluting de-icing agents. • Materials can be biodegradable or recyclable. • Promotes long-term sustainability in multiple sectors. **6.2 Revise and revisit previous steps as necessary to generate a viable solution.** • Customise microstructure designs for different climates. • Combine with solar-absorbing or insulating materials. • Modularise surface applications for ease of repair or replacement..

Additional resources:

https://asknature.org

https://biomimicry.org/

https://www.downtoearth.org.in/wildlife-biodiversity/penguin-feathers-help-inspire-new-de-icing-techniques-87092

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Lotus Leaf & Butterfly Wing-Inspired Water-Repellent Textiles

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do lotus leaves and butterfly wings repel water using structured surface textures and hydrophobic chemistry that prevent moisture from clinging to or penetrating the surface? **2.b What do I want my design to do?** • Passively repel water and moisture. • Be safe for skin and the environment. • Retain flexibility, softness, and breathability. **2.c Flip the question** • Instead of waterproofing by sealing or blocking, how can we **keep surfaces dry through texture alone**?. • Can we create **structured, breathable surfaces** that repel water at a microscopic level?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • Lotus leaves: Have micro-papillae covered in nanostructures that trap air and reduce water contact. • Butterfly wings: Scales form patterns that create superhydrophobicity and iridescence. • Duck feathers: Water rolls off thanks to layered, waxy barbs. • Spider silk: Beads and channels direct water away. **3.b Identify experts & connect to communities of biologists and naturalists.** • Textile engineers focused on functional finishes. • Biophysics researchers in micro/nanostructures. • Green chemistry professionals working on fluorine-free repellents..
Step 4 – Abstract	**4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram/ drawing and/ or find images that can inform the design.**

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Core functions

Super hydrophobicity, breathability, and capillary-driven water removal.

Key elements

- Multi-scale (micro and nano) roughness.
- Hydrophobic surface materials or treatments.
- Flexible structure allowing movement and air flow.

Deriving technology from nature: A team of chemists from the PTRI reproduces the Lotus Effect as demonstrated by the taro leaf *(left)* to develop pineapple/cotton water repellant fabrics *(right)*.

Image retrieved from Ptri.dost.gov.ph

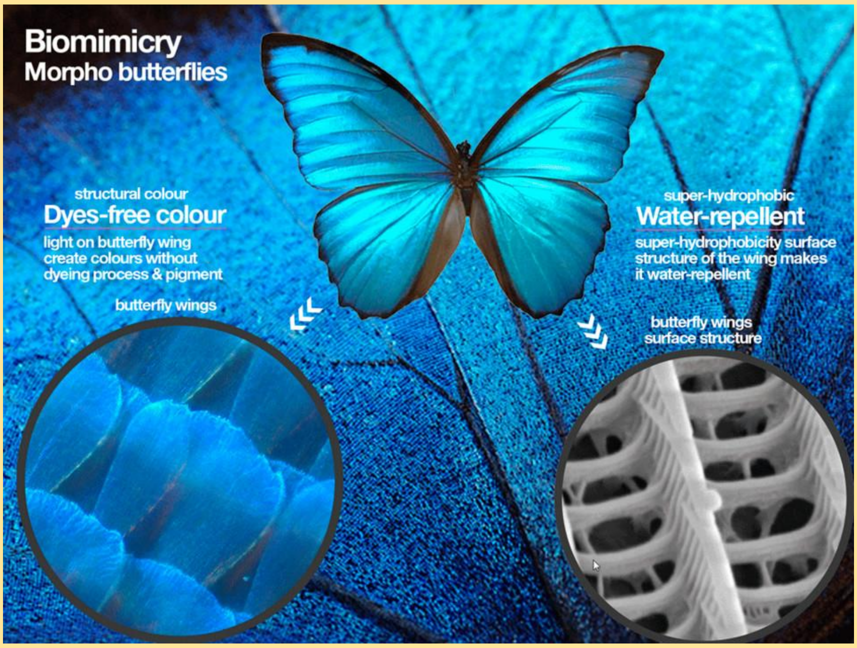

Image retrieved from LinkedIn

4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.

Develop fabrics with structured fibres or surface treatments that mimic the lotus leaf and butterfly wing. Use non-toxic hydrophobic compounds (e.g. silicones, waxes, or graphene-based coatings) and

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	textured fibre weaving techniques to create water-shedding, breathable textiles.
Step 5 – Emulate	**5.1 List your key information and explore as many ideas as possible.** **Key ideas** • Athletic wear that remains dry and breathable during intense activity. • Rainproof medical gowns or PPE with natural superhydrophobic coatings. • Fashion textiles with water-beading effects and colour-shifting surfaces (butterfly-inspired). • Eco-friendly outdoor gear without chemical repellents. **5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.**
Step 6 – Evaluate	**6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.** **Criteria fit** • Passive, non-toxic, breathable solution. • Mimics two well-understood, effective biological models. **Feasibility**

Context	Features	Constraints
Outdoor sportswear	Breathable fabrics with lotus-like water repellence	Wash durability, tactile softness, and swvapourapor transfer
Protective medical clothing	Non-toxic hydrophobic coating, lightweight barrier properties	Sterilization compatibility, biodegradability
Fashion & design textiles	Color-shifting, water-shedding micro-patterns (butterfly)	Cost of structure replication, consistency in large areas
Technical uniforms (rescue, military)	Durable, dry-on-contact outer layers	Abrasion resistance, bulk/weight balance

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	• Ongoing success in textile nanotechnology and green chemistry. • Requires a balance of performance, comfort, and sustainability. **Compatibility with the Earth's systems** • Avoids harmful fluorochemicals (PFAS). • Can use recycled fabrics and biodegradable polymers. • Reduces the need for reapplication or harsh cleaning. **6.2 Revise and revisit previous steps as necessary to generate a viable solution.** • Improve resistance to washing cycles and abrasion. • Test compatibility with dyed or printed fabrics. • Combine bioinspired design with renewable fibre technologies (e.g., hemp, bamboo). .

Additional resources:

https://asknature.org

https://biomimicry.org/

https://www.ptri.dost.gov.ph/s-t/philippine-silk-s-t-program/2-transparency-seal/uncategorised/73-mimicking-nature-s-waterproof-technology

https://www.linkedin.com/pulse/biomimicry-nature-inspires-design-high-tech-apparel-siddhi-mathur/

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WP3 Training Modules on Biomimicry Process Design

Task 3.1/ A1. Developing Self-learning Kit for VET students - LP: ATS / CPs: ALL

LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Whale-Inspired Wind Turbine Blades

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do humpback whales achieve extraordinary agility and lift in water using large, irregularly shaped flippers with tubercles (bumps) that optimise flow separation and reduce drag? **2.b What do I want my design to do?** • Improve lift and efficiency in wind turbine blades. • Enhance performance in turbulent or low-speed airflow. • Reduce structural stress and mechanical wear. **2.c Flip the question** • Instead of streamlining blades for smooth surfaces, what if **irregular shapes like tubercles improve performance**? • How can turbulent airflow be used constructively?
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Humpback whale flippers:** Tubercles on leading edges create alternating pressure zones, increasing lift and delaying stall. • **Bird wings:** Adjust shape dynamically for efficient gliding or flapping. • **Fish fins:** Passive flexibility enhances propulsion and steering. **3.b Identify experts & connect to communities of biologists and naturalists.** • Marine biologists and fluid dynamics researchers. • Aerospace engineers working in biomimetic aerodynamics. • Renewable energy institutions.
Step 4 – Abstract	**4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, make a diagram/ drawing and/ or find images that can inform the design.** **Core functions** Lift generation, turbulence management, stall delay. **Key elements** • Leading-edge bumps (tubercles).

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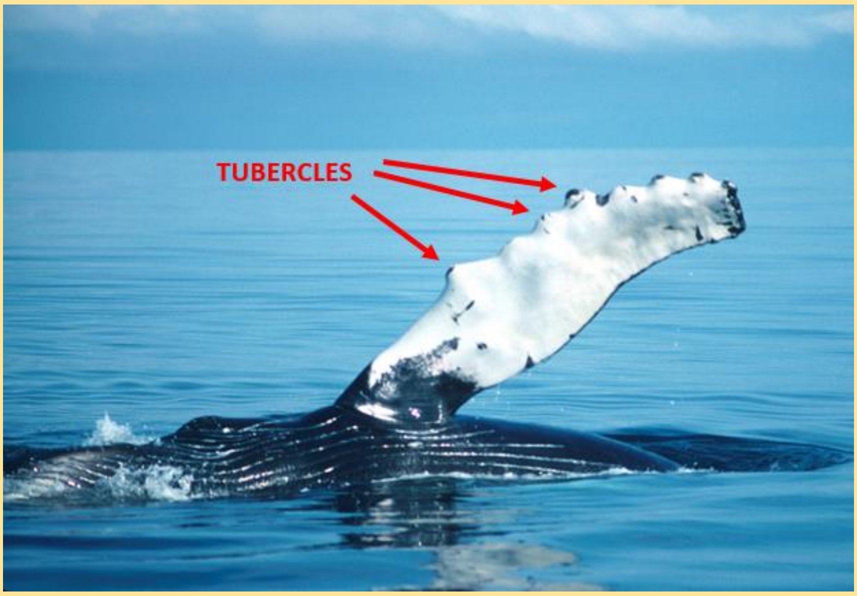
	- Localized airflow control. - Enhanced stability under varying fluid speeds.  Image retrieved from [EnergiMedia]  Image retrieved from [ResearchGate] **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design wind turbine blades with scalloped, tubercle-inspired edges. Use composite materials and precision moulding techniques to replicate the aerodynamic benefits of whale flippers, improving airflow dynamics under a range of wind speeds.
Step 5 – Emulate	**5.1 List your key information and explore as many ideas as possible.** **Key ideas** - Entire turbine blades are shaped with tubercle leading edges.

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- Retrofitting kits for existing turbines.
- Mini-wind turbines for urban or off-grid use with biomimetic blades.
- Drone propellers or underwater turbines using the same principle.

5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.

Context	Features	Constraints
Onshore wind farms	Whale-inspired blades for enhanced lift in variable winds	Manufacturing cost, retrofit challenges
Offshore turbines	Better performance in turbulent ocean wind	Corrosion resistance, maintenance logistics
Urban wind installations	Small turbines with tubercle blades to increase output	Space limitations, aesthetic integration
Drone and UAV propulsion systems	Efficient, quiet, biomimetic propellers	Precision required, lightweight material compatibility

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Evaluate the feasibility of the technical and business model.

Criteria fit

- Boosts energy output and reliability.
- Reduces noise, stall, and stress.

Feasibility

- Supported by CFD (computational fluid dynamics) and real-world testing.
- Commercial prototypes (e.g. WhalePower blades) have shown efficiency gains.

Compatibility with the Earth's systems

- Supports renewable energy scaling.
- May allow smaller turbines to replace fossil-based generators in more zones.
- Promotes longer-lasting components with lower environmental impact.

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	6.2 Revise and revisit previous steps as necessary to generate a viable solution. • Optimise tubercle geometry for different turbine scales. • Test performance under extreme weather. • Partner with manufacturers for sustainable material options.

Additional resources:

https://asknature.org

https://biomimicry.org/

https://energi.media/innovation/canadian-inventors-turbine-humpback-whales-increasing-wind-efficiency/

https://www.researchgate.net/figure/a-Humpback-whale-pectoral-flippers-and-b-Manufactured-adapted-tubercles-on-the_fig4_322112572

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LET'S MIMIC SOLUTIONS

A solution refers to the steps applied to solve the challenge identified, through biomimicry.

Solution: Bio-Inspired Mussel Microplastic Filtration

BIOMIMICRY DESIGN	Description
Step 2 – Biologise	**2.a Ask yourself how nature can solve this.** How do mussels, sponges, and oysters efficiently filter particles from water and manage to bind to surfaces using bioadhesives in wet and turbulent conditions? **2.b What do I want my design to do?** • Capture microplastic particles from flowing or standing water. • Function without requiring continuous power or chemicals. • Be biodegradable, recyclable, and safe for ecosystems. **2.c Flip the question** • Instead of removing plastics at collection points, how can we **integrate nature-inspired filtration into existing water systems**?. • Can we replicate the **passive, sticky, fibrous, or mesh-based strategies** of aquatic filter feeders?.
Step 3 – Discover	**3.a Search for natural models that match the same functions and context as your design solution.** • **Mussels:** Filter out particles and secrete sticky threads (byssus) to anchor and trap. • **Sponges:** Filter water through porous canals using passive flow and choanocytes. • **Oysters and clams:** Trap suspended solids while protecting themselves. • **Mangrove roots and seagrass:** Trap debris in natural fibre webs. **3.b Identify experts & connect to communities of biologists and naturalists.** • Marine biologists studying benthic filtration. • Bioadhesive material researchers. • Water purification and biomimicry startups..

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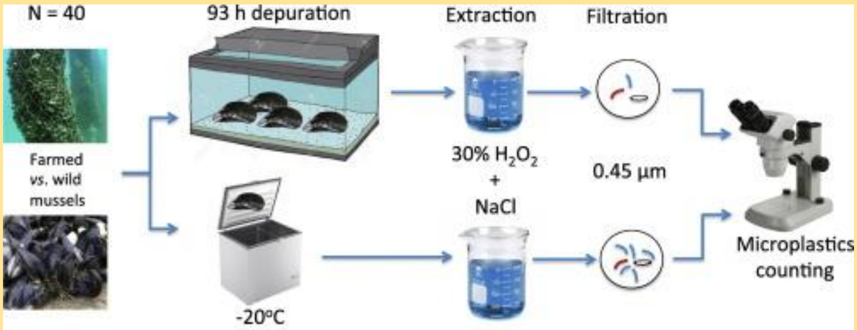
Step 4 – Abstract	**4.1 Summarise the key elements of the biological strategy. Highlighting the core functions and keywords. If possible, create a diagram/ drawing and/ or find images that can inform the design.** **Core functions** Passive filtration, adhesive binding, particle entrapment. **Key elements** • Sticky, fibrous networks. • Porous, flow-optimised geometries. • Bioadhesive secretion and mesh regeneration.  Image retrieved from ScienceDirect **4.b Translate lessons from nature into design strategies. Rewrite the strategy without using biological terms and connect it to the functions and the context from a human perspective.** Design bio-inspired filtration membranes or meshes that mimic mussel gills and threads to trap microplastics. Use biopolymer-based adhesives or create modular filter panels that can be inserted into urban waterways, treatment plants, or floating cleanup stations.
Step 5 – Emulate	**5.1 List your key information and explore as many ideas as possible.** **Key ideas** • Mussel-inspired floating filters deployed in rivers or storm drains. • Bio-adhesive mesh inserts in water treatment plants. • Modular microplastic traps attached to docks, buoys, or bridges. • Sponge-inspired porous biofilters for aquaculture or greywater reuse. **5.2 Organise your ideas into categories that include the features, the context, the constraints, etc. and select the design concepts that best fit your solution.**

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	Context	**Features**	**Constraints**
	Urban drainage systems	Bio-mesh inserts for microplastic capture	Debris buildup, retrofit compatibility
	Coastal and river environments	Floating mussel-mimic filtration units	Buoyancy control, marine life interaction
	Water treatment infrastructure	Mussel-thread-inspired filters with bioadhesive capture zones	Biofilm maintenance, flow pressure optimization
	Aquaculture & marine farming	Sponge-like passive microplastic traps in net pens	Durability in saltwater, species-specific compatibility

Step 6 – Evaluate

6.1 Evaluate the design concept(s) concerning their alignment with the design challenge's criteria and constraints, as well as their compatibility with Earth's systems. Assess the feasibility of both the technical and business models.

Criteria fit

- Removes plastics with low energy input.
- Compatible with regenerative water management.
- Supports biodiversity by using non-toxic, biologically safe methods.

Feasibility

- Bioinspired filtration is already under pilot (e.g. Nature-Inspired Solutions at MIT).
- Requires iterative prototyping for flow and clog resistance.

Compatibility with the Earth's systems

- Uses biodegradable, non-toxic materials.
- Avoids harm to wildlife or ecosystems.
- Encourages long-term cleanup over reactionary interventions.

6.2 Revise and revisit previous steps as necessary to generate a viable solution.

- Test filtration performance across particle sizes and conditions.
- Develop modular systems for easy removal and cleaning.
- Monitor for unintended ecological effects (e.g. species entrapment)..

Additional resources:

- https://asknature.org

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- https://biomimicry.org/
- https://www.sciencedirect.com/science/article/abs/pii/S0025326X1930061X

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