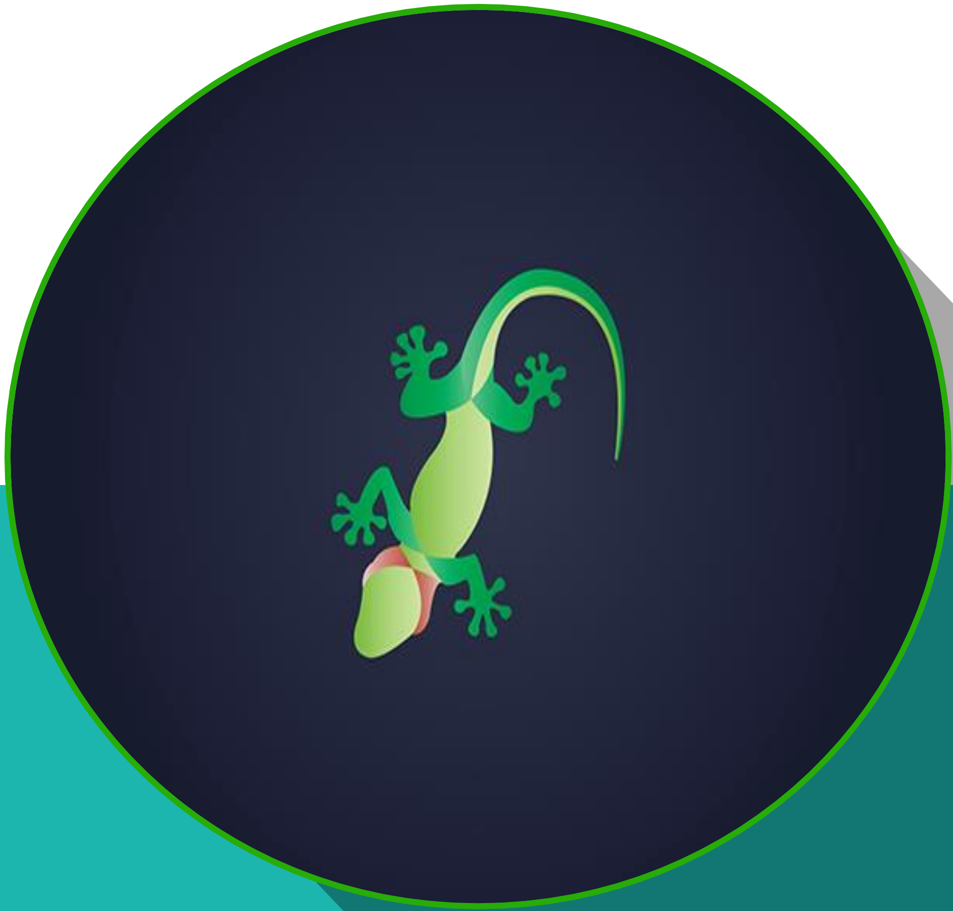
DECEMBER 9TH 2016

THE GECKO & THE GLOVE

LAWRENCE CABATUANDO



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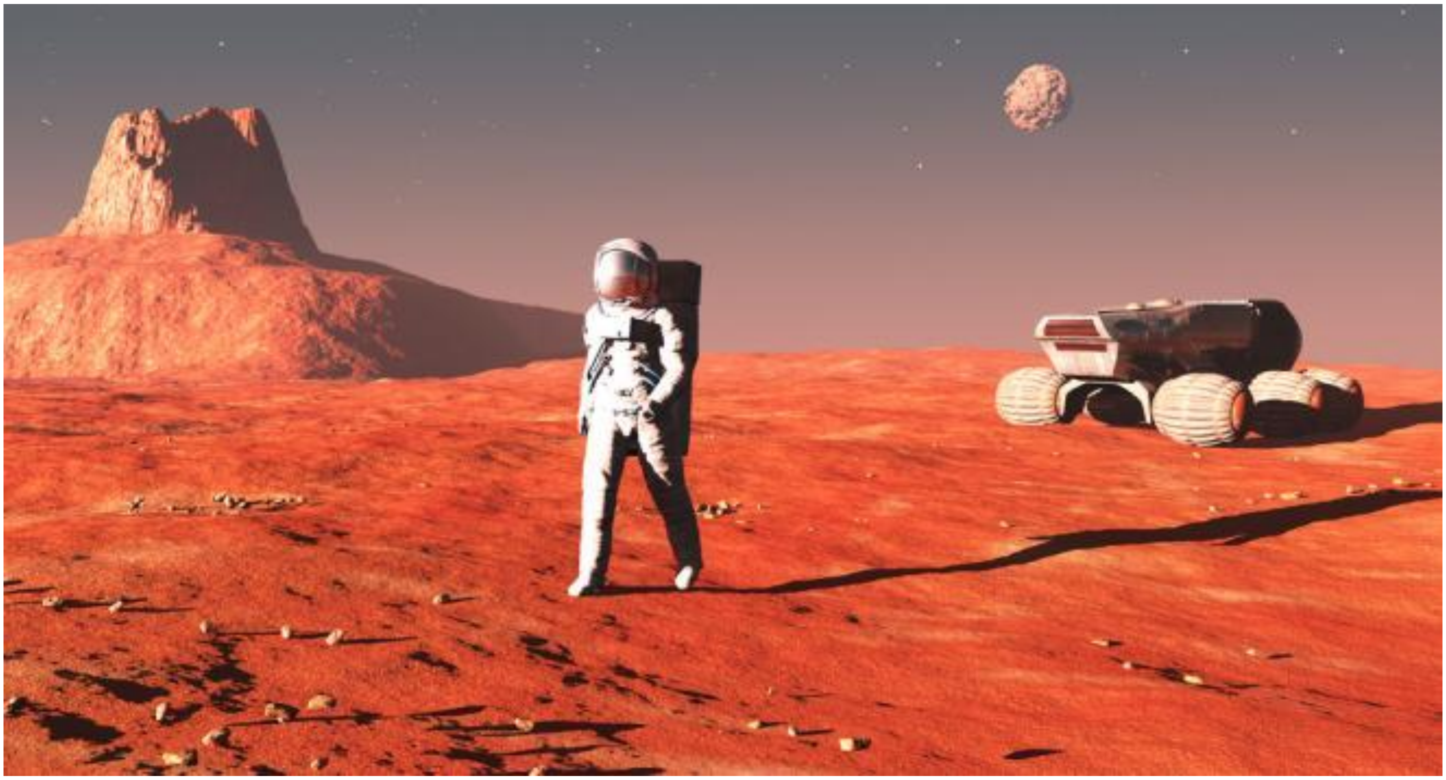
ENG 142

SCHULICH SCHOOL OF ENGINEERING

Exploration of NASA Challenges



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Martian Dust

"The number one problem on the surface of Mars is going to be dust," said Grant Anderson [1]. Martian dust poses a huge threat to the persistence of life on the planet due to its volume and caustic attributes. The Martian environment is riddled with tiny dust particles that have circulated the planet for billions of years. Mars' surface is essentially described as a giant salt flat; as the soil contains chemicals called perchlorates or, more simply known as highly chlorinated salts.

Due to Mars' extremely thin atmosphere, the surface dust is approximately 50 times finer than on Earth [2]. This in culmination with the dust's caustic attributes could present a risk for human life as it could enter our lung capillaries and filter out into our bloodstream. The fineness of the dust presents another unique problem, the triboelectric effect. Essentially "*As you walk, you scrape off electrons in the carpet and into your body. When you reach for the door's handle, those electrons jump and create an arc."* [2]. This presents an issue as the spark created by this effect could endanger the integrity of sensitive electronics existent in a spacesuit.

The discovery of perchlorates presented both good and bad news. Researchers have learnt that perchlorate is existent on Mars at concentrations between the ranges of 0.5 to 1 percent [3]. This concentration of perchlorate is considered to be a chemical hazard by NASA.

However, due to the problem being essentially one of dust build up, in the case of non-living materials, there are quite trivial solutions to the problem. One solution is to simply wash down the material or structure regularly.

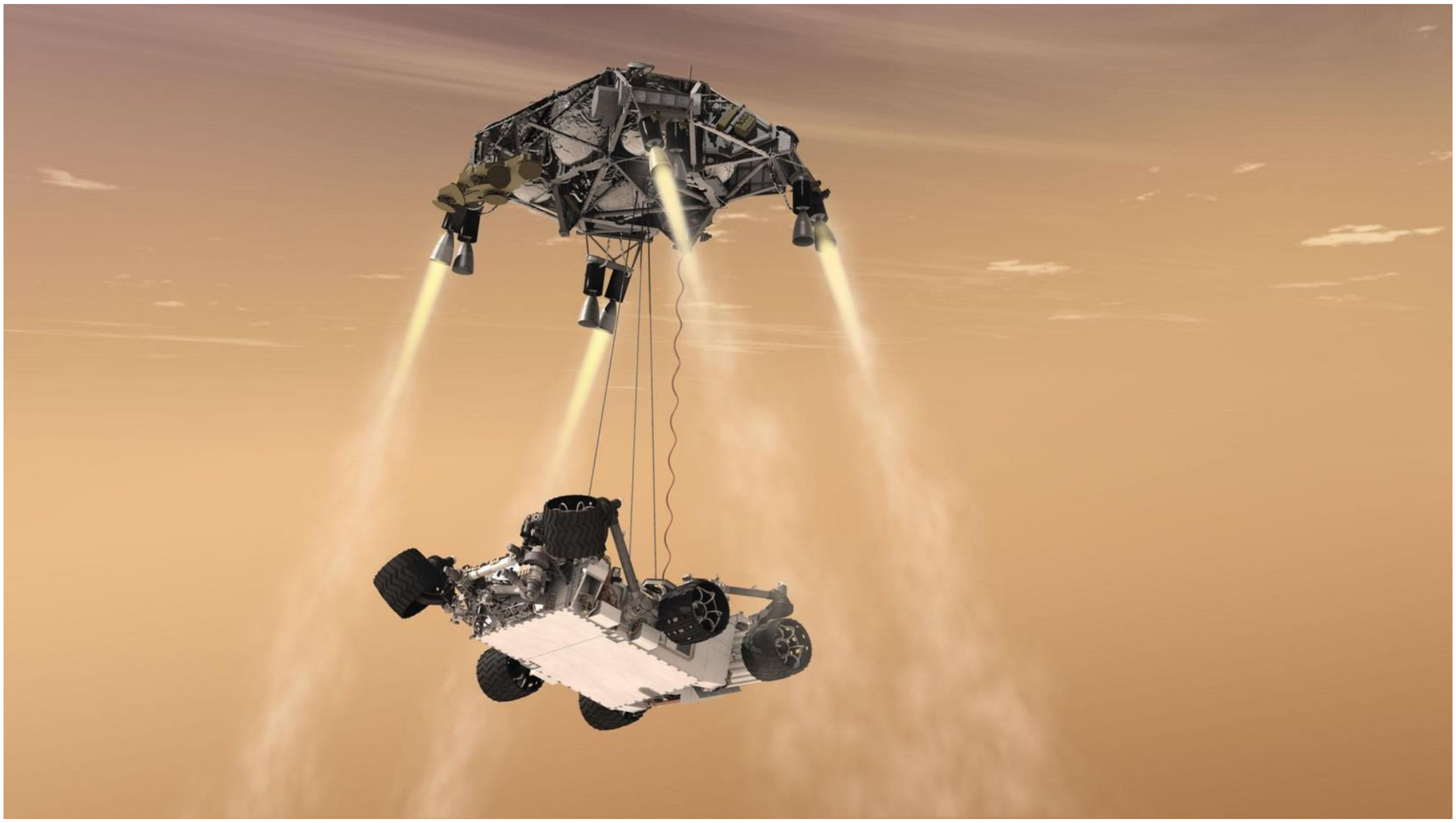
The problem with this solution is that there is a limited supply of water on Mars, and using the water to clean would be extremely inefficient as water should be primarily used for consumption. This implies that tools, shelters and any basic structures planned to be established in Mars must be built in order to be tolerant to this corrosion with minimal use of additional fluids.

The issues of the dust for both non-living and living materials, is essentially a materials science problem. If they were to be a material that could prevent the triboelectric effect as well as serve as a surface that is tolerant to the caustic effects of perchlorates, then the issue of dust build up would be solved. However we see in the example below, this is not the only problem Martian dust presents.

Figure 1.1

The manned Mars mission has been designed to fully exploit, wherever possible, solar power generation. However the solar panels are not only faced with adversity of dust build up but also frequent dust storms that occur on planet Mars. Dust storms cover the entire planet with dust which limits the amount of useable sunlight solar panels can utilize. During this period of time non-critical systems will be shut down or restricted to save energy. This affects a multitude of things required for human survival on planet Mars, such as the fact that water and oxygen will have to be consumed via storage tanks instead of powered extraction. These storage tanks do not have the ability to sustain human life for very long. This presents the challenge of finding various other methods of power generation that could be potentially utilized on Mars or a way to create an environment or system where sunlight absorption is not excessively affected by the dust storms.

Exploration of NASA Challenges



Sky Crane in aerial ballet mode during the descent of NASA's Curiosity rover to the Martian surface.

Credit: NASA/JPL-Caltech

Landing on Mars

"Landing Curiosity was landing a small nuclear car." [1]. One of the most spectacular feats NASA has accomplished was the successful landing of the Curiosity Rover. The landing required the use of an extremely large parachute as well as technology called retropropulsion as explained in Figure 1.2. The reason so much technology is required to land on Mars safely, is due to its extremely tenuous atmosphere. With this in mind, landing a vehicle that satisfies a manned Mars mission is unimaginably more difficult to land than a 0.9 tonne Curiosity Rover [1].

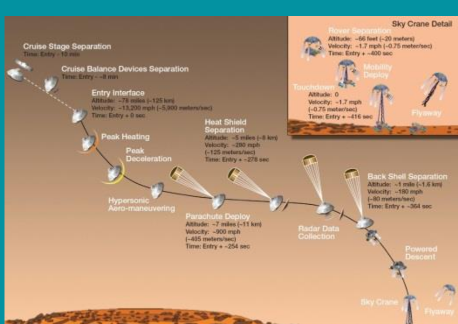
"We've maxed out our ability to take mass to the surface of Mars," said engineer Bobby Braun [4]. With the current technology we use, landing any vehicle heavier than NASA's MSL (Mars Space Laboratory) is out of the question. If we were to use a parachute to slowdown what is estimated to be a 36 tonne vehicle, it would need to have a diameter of approximately 225 meters [4]. The problem with this is, by the time the parachute is fully inflated the vehicle would have already hit the surface of Mars. Scientists at NASA are currently looking in to HIAD (Hypersonic Inflatable Aerodynamic Decelerator) technology [1]. The devices using this technology would be inflated at extremely fast rates, and would become rigid upon its inflation allowing it to operate at speeds the current parachutes cannot withstand.

Another obstacle researchers face is the ability to use retropropulsion at speeds faster than sound. This is a requirement because as a spacecraft enters the Martian atmosphere at speeds of 24,000 km/h, using regular retropropulsion technology would basically render itself null, as it is essentially "trying to light a candle while someone is blowing on the wick the entire time." This technological advancement is so crucial, it has been identified by NASA as a must have for a human mission to Mars.

Going back to the successful landing of Curiosity, it actually had a relatively large landing ellipse. Researchers were reasonably sure where the rover would land within a 20 kilometer diameter. This becomes a problem because NASA plans to send materials needed to survive ahead of the astronauts, as carrying materials along with them would serve to be quite difficult.

If the materials land 20 kilometers away from the astronauts landing site, this could serve to be a threat to the persistence of their life. Moving forward, researchers must either find technology that will increase the accuracy of a landing ellipse to an order of hundreds of meters or find that technology that allows a vehicle to land on harsh terrain.

Figure 1.2



"The one thing we do not want landing for humans to be characterised as is 'Seven Minutes of Terror'," said engineer Kendall Brown.

Due to the thin Martian atmosphere, Curiosity requires the aid of small rockets to guide and reduce its speed to an estimated 1600 km/h upon entry. When the speed additionally reduces by 10%, a 100 pound supersonic parachute inflates. This parachute is capable of 65,000 pounds of force. This slows the spacecraft down to approximately 600 km/h, at which the heat shield detaches. At this point, reverse rockets will stabilize the vehicle to set up for the Sky Crane system.

The Sky Crane system will detach from the spacecraft with the help of 8 rocket thrusters to slow its speed down significantly. At an optimal distance of 25 feet above Mars' surface, the Sky Crane will lower the rover at a speed of 5km/h. When the rover has safely landed, the Sky Crane system will detach and move towards a crash landing site.

Exploration of NASA Challenges

Photo courtesy of Shutterstock

Cosmic Ray Radiation

Upon hearing the word "radiation", we are automatically inclined to the think of the effects of nuclear disasters such as Hiroshima, Chernobyl or any recent nuclear power plant crisis. However the energy of the radiation that we are familiar with, pales in comparison to the radiation existent in open space. The main concern for future space explorers are galactic cosmic ray radiation.

Due to the speed of galactic cosmic rays (GCRs), they cannot be simply stopped by shielding. Unlike other types of radiation which are relatively weak, GCRs contain incredible amounts of speed and energy. If GCRs were to hit our important cellular structures, they could create mutations in the body. These mutations can mean an increased risk for cancer or acute radiation sickness if the dose received was substantial.

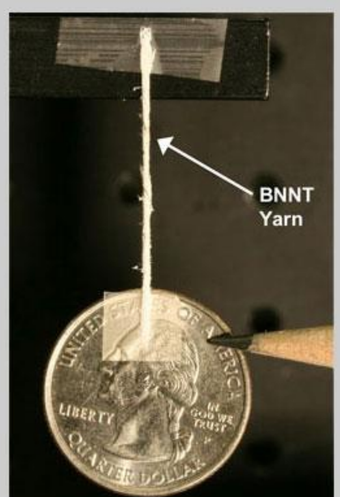
Learning the harmful effects of GCRs, makes the vision of a manned mission to Mars more complicated and sensitive. Assuming the mission takes 180 days, the radiation exposed to astronauts would equal to a total of 300 millisievert (mSv) [5]. This exposure to radiation is 15 times the annual limit for a worker in a nuclear power plant. With this in mind, NASA agreed that protection against these GCRs was to be of top priority.

There are two ways to shield us from these high-energy particles; use more mass of traditional spacecraft materials, or use more efficient shielding materials. One idea that supports the first method is to line the spacecraft with water. This would effectively absorb radiation and provide some amount of shelter during a solar storm. However, this and anything supporting the use of more mass is inefficient in terms of cost, as added weight would result in a need for more fuel. The only plausible direction to pursue is the discovery of more efficient shielding materials and strategies.

"The best way to stop particle radiation is by running that energetic particle into something that's a similar size," said Pellish [6]. Taking this quote into consideration, hydrogen would be a great repellant for these GCRs as it is quite an abundant element. Hydrogen exists in some common compounds, namely, polyethylene or rather the plastic found in water bottles and garbage bags. Although it is a potential contender, it has some constraints as it does not have the structural integrity to build large structures such as a spacecraft.

Finding a cost efficient material that would shield more efficiently is a journey NASA is currently pursing; as finding the right material would result in a solution to multitude of challenges. NASA has made some progress and has seen some great results in a variety of materials, one of which is exemplified in Figure 1.3.

Figure 1.3



There is currently a material that could potentially satisfy the needs for GCR protection and structural integrity. Hydrogenated boron nitride nanotubes (BNNTs) are tiny nanotubes made of carbon, boron and nitrogen with hydrogen interspersed throughout the empty spaces of the material.

This material is classified as incredibly strong even under extreme conditions. This makes it ideal to be utilized as structural material. What is even more amazing is that researchers have successfully manufactured yarn out of this material, meaning that it can be woven into space suits or even solve NASA's current glove challenge.

FUNCTION

To repel dirt to maximise sunlight exposure

ORGANISM

Sacred Lotus

Nelumbo nucifera

BIOLOGY STRATEGY

"The lotus effect." An effect that refers to the self-cleaning properties the Sacred Lotus (*Nelumbo nucifera)* showcases. Like many other plants, the lotus achieves these properties due to a wax-like cuticle. The difference is that the lotus' surface is **extremely hydrophobic** in relation to other plants. This is accomplished through the specific structure of the lotus' surface/epidermis. The surface exhibits extensive folding (**papillose epidermal cells)** and wax crystals that jut out from the plant's surface, resulting in a **roughened microscale surface.** Due to the roughened surface, water will have 95% less contact with the leaf's surface and more so with the air in between the numerous folds [8]. This is in conjunction with water's properties of adhesion, allows its polar attributes to be more apparent, causing the formation of water droplets.

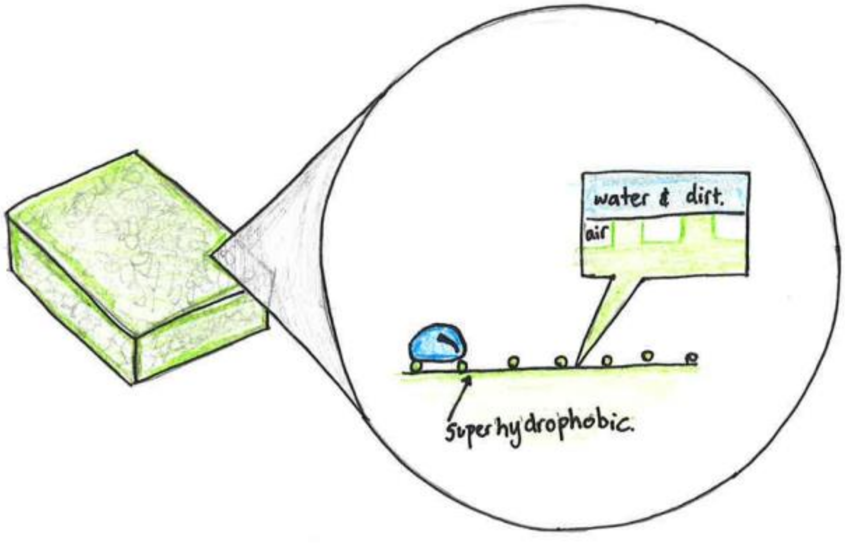
MECHANISM

Surface contains papillose epidermal cells in conjunction with epicutular wax crystals, to reduce water adhesion to the surface.

This is where the self-cleansing occurs. When the leaf is titled due to an external force, normally wind, the droplets will roll of easily due to lotus' roughened microscale surface and gravity. Due to the natural adhesion of water and solids, dirt particles will be attracted to these droplets and will wash off simultaneously.

SACRED LOTUS

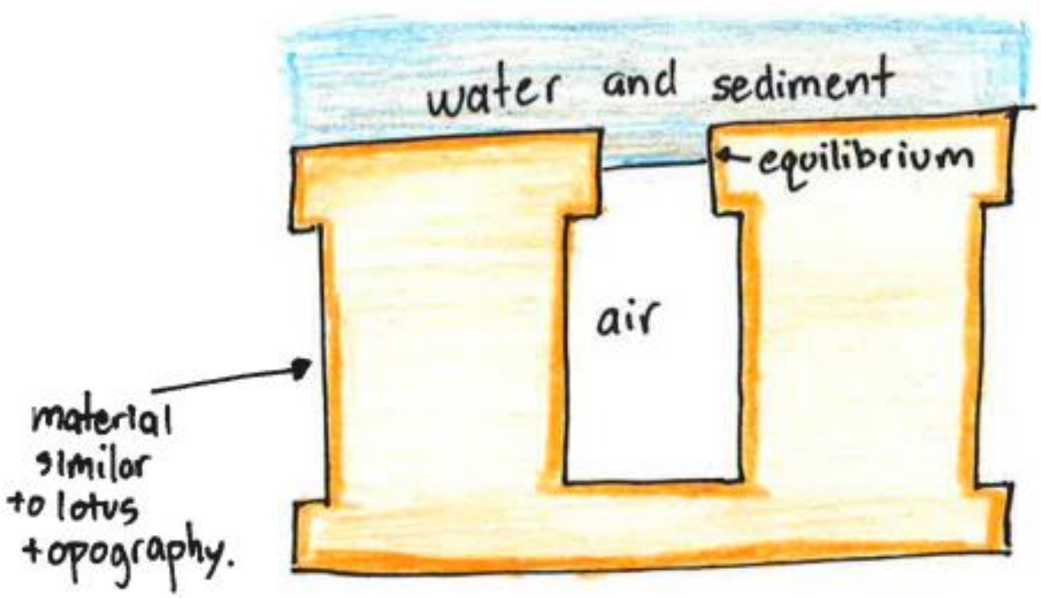
FIGURE 2.1



DESIGN PRINCIPLE

A roughened microscale surface that is not easily tarnished by its surroundings (eg. dust and dirt).

FIGURE 2.2



APPLICATION IDEA

- Use lotus' topography (surface structure) in systems that require the surface to be constantly or easily cleaned (e.g. solar panels, lenses, medical tools).

EXAMPLE OF APPLICATION

GreenShield is an amazing example of how the lotus effect was used in the manufacturing of a hydrophobic and low maintenance material. It has exemplified outstanding stain-resistance, oil resistance as well as antimicrobial functionalities. In addition, with this being a design based on biomimetic design, the material has been proven to reduce the use of environmentally harsh chemicals.

FUNCTION

To preserve itself in an environment that may affect its survival.

ORGANISM

Water Bear

Phylum tardigrada

BIOLOGY STRATEGY

Under extreme conditions, such as drought or extreme temperature, the water bear practices varying processes of **cryptobiosis**. Essentially when the environment dries up, so do they. Tardigrades will enter a state called **desiccation**, in which they shrink to what is commonly known as a “tun”. Upon entering this state they lose about **95% of their free and stored water** [9], as well as slowdown their metabolic rate by up to 99.99%.

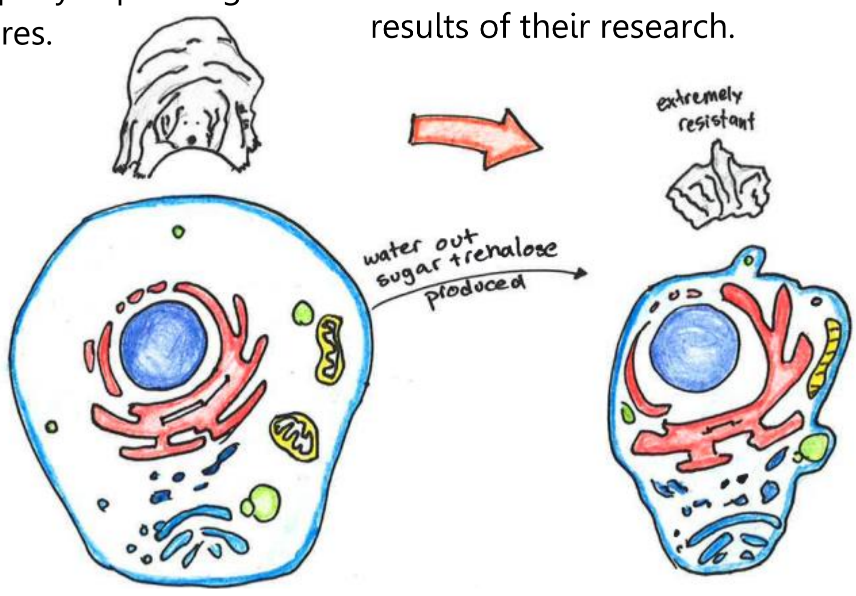
In this state, the water bear manufactures different proteins and sugars. The particular sugar they produce is called **trehalose**. This sugar forms a **glass-like state** inside their cells that stabilises key structures, that otherwise would have been destroyed by its desiccation state. In addition, trehalose can also associate with any remaining water particles to prevent them from rapidly expanding and rupturing vital structures.

MECHANISM

By creating particular sugars called trehalose, Tardigrades can safely dehydrate themselves while considerably slowing their metabolism rate.

What is particularly interesting is their ability to be particularly resilient to space radiation. In a recent study by the University of Tokyo, they have found a protectant attached to the tardigrade’s DNA in which they called **“Dsup”** [10]. “Dsup” was tested on humans, and it resulted in **decreased effects of radiation**, thus confirming the results of their research.

FIGURE 2.3

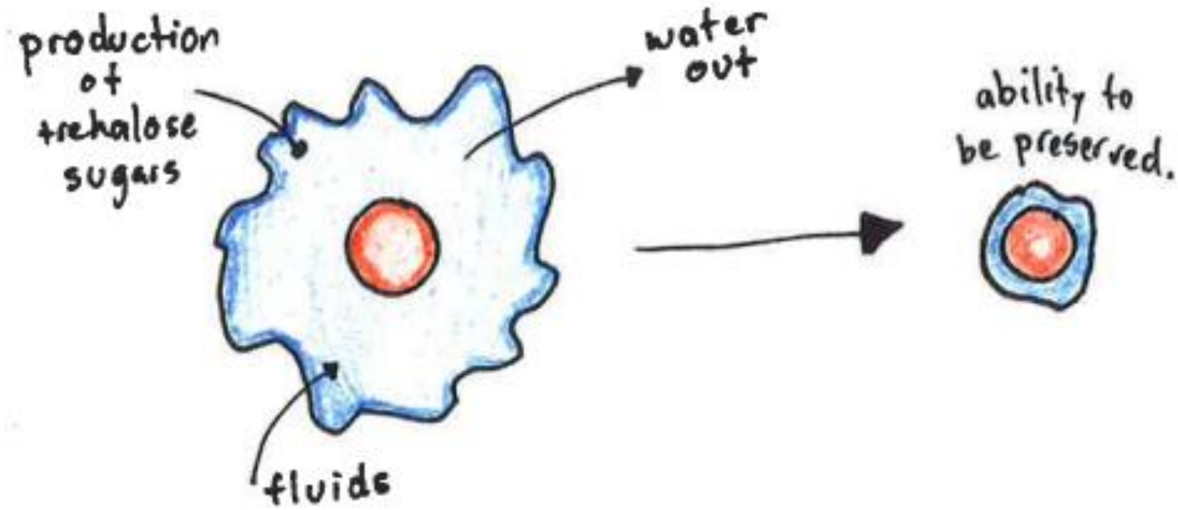


WATER BEAR

DESIGN PRINCIPLE

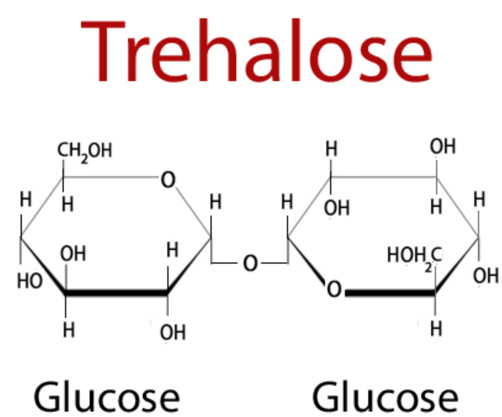
To preserve biological materials through dehydration and the production of trehalose sugars.

FIGURE 2.4



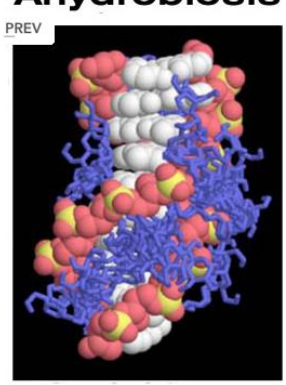
APPLICATION IDEA

- If researchers can mimic the properties trehalose sugars on to a larger scale, there could be a potential to create glass or materials that could resist radiation or any harsh environment for that matter.

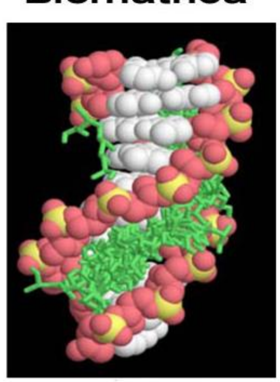


EXAMPLE OF APPLICATION

Anydrobiosis



Biomatrica



Inspired by the tardigrade process of cryptobiosis, a company called Biomatrica has developed a mimicked polymer to store biological samples such as DNA and organic tissues without the use of refrigeration. This technology saves the lab's money, as well as gives them a sense of relief that their research cannot be lost due to random power outages.

FUNCTION

Orienting their body to land precisely and smoothly on any surface.

ORGANISM

Western Honeybee

Apis mellifera

BIOLOGY STRATEGY

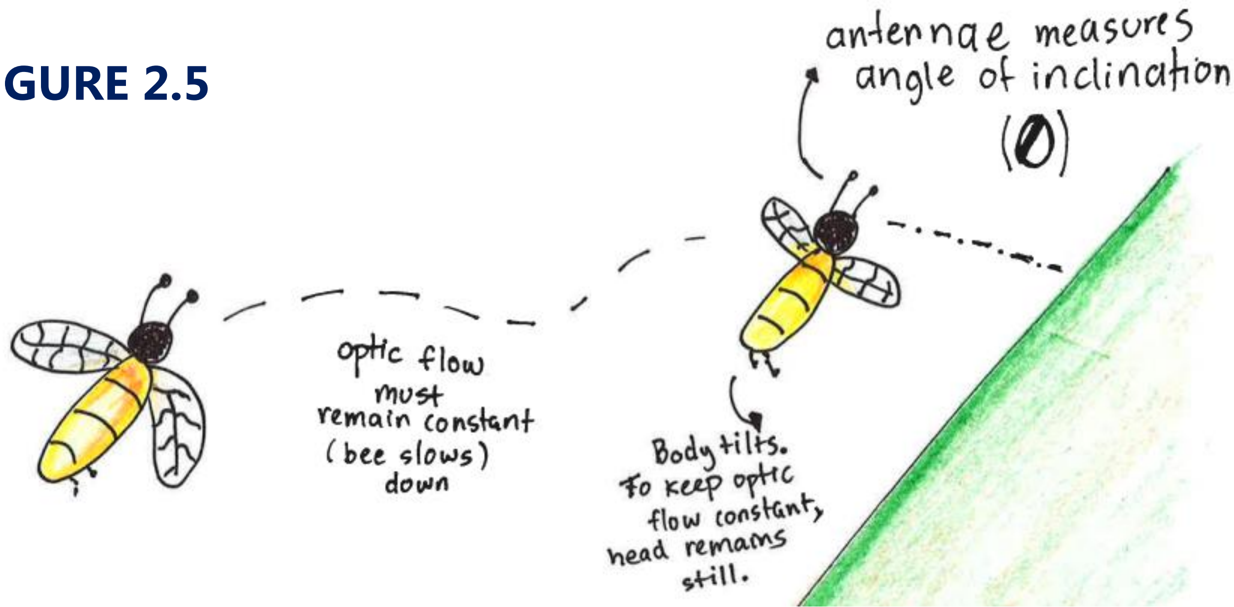
Bees, like any other insect, have immobile eyes with **fixed-focus optics** which infers that they have inferior spatial acuity to humans. The trick to their landing as well as many of their other flight attributes is their exploitation of **optic flow** in conjunction with their **antennae's functions**. Essentially, bees capture their surroundings as a thousand distinct color dots, which allow them to perceive rapid movement or more specifically in this case the rate of expansion (optic flow) of the landing area. The bee's apparent deceleration before landing is actually the bee's attempt to keep the **optic flow of the surface constant** [13]. Basically as the surface comes closer, the bee will begin to slow down to compensate. Now the question raises, how do they orient themselves to land on surfaces with steep angles?

MECHANISM

By attempting to keep the optic flow of its landing surface constant and using its antennae to calculate the angle of inclination, the bee adapts to any surface and lands precisely and smoothly every time.

This is where the antenna's functions come in handy. The antennae senses **the angle of inclination**, and gives information of how much the bee needs to tilt in order to keep the optic flow rate constant. In layman's terms, the bee's body is the only thing that tilts as the head of the bee must remain at a **constant distance away** from the surface.

FIGURE 2.5

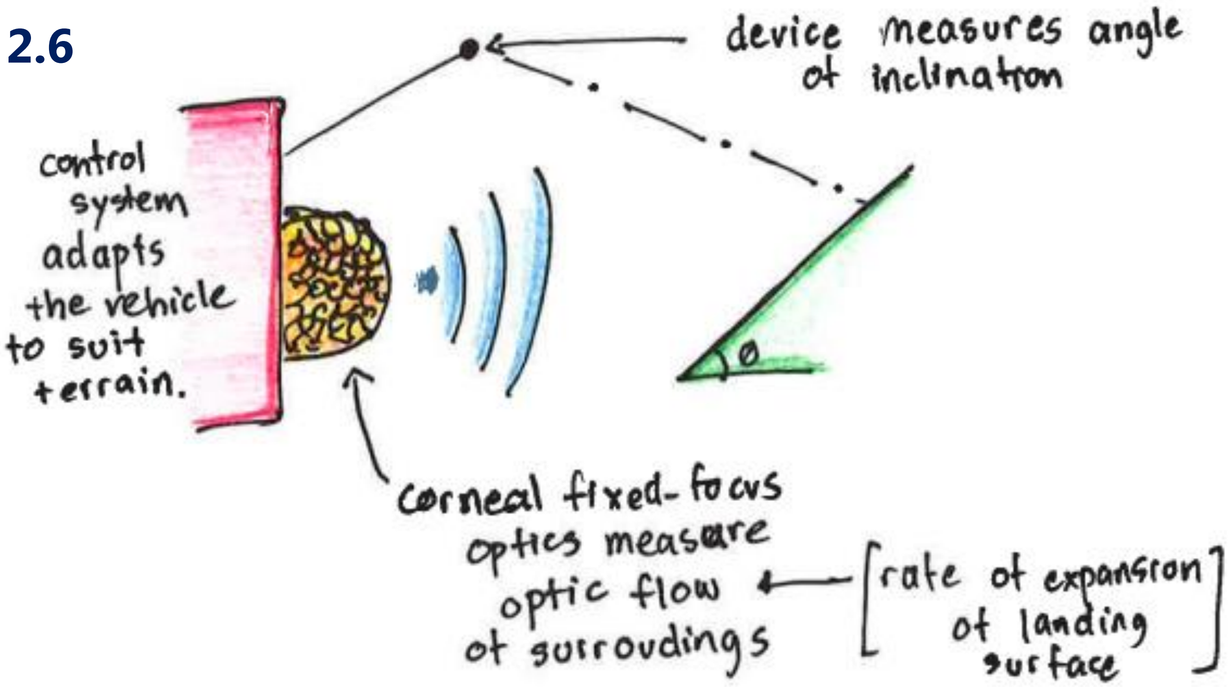


HONEYBEE

DESIGN PRINCIPLE

To use the concept of optic flow and angle of inclination to remain at a constant distance and orientation away from obstacles.

FIGURE 2.6



APPLICATION IDEA

- Hover systems, such as the sky crane system used to land the Curiosity rover can use the processes used by the honey bee to remain at a constant safe distance no matter the terrain.

EXAMPLE OF APPLICATION

Extensive research and development is being done on how to implement bee's concept of optic flow towards the creation of self-navigating drones. In addition, Nissan Motors are working on a laser range finder on their robotic car based on this concept to detect and avert potential collisions.

FUNCTION

To transition from hard to soft and back again in a matter of seconds.

ORGANISM

Sea Cucumber

Holothuria

BIOLOGY STRATEGY

When faced with a threat the sea cucumber has the uncanny ability to change its rigidity until the threat is gone. It does this through the use of their catch connective tissue or rather **collagen**. The rigidity of this collagen is controlled **neurologically**, meaning that these animals can rapidly soften and harden at will. Studies have confirmed that the sea cucumber can adopt three different states. These are stiff, standard and soft states which are differentiated by the viscosity and elasticity of the sea cucumber's tissue.

According to the study conducted by the Tokyo Institute of Technology, it is apparent that there are **varying peptides** existent in sea cucumbers.

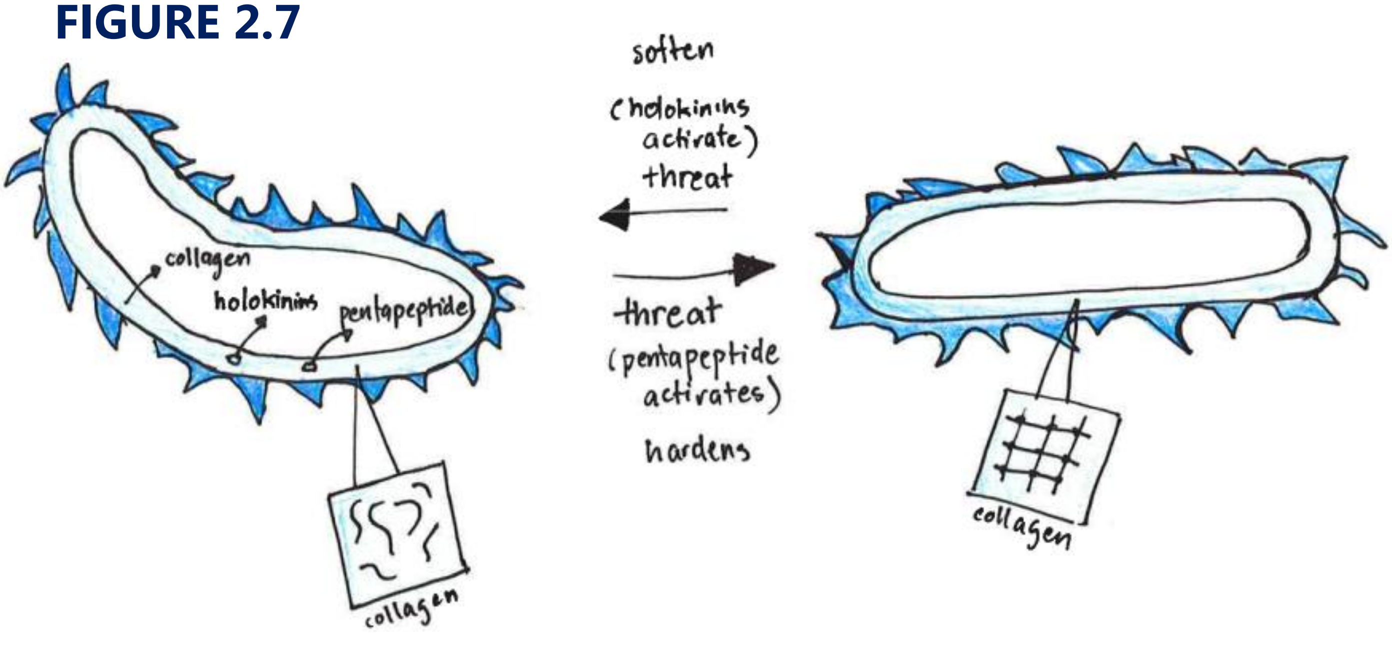
MECHANISM

The release of varying neuropeptides causes the collagen of the sea cucumber to soften or harden upon command.

These peptides, controlled by complex neurological systems, dictate what state the sea cucumber will adopt.

The difference lies in what peptides are activated. Two peptides named **holokinins** are responsible for the softening of the sea cucumber, whilst **pentapeptide NGIWYamide** causes the stiffening [16].

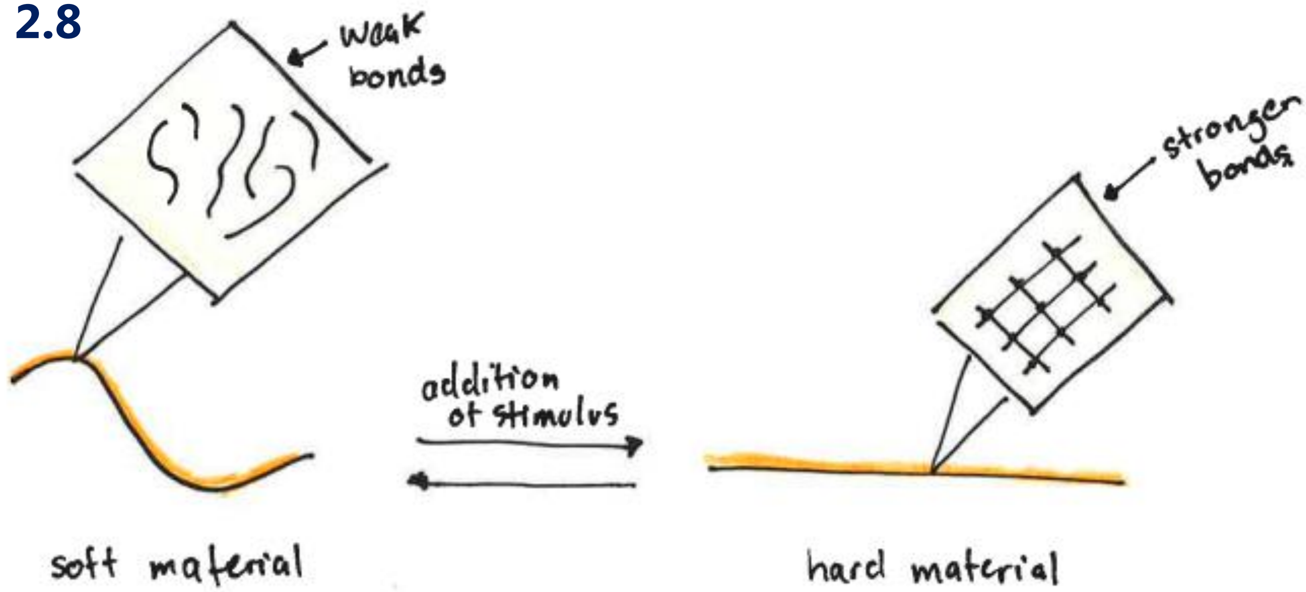
FIGURE 2.7



DESIGN PRINCIPLE

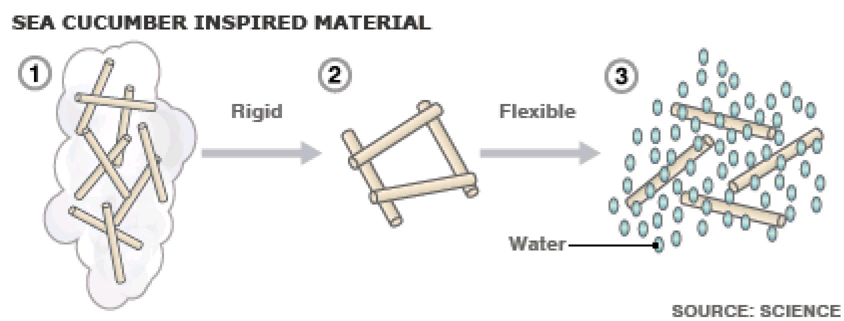
A material that can rapidly adjust its rigidity with the introduction of a stimulus

FIGURE 2.8

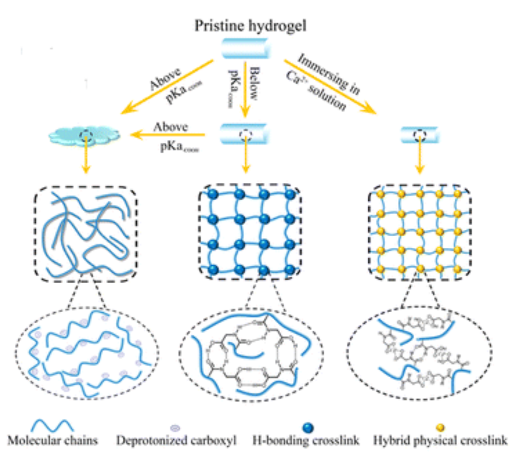


APPLICATION IDEA

- A material that can harden upon command can be manufactured into extremely useful putty that provides a temporary fix to leakages.



EXAMPLE OF APPLICATION



Inspired by the sea cucumber, the Department of Chemical Engineering and Materials Science of Wayne State University has synthesised a hydrogel that has incredible characteristics. Upon the addition of Ca^{2+}, the hydrogels demonstrated high tensile strength, stretchability, compressive strength and durability.

FUNCTION

To self-clean feet while keeping its adhesive qualities

ORGANISM

Tokay gecko

Gekko gecko

BIOLOGY STRATEGY

Gecko's have tiny hairs on their feet called **setae**. The gecko has similar attributes to the lotus, but does **not require the addition of water to self-clean** [18]. This is an effect of the fiber structure of the gecko's adhesive (setae). Adhesion in the setae is a consequence of many divided contact points that deform to create maximum contact with the surface. When touching a smooth surface, such as glass, the fibers have **less contact area with the particle** than the glass does. Since adhesion strength is proportional to contact area, the particles will prefer to adhere to glass rather than the gecko's setae. The preference to adhere to the glass is due to the fact that Van der Waal forces are strongest between the glass and the dirt particles.

After deposition of the dirt particles, it is observed that the setae will **recover the full strength of their adhesive qualities** until all dirt particles are deposited. This is quantified through testing done by the University of California (Figure 2.10) [18].

MECHANISM

Fiber structure of setae, allows for self-cleaning due to reduced surface area for the dirt to adhere to.

FIGURE 2.9

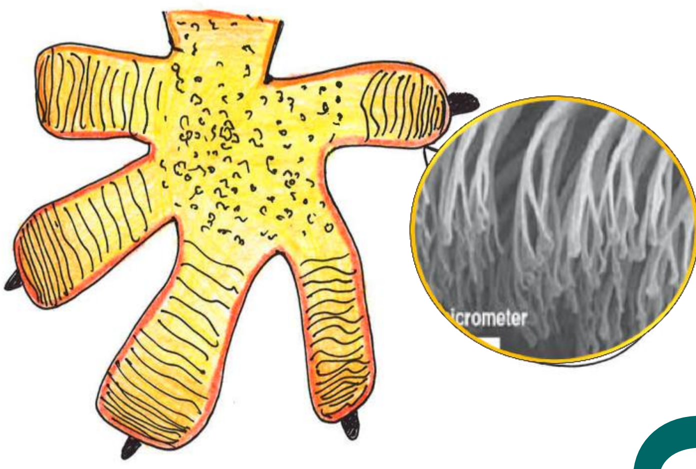
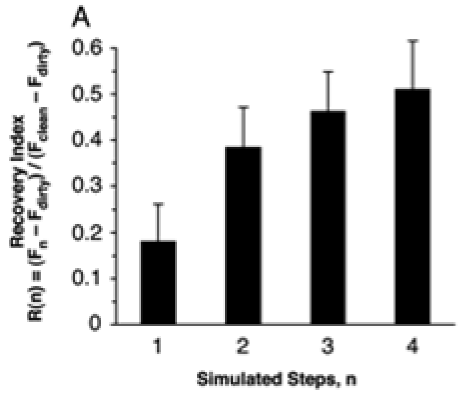


FIGURE 2.10

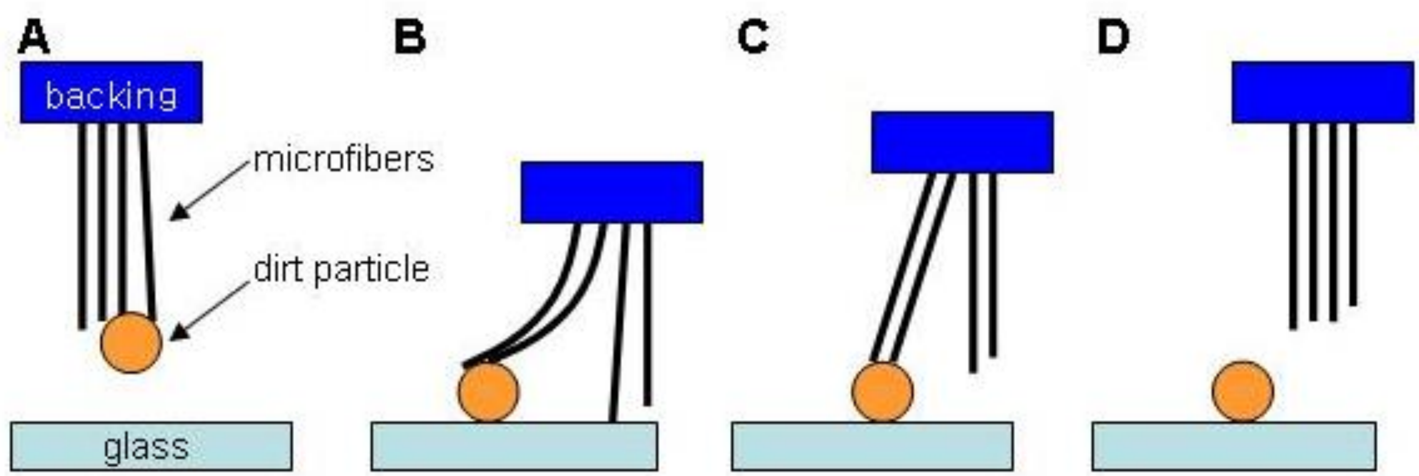


GECKO

DESIGN PRINCIPLE

An adhesive that has deformable microfibers to maximize and intimate contact with the surface

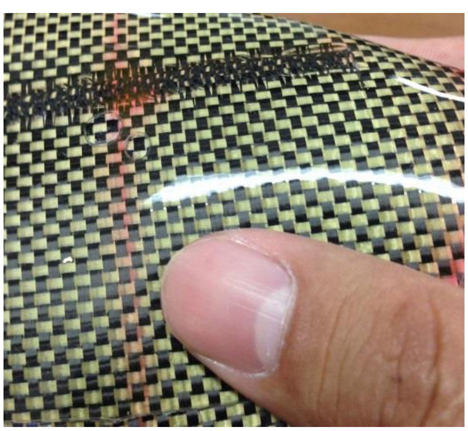
FIGURE 2.11



APPLICATION IDEA

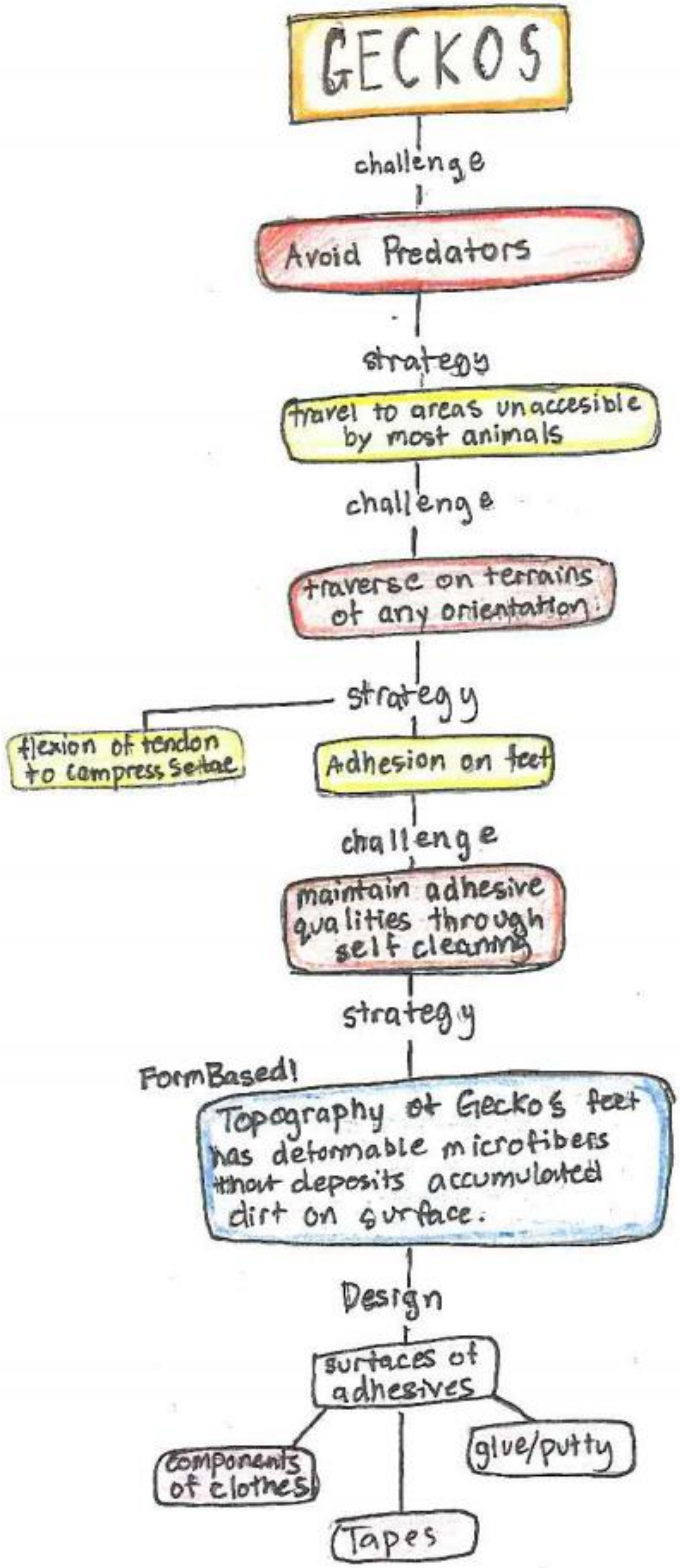
- Adhesives with self-cleaning properties is so outstanding it can be used almost anywhere. This design principle could be used for adhesives and materials in space or other extreme environments.

EXAMPLE OF APPLICATION

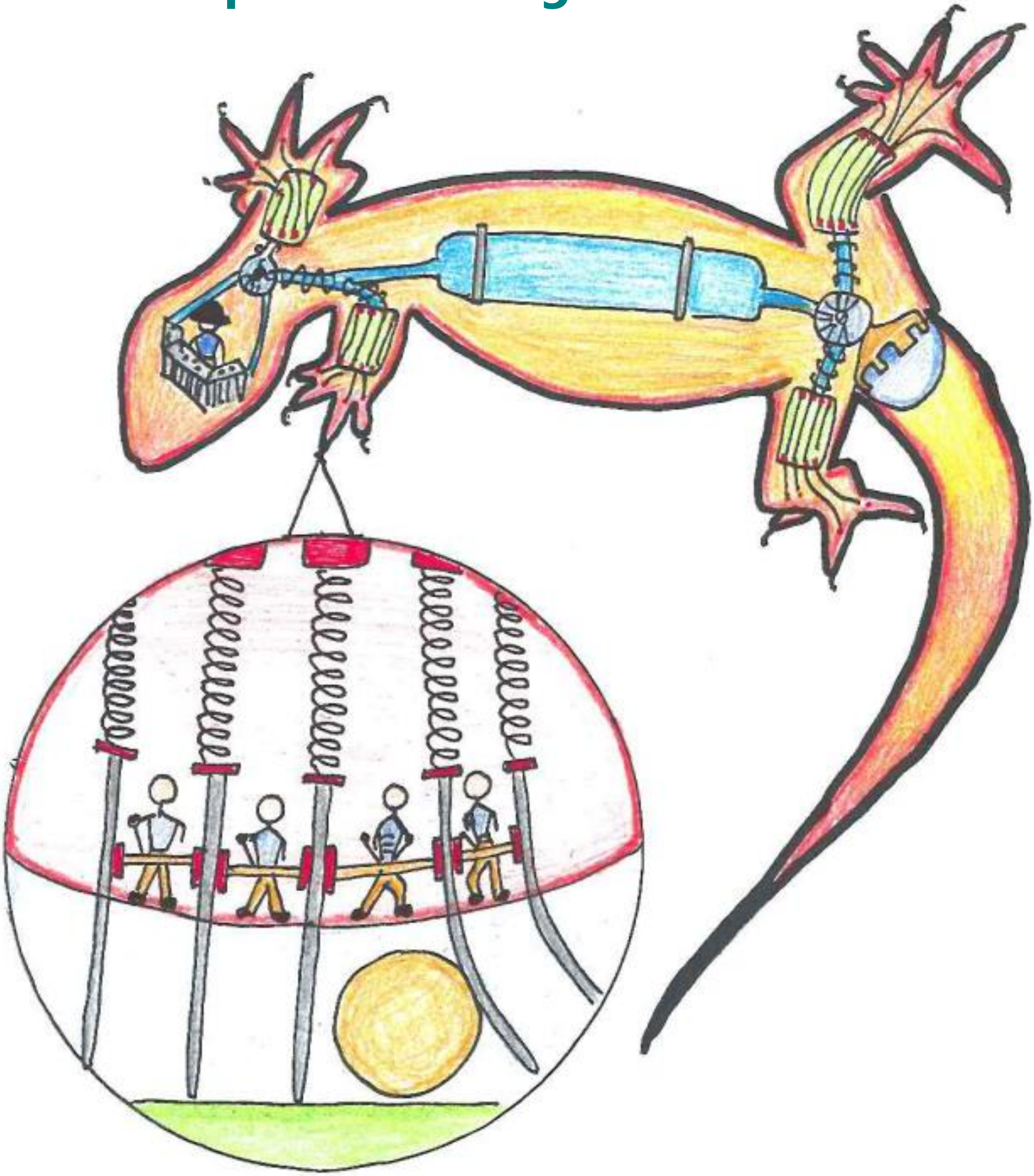


Geckskin is one of the top five science breakthroughs of 2012 by CNN Money as it has incredible strength as well as properties similar to a gecko's setae. It leaves no residue, is easily removed and offers numerous possibilities for future products to come.

Challenges and Strategies Diagram

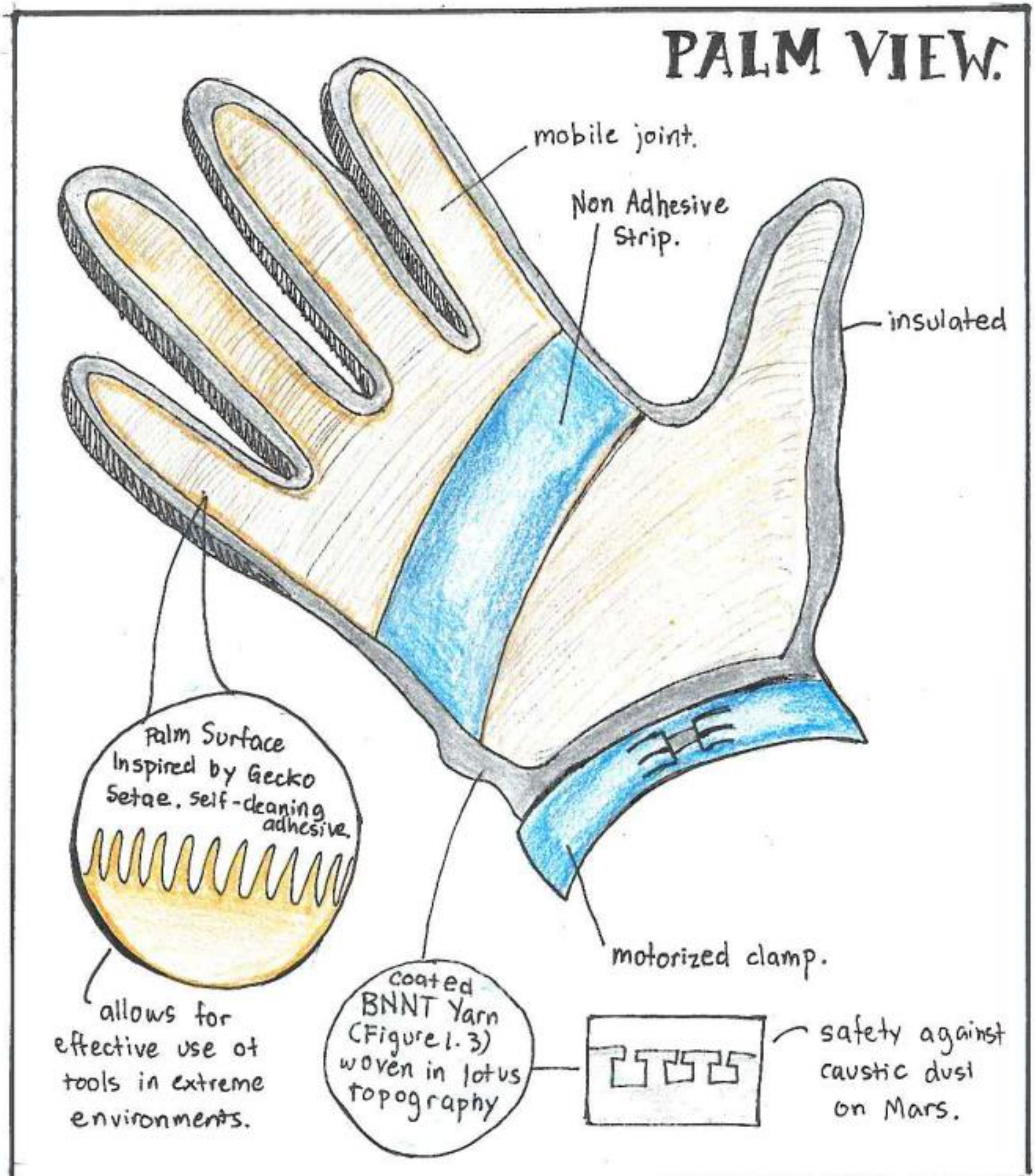


Fritz Kahn Inspired Drawing



Final Design

NASA GLOVE



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