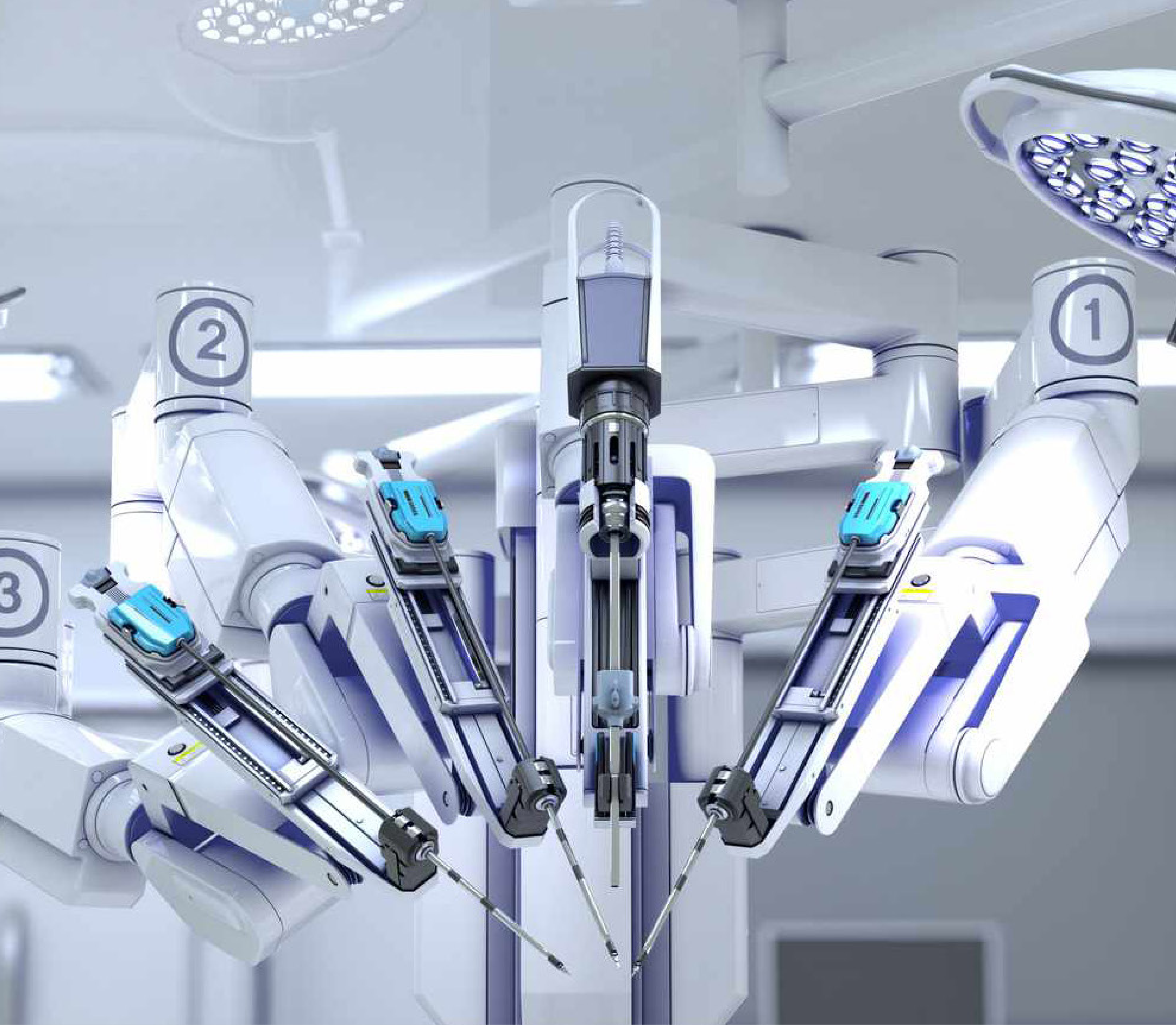
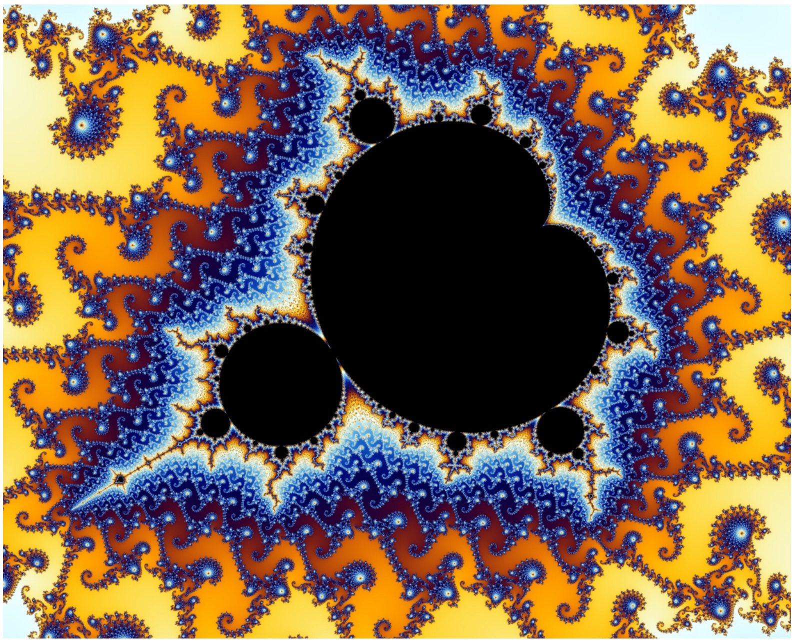


S.T.E.A.M MAGAZINE

Harrow Family of Schools

Winter 2021 Edition



Contents

Introduction

It gives me great pleasure to present the second edition of our bi-annual Harrow Family of Schools STEAM magazine. A collection of articles spanning different topics from the STEAM subjects contributed by students from Year 7 to Upper Sixth from Harrow Schools across the globe.

We hope you enjoy reading this magazine.

Tom Knight

Head of Design Technology & Engineering,
Harrow School, UK
Winter 2021

STEAM Interhouse Competition 23rd November 2021

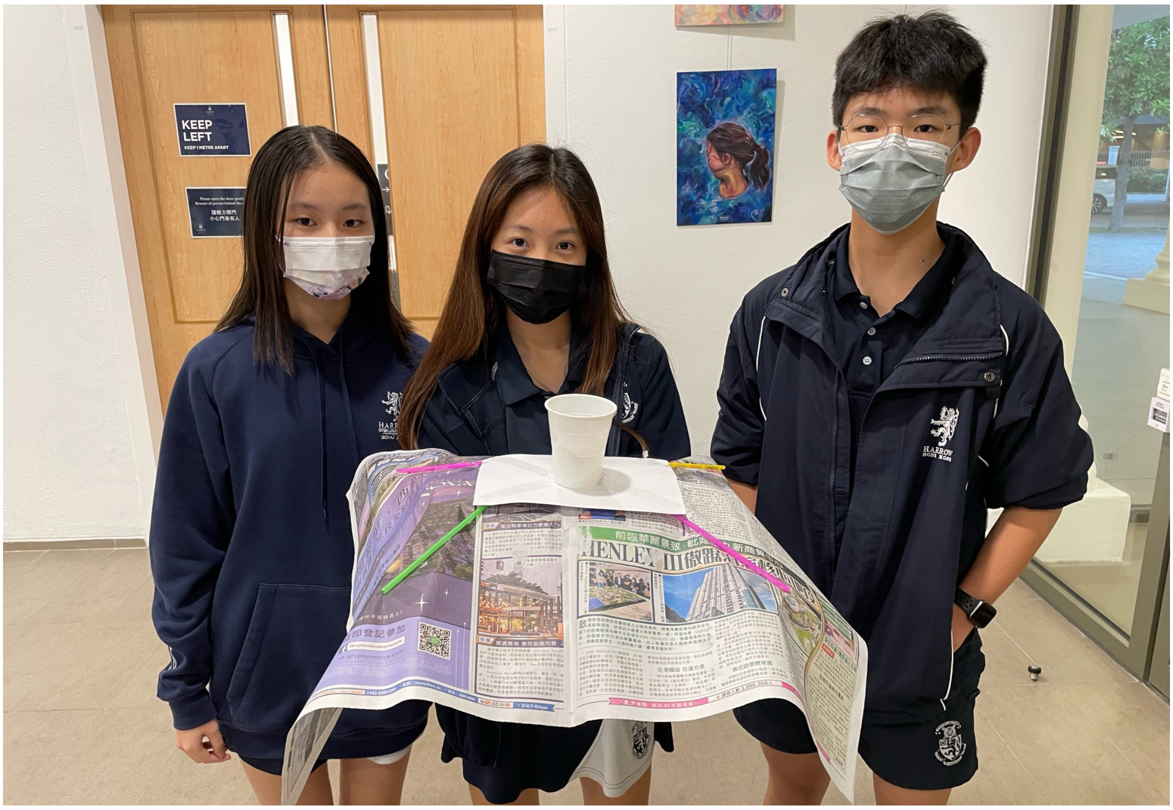
Henry Webster,
Harrow School, London

On 23rd November 2021, the Harrow Schools across the globe took part in the DTE competition. The task that was put to the schools was the same everywhere which was: Design a spaceship/spacecraft which will land you to the moon safely after having run out of fuel. In reality, everyone was given a plastic cup which contained two marshmallows (the astronauts) which was stuck onto a piece of paper. We were all given 10 credits to spend on resources which were:

- Newspaper Sheets
- Mini-Marshmallows
- Tape
- Card
- Straws

Then the winner would be the house with the spacecraft that could be dropped from the largest height such that the marshmallows contained within the cup did not fall out. The rules prevented all houses from building on top of the piece of A4 paper which was already stuck to the bottom of the cup. After half an hour of planning and a further ninety-minute building session, the houses tested their spaceships in Round 1. We were only given one chance to show off our build in the 1-4 metre range – if we failed, that would be our maximum height reached. As a result, most teams started off slow, dropping their spacecrafts off at about 1-2m (apart from The Park, who dropped theirs straight from the 4-metre height, which just about passed). After the first round, most houses were knocked out apart from The Park, The Headmaster's, Elmfield and Druries. We then escalated to the top of DTE schools and dropped it from a height of 7 metres. Sadly all but Elmfield failed at this height. However, Mr Knight also took into account the number of credits spent by the teams. With Druries only spending 60% of their credits and Elmfield spending all of their credits, it was Druries were crowned champions of the Harrow School, London event.

"At Harrow Shanghai, the Upper school students showed great fellowship and innovation to design their lunar landers in an inter-house competition. There were definitely plenty of budding aeronautical engineers at work. After preliminary landings in the lab, qualifying landers were dropped from the 6th floor roof onto the 3rd floor Yarder! Fun was had by all and every house came up with some impressive designs. In the end, Shaftesbury house came away as overall winners with 3 out of 5 of their teams keeping all of their marshmallows in the cockpit (cup) during the final drop from the 6th floor!"



The team from Hong Kong with the record moon lander of the day of 18 metres.

Cafe Racer Build

Mete Kuner
Harrow School, London

This is a custom motorcycle project I started at the beginning of 2021, which took around two and a half months to complete. The whole experience was great, and it helped improve both my technical and practical skills, expand my knowledge of motorcycles, as well as meet new people along the way. Special thanks to my parents and brothers for helping me throughout, and also to Inanç from Apex Motor for letting me use his workshop.

After a long day of online lessons, during dinner, my older brother suggested that we built a custom motorcycle. We both looked at each other, nodded our heads and put on a big smile. My dad seemed intrigued. I could almost hear my mum's thoughts. After dinner, we started looking at potential designs and donor bikes. My brother and I both liked the design of café racers. They had an aggressive stance and were highly customisable. There were a lot of design options to choose from, but the bikes were uncommon and difficult to get a hold of. The bike had to be no more than 125cc for us to legally ride it. This limitation cut down the options even more.

After some further research and planning, we chose the Honda CGL125. It's a very widely used motorcycle, due to its good fuel efficiency and affordable price. The low price meant that we could afford to make mistakes and learn. We found a seller that lived nearby and went to see the bike. The important things to look out for when buying used motorcycles are damage to the chassis, engine problems and other hard-to-fix issues. Cosmetic damage can be dealt with easily, especially since most parts are being changed during the customisation. The bike looked all good, we gave it a test ride and we signed the paperwork to officially take possession of it. We were now ready to customise.

The first order of business was of course taking the whole thing apart. We improvised a stand to raise the motorcycle to a comfortable height. One by one, starting from the seat and battery, we stripped the bike until we were left with the engine and chassis. Screws, bolts, nuts, and other small parts were labelled with masking tape. This helped later on when assembling the bike to know where each part came from.

Once the bike was taken apart, it was easy to visualise what changes I wanted to make on the bike. My brother was occupied with his own things, so he wasn't around until the finished product.

After figuring out what I wanted to change, I started ordering the parts online. I ordered the headlight and mirror-signals in advance, as the shipment from China would likely take a long time to arrive. While looking for second-hand parts such as rims, fuel tanks and forks, I found Emre. My dad and I drove down to his shop, where he built custom motorcycles, and looked around for parts we could use.

After talking to him about his experiences building custom bikes and seeing some of his builds, I was even more motivated to build this bike. We purchased two rear Yamaha XV250 wheels, along with a complete front end from the same model.

Once all the parts were collected, I took some measurements of the rear swing arm and marked it on the chassis, to cut out spacers. Although the front end was from a different motorcycle, the stem of the triple tree fit perfectly into the hub with new bearings. Once the forks were fitted, the bike was lifted, which wasn't the look I was going for. To lower the main body, all I had to do was drop the triple tree lower. This would mean that the actual forks stick out around 20mm higher, but it was no problem as I was going to use handlebars with risers anyway.

I also wanted the seat shorter, with a round scoop. I found and bought a black seat with red stitching, which was the colour scheme I was going for overall. In order to fit the seat, the chassis had to be cut to make a seat hoop. This change took away all the visual weight from the back to create a cleaner, simpler look.

Next was fitting the front centre hub from the front rim of the XV250 onto the rear rim. This was relatively simple as they were both 32 spoke rims. The centres of both were taken out and simply swapped. This is one of the advantages of not using too many different donor bikes, as it can be difficult to make them fit when there is a wide range of lengths, diameters etc.

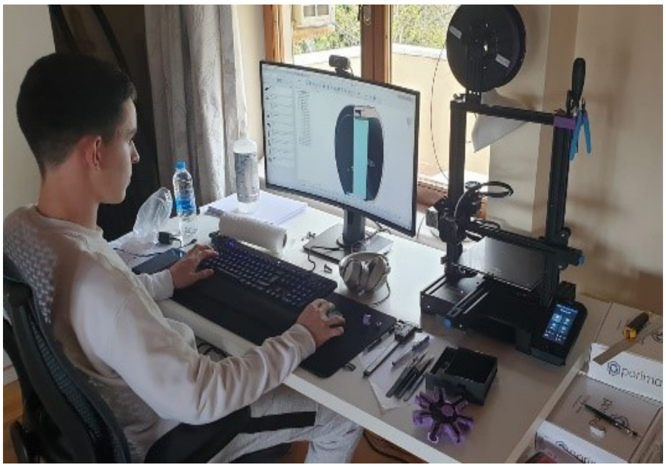
The big change of course was the fuel tank, which had the biggest effect on the overall appearance of the motorcycle. The original fuel tank had a slight dent on it, and it just didn't look very nice. I wanted a chunkier, more aggressive look. I found and bought a IZH Planeta 5 fuel tank, which was clearly very old, but it had no problem structurally. Of course, it was going to get painted, so the only thing that mattered was the shape, which I liked. I put all of the parts onto the bike, loosely attached, like a test assembly. The shape and stance of the bike looked good, especially with the brand new Metzeler tyres.

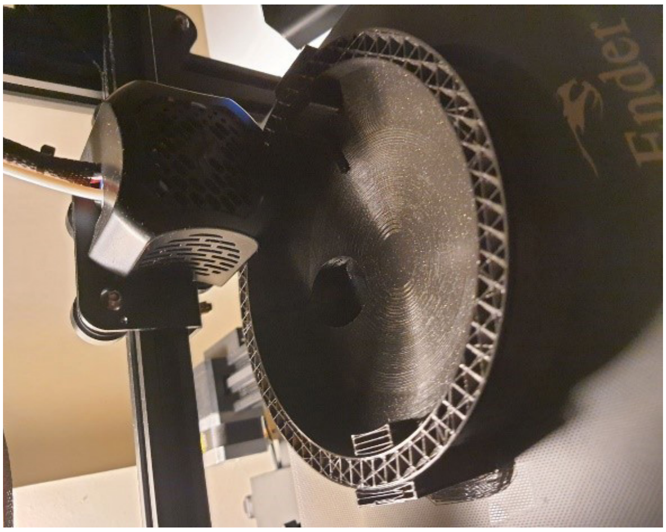
Once I was happy with the parts and fittings, the parts were sent to get painted. The chassis required electrostatic paint, as it needed protection from rust, but it also made sure that the paint was sprayed evenly. The rest of the parts were painted in the workshop, including the engine, rims, fuel tank, forks, and fasteners, simply painted by hand with high temperature spray paint. I chose a predominantly black colour scheme with red highlights. The fuel tank was painted glossy black with two red stripes running offset from the middle, with Honda lettering on the sides. The engine was also painted glossy black with the fins grinded slightly, for a nice contrasting tone.

The electrical wiring of the bike stayed relatively similar to the original, with the exception of the new headlight and turn signal connections. Inanç helped me out with the wiring, and we made a small cage under the seat for the electronics to go into.

After receiving my order from China, I realised that the headlight didn't have a housing, so there was no way of attaching it to the bike. If I had ordered another one, the build would be delayed by around three weeks. A few days before this, I bought and assembled my 3D printer, and tried out a few small prints.

Once I decided to build the housing rather than buying it, I loaded up Fusion 360 and started designing. The reference model was the headlight itself, so I had to create a model with the correct size and tolerances. This was one of the biggest challenges throughout the build, as I only had one chance to get it right. The overall print time was 26 hours, so I had to leave it to print overnight. I had PLA to print with at the time, but looking back, PETG would have been the better option due to its resistance to sunlight.





The headlight bracket was a perfect fit after some sanding, both for the headlight and for the nut inserts which would hold the brackets. After this print I realised the potential of this technology for custom parts and fabrication. Straight after, I designed and printed a mudguard out of ABS, with four separate parts. I matched the colour to the motorcycle and attached it to the forks. I think this process of designing, making and using the finished product was one of my favourite parts of the build. It improved my CAD skills, introduced me to 3D printing, thermoplastics but also the process of prototyping and manufacturing. I also wanted some clip-on handlebars as an alternative to the riser handlebars, so I created a CAD model and also a technical drawing for the part. After getting a quote from a CNC machinist however, I decided that buying one would be much cheaper, so I scrapped the idea.

After a full assembly with all the parts fitted properly, fuel tank filled, engine oil renewed, battery charged and the finishing touches put on, the motorcycle was complete. I am very happy with how the bike looks, and it was worth all the time and effort. I am hoping to build another bike in the future, and I would definitely recommend it to anyone who is interested but hesitant. If you have the opportunity, don't miss out: every mistake you make along the way will be a lesson learnt for the future.

Before versus After

Steam into the Future. The Future of Robotics in Surgery

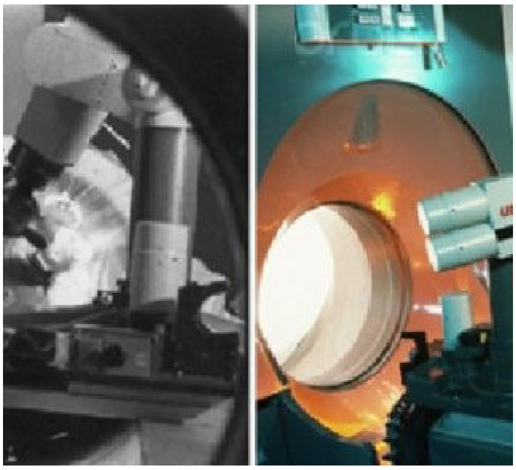
Krish Swaly
John Lyon School, London

Here at The John Lyon School, we have been researching ways we can use robotics in our everyday lives. Robotics can be used for many things from transport use and disabled assistance to nanotechnology and BCI (Brain Computer Interface). However, arguably the use of robotics in surgery is a whole new step in both health and engineering that will actually save lives.

Robotic Surgery Theatre

A Brief History of Robotics In Medicine

Robotics was first used in medicine in the 1980s, but it was not fully developed until the 1990s. The first medical robot was called the PUMA 560 in 1985.



Robotic PUMA 500

Here are some additional key moments in robotic surgery history:

- The first robotic surgery occurred in 1997 and reconnected a woman's fallopian tubes.
- The first unmanned robotic surgery was performed in Italy in 2006.
- Canada saw their first coronary artery bypass graft performed by a robotic surgical system in 1999.
- Approximately 400,000 robotic surgeries were performed across all types of surgery in the U.S. in 2012.
- In 2000, the Da Vinci Surgical System became the first robotic surgical platform commercially available in the United States to be cleared by the FDA.

Our understanding of robotics in medicine has radically improved but the question still remains whether or not we will be able to transition to fully mechanical surgical operations.

The Impact of Robotics In Surgery

Robotics in surgery is the future of medicine, however we still have a long way to go. Robotics is advancing to mimic human abilities with perfection and precision. There are advantages and disadvantages to robots, both technological and ethical. Companies such as Mazor X and Renaissance have over 20,000 robotic implants placed and are constantly innovating to build more surgical robots and implants. Robotic surgery can also be applied to assisted surgeries rather than simply being a robot operating alone.

Robotic Arm Prototype

Ethics and Morality

The question is whether or not it is right ethically. To get a medical degree takes years of education and practical experience. If we were to use robotics in medicine, would we be taking away the hard-earned jobs of medical workers, or could their intellect be diverted elsewhere? The reality is that at the same time, we could save more lives and cure diseases if we had more robots in the health care industry. Robots can theoretically work in any environment from deserts to jungles to war zones, providing access to life saving surgery as never before.

There are also technical issues as we do not fully understand how Artificial Intelligence works or adapts. The other weak spot here is ensuring a continuous power supply and no software or computer glitches. We do not know what a robot will do if it encounters something unexpected whereas a human could improvise. The programming of robots is also open to ethical questions – who decides when a patient can no longer be saved in an operation?

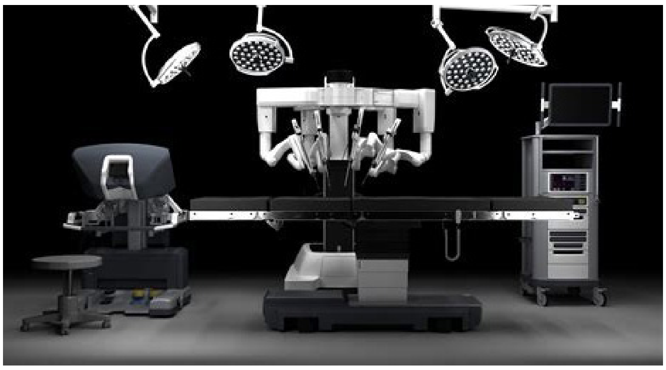
Aside from all of this there is the current enormous cost of designing, testing and implementing these machines. It also costs a lot in resources and instruments to perform a robotic surgery and it is still a barrier for most hospitals. Should we be spending so much on the development when so few can benefit from it?

Could these be our surgeons of in the future?

How Robotics Will Benefit Healthcare

Robotics is the future and using it in our medicine will be the next step in our journey. Not only are robots more consistent with concentration but they can perform long-term surgery with fewer breaks. Whilst a robot uses its programmed code, the code can be used on multiple robotic arms – it is not limited to one machine. These machines can be used in most environments around the world.

Although we may destroy medical jobs, we could also create alternative jobs in computer programming and mechanical engineering. We could even divert more human intellect for medical research. It could also be an opportunity to study how Artificial Intelligence reacts to high pressure situations. For example, using robotics in surgery could prove useful for long operations e.g., 12 hours as robots can work at a continuous rate with no variation in productivity unlike a human surgeon who would require rest breaks. Robots also have a lower error rate than humans when following a plan, which should increase the safety and success rate. Whilst robots can replace the mechanics of performing a surgery, we will still need humans to oversee the process.



Robotic Surgery Theatre Set Up

Some Robotic Surgery Facts

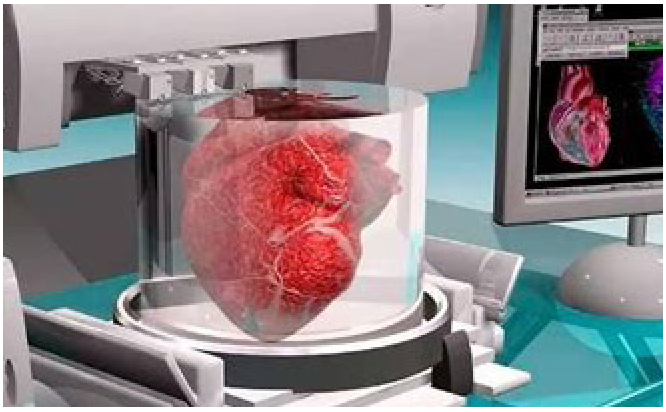
- The rate of robotic surgeries is increasing by approximately 25% annually. The industry is expected to be worth about $100billion by 2025.
- Most surgeons only need to make two or three small incisions (about 2cm) in order to successfully complete a surgery with robotic equipment.
- Blood transfusion rates during robotic surgeries can be near 0%. Compare this to open surgery blood transfusion rates that may be up to 40%.
- If a doctor has performed fewer than 250 robotic surgeries, the outcome is significantly worse than traditional open surgery.
- Studies have shown that there is a higher risk of having cancer left behind during the robotic surgery when compared to traditional open surgery. It is not always as accurate as a human surgeon who is more flexible in the operation and can improvise better based on what they find in surgery. However, researchers are constantly learning more and improving ways to avoid this and build it into a robot's code.

Robotic Assisted Surgery

Bio-Printing : The next stage in technological surgery advances

Whilst robotic surgery can fix some issues, organ transplants remains a major part of modern-day surgery. They are long, complicated operations with mixed results depending on the donor and transplant. One of the main reasons transplants have a mixed success rate is due to the donor organ and organ receiver compatibility, as well as a shortage of suitable donor organs available. Scientists are currently developing a ground breaking solution – 3D printed organs custom designed for the patient.

Scientists have developed a bio ink that can be used to 3D print human organs with the help of the patient's cells. The aim is to eventually custom produce donor organs. This would be a game changer for both medicine and those needing any type of transplant. Bioprinting has many potential uses to repair and replace all types of human tissue in the long term. Removing the "human element" and combining robotics and custom-made donor organs is the next step in improving the success and accuracy of future surgeries as well as reducing waiting lists for transplants.



Artist's impression of a 3D printed organ

Conclusion

I believe that we will eventually fully rely on robots in surgery, but this will be far in the future. We do not have the infrastructure or the finances in place to switch completely to automated surgery yet. We must further expand our knowledge of both Artificial intelligence and medicine before we can advance, whilst also finding ways of reducing the cost to make it more accessible around the world. The benefit to patients in many different situations is huge and will continue to increase as the technology behind robotics in the medical world improves.

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Stem Cell Transplants as a Potential Therapeutic Treatment of Parkinson's

Bam Chairoch
Harrow School, Bangkok

What is Parkinson's disease?

Parkinson's disease or (PD) is a neurodegenerative condition where dopamine neurons degenerate excessively in the brain structure called substantia nigra. The substantia nigra is a part of the basal ganglia, whose major function is to inhibit unwanted motor activities (Fig.1).
The major problems associated with PD are motor problems including tremors, rigidity, akinesia, and postural instability. Other than motor issues, PD problems can be related to non-motor problems such as slurred speech, abnormal facial expressions, mood, and behavioural changes. The causes of the disease can vary. Parkinson's is likely caused by external and internal factors, especially by genetics (genes implicated: SNCA, LRRK2, GBA, PRKN, PINK1, and PARK7) (Zheng and Hunter, 2013) or environmental factors such as exposure to herbicides (Siderowf and Stern, 2003).

Current treatment available

The most effective medication to increase dopamine in the brain is called Levodopa (L-DOPA), where it can cross the blood brain barrier and be converted into dopamine inside the brain. Therefore, L-DOPA can boost the brain dopamine which results in a temporary cure for symptoms. Additionally, when treatment with L-DOPA reaches its limits, some people opt for deep-brain stimulation or (DBS) instead, this is when the surgery is required (Fig.2), where electrodes are inserted into a targeted area of the brain; the most commonly utilised areas include subthalamic nucleus (STN) and the globus pallidus interna (GPi). Despite the problems associated with the brain's target area, medication reduction can be seen on STN whereas Gpi can be slightly safer for cognition and language. These electrodes act as a pacemaker for neural impulses, controlling a pulsatile release of dopamine in substantia nigra neurons. Although the implanted pacemaker does block signals that cause abnormal movement, the pacemaker, as well as Levodopa, do not stop neurons from dying and the effectiveness varies in different stages.

Stem cell treatment

Even though there seem to be no real solutions for the treatment of Parkinson's, recent research using stem cells, a type of cell that has the ability to differentiate into specialised cell types in the body, has shown a promising effect that could potentially treat dopaminergic neurodegeneration. The research into this area has been ongoing since 1980, but the results have been controversial. In the first experiment, the first neural progenitor cell was transplanted into the putamen of Parkinson's patients. Because stem cells were not a viable option at the time, the transplanted tissue was derived from donated foetal ventral midbrain tissue.

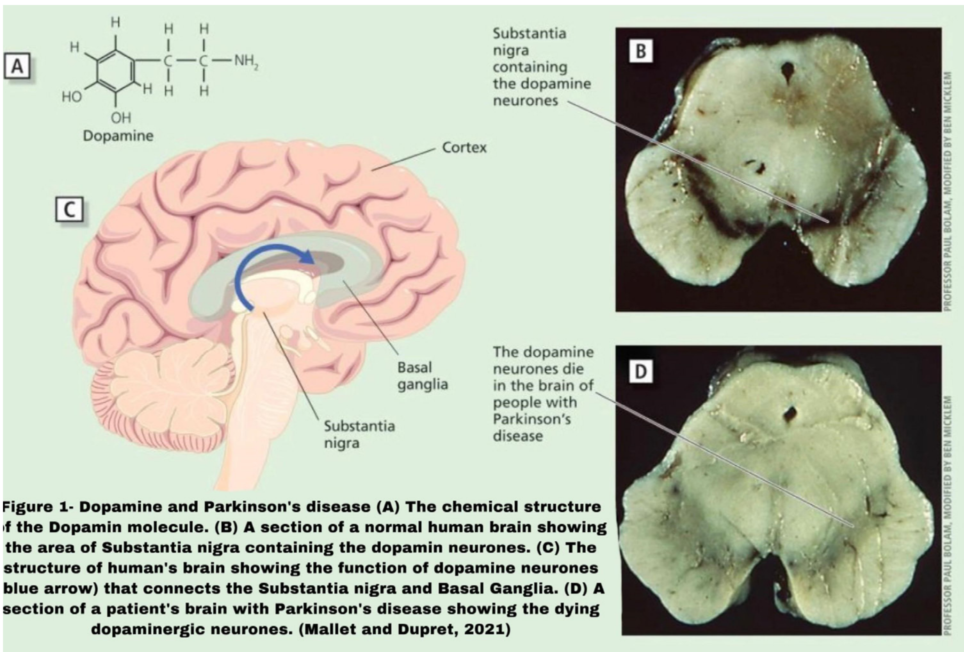

Figure 1- Dopamine and Parkinson's disease (A) The chemical structure of the Dopamin molecule. (B) A section of a normal human brain showing the area of Substantia nigra containing the dopamin neurones. (C) The structure of human's brain showing the function of dopamine neurones (blue arrow) that connects the Substantia nigra and Basal Ganglia. (D) A section of a patient's brain with Parkinson's disease showing the dying dopaminergic neurones. (Mallet and Dupret, 2021)

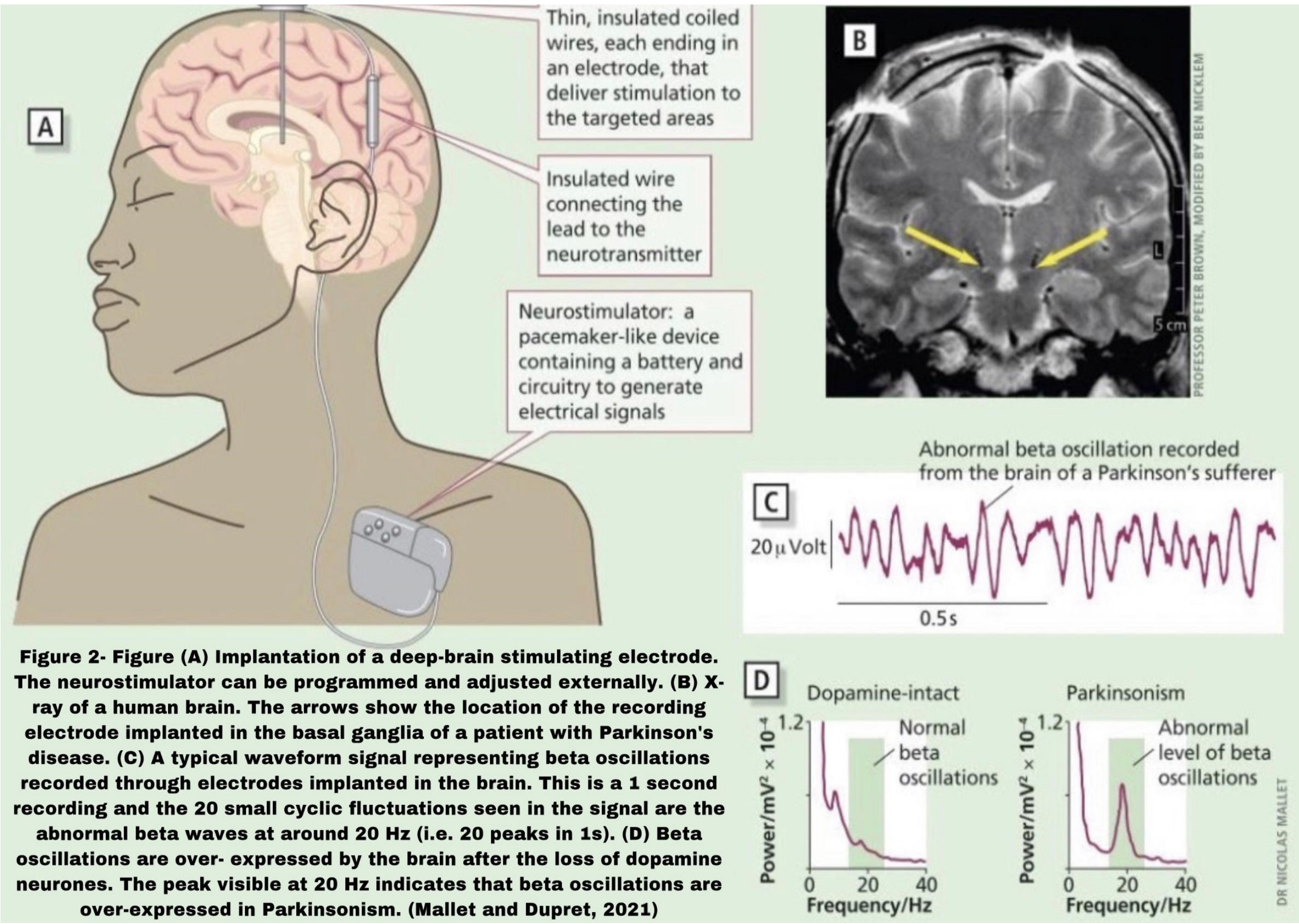

Figure 2- Figure (A) Implantation of a deep-brain stimulating electrode. The neurostimulator can be programmed and adjusted externally. (B) X-ray of a human brain. The arrows show the location of the recording electrode implanted in the basal ganglia of a patient with Parkinson's disease. (C) A typical waveform signal representing beta oscillations recorded through electrodes implanted in the brain. This is a 1 second recording and the 20 small cyclic fluctuations seen in the signal are the abnormal beta waves at around 20 Hz (i.e. 20 peaks in 1s). (D) Beta oscillations are over- expressed by the brain after the loss of dopamine neurones. The peak visible at 20 Hz indicates that beta oscillations are over-expressed in Parkinsonism. (Mallet and Dupret, 2021)

However, after a decade of effort, embryonic stem cell transplantation successfully restored dopamine release in dopamine-depleted rats (Björklund et al., 2002). In addition, some PD patients responded well to DA replacement therapy, which included transplanting mesencephalic cells into the putamen (Mendez et al., 2008). However, some people suffered from postpartum depression. Despite the inconclusive results from the previous experiments, the recent research was done differently (Gravitz, 2021). During the experiment treating patients with Parkinson's, stem cells can be located in a patient's own skin, where cells have been coaxed back into the totipotent stage and tissue in the body including brain cells can be produced. These cells were then prompted to differentiate into dopaminergic neuron (DA) progenitors. This was an impressive procedure as it aimed to avoid transplant rejection, hence preventing the need of immunosuppressive drugs.

Limitations of the research

Stem cells alone may not be as efficient as a combination of L-DOPA plus DBS in slowing or stopping the disease. Stem cells have a constraint that they can't be fine-tuned once they've been implanted. "We're putting cells in there with no way of controlling how much dopamine they release", said Bronstein, a scientist in the research of stem cell transplant. Furthermore, people who undergo the transplant must take medications and a minimum dose of Levodopa for more than 20 years in order to maintain their stability.

Conclusion

Neurodegeneration plays a significant role in PD as it progresses, especially in the Substantia Nigra, with ageing. Progress has been made in the last few decades in finding out about Parkinson's disease, driven by improvements in our understanding of human genetics and stem-cell technology. Hopes for patients who have Parkinson's disease are increasing and waiting for the available effective stem-cell technology that can cure the disease permanently rather than having DBS and L-DOPA treatments, which can only alleviate symptoms and briefly prolong the life of patients.

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The Evolution of Surgery

Perth Chirawichada
Harrow School, Bangkok

Surgery in today's world has incredibly improved in the past thousands of years. Its purpose has extended beyond the need of saving lives into the field of cosmetics to satisfy people's wants. But have you ever wondered what surgery was like in the perspective of the olden eras? We are about to dig into the journey that it took to accumulate knowledge that revolutionized the world of surgery!

Ancient times

The earliest evidence of surgery can be dated back to 6500 BC. However, the surgery performed back then was nothing like the surgery that we know today. In ancient times, surgery was not based on science but rather on superstitious beliefs. Procedures such as trephination; a surgery in which a hole is drilled into the human skull; and bloodletting, were believed to release evil spirits and demons that were causing the diseases.

Without the aid of effective anaesthetics, patients would be strapped down to the table during operations and needed to stay awake in order to increase the probability of coming out alive. Many patients would rather choose death than undergo surgery due to the horrific pain. The surgical mortality rate was really high due to blood loss and infections.

Even though our ancestors had their own ways of alleviating the horror; for example, honey and mouldy bread were used as antiseptics in ancient Egypt; wine and cannabis were used as an anaesthetic in ancient China; they were not widely used and not as effective compared to those we use today.

Since human dissections had been strictly forbidden in many ancient civilizations, the study of anatomy could not progress as much. One of the famous ancient anatomists in the Roman Empire, Galen, resorted his study to dissecting animals such as monkeys and pigs instead. His works were pioneering but also led to many misconceptions which influenced western medicine for over a thousand years.

Middle ages

Surgery was rarely performed by physicians due to it being regarded as a lowly job and was done by barbers instead. Barbers' jobs during this time were not only to cut hair but anything ranging from dressing wounds, pulling teeth to amputating limbs, therefore, they were called barber surgeons. In fact, the coloured stripes; red, white, and blue; on the spinning barber poles that you see at barbershops represent blood and bandages.

With little to no proper medical education, barber surgeons were trained by apprenticeship, and so generally had a bad reputation. It was not until later on in the Age of Enlightenment that surgery had improved by becoming more academically disciplined and was counted as a specialty in medicine. You might notice that surgeons in Britain address themselves as "Mr" rather than "Dr". This dates back to the period when surgeons did not have any formal qualifications.

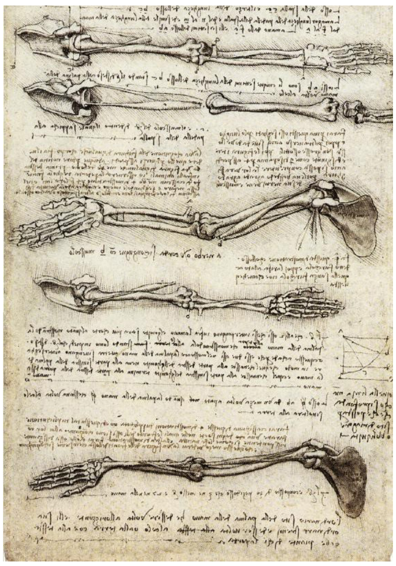
Renaissance

The period of renaissance is known for its transition from the Middle Ages to modernity which occurs in all aspects, ranging from art to science, and surgery is no exception. Medical education began to reform during this time, catalysing many surgical breakthroughs.

In the 16th century, the practice of cauterizing using boiling oil or searing with a red-hot iron was common to seal severe wounds such as amputation or gunshot wounds on the battlefield. Not only was it an extremely painful procedure but also dangerous. Luckily, a barber surgeon named Ambroise Paré, known as the father of modern surgery, discovered that stitching wounds using threads and using cold ointments resulted in a better recovery. He also initiated more efficient methods for ligation of the blood vessels, leading to a significant improvement in surgical techniques.

For the first time since ancient times, human dissections had become more lenient. Andreas Vesalius, an anatomist, began to do his own research on human anatomy by dissecting cadavers himself. He pointed out Galen's anatomical misconceptions which were taught to students for centuries. This shocking discovery led to a paradigm shift in medical education, encouraging students to study anatomy from engaging in 'hands-on' dissection, to fill in the knowledge gap, instead of passively observing and learning from ancient texts that had been the practice for a long time.

Renaissance was undoubtedly the period when art was at its peak. Consequently, anatomical publications where illustrations were used alongside texts emerged from then. This allowed students to truly gain a deep understanding of human anatomy which is the basis of medicine. For comparison, imagine studying transcription and translation in protein synthesis without any diagrams, that would absolutely be a nightmare! This also highlights how art complements the world of science.



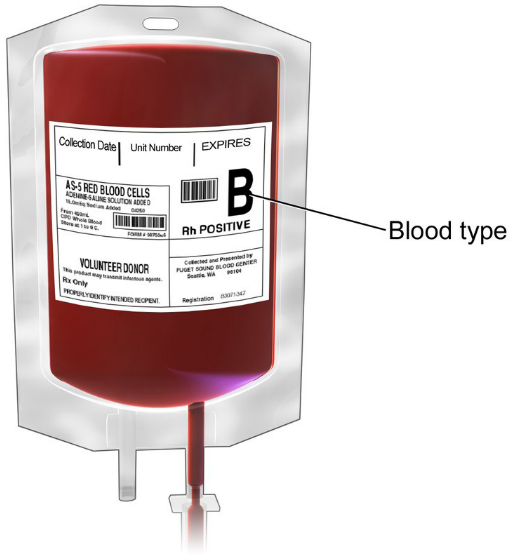
Modern times

During this time, medicine became more disciplined with its knowledge based on a scientific footing, leading to a more scientific surgery. Discoveries such as anaesthetics and germ theory that significantly advanced the world of surgery originated from this period of time.

Certain scientific discoveries in the late 18th and early 19th centuries were crucial to the development of modern anaesthetic techniques. Despite the ongoing debate about who deserves the most credit for the discovery of general anaesthesia, the first public demonstration of the use of inhaled ether as a surgical anaesthetic was performed by William T. G. Morton in 1846. Ether and chloroform started to become popular as general anaesthetics around that time.

Anaesthetics hugely benefit surgery as patients don't have to experience excruciating pain. Surgeons no longer need to rush the operations in order to minimize suffering, allowing them to be more accurate so lessening the chance of complications. The field of using anaesthetics eventually evolved into having its own specialist, anaesthesiologists. With better techniques over time, anaesthetics can be controlled to have different types of effects such as general anaesthesia and local anaesthesia.

Moreover, another important aspect that further advanced modern surgery is the germ theory of disease. Through this concept, we can understand that microorganisms known as pathogens can lead to disease. This led to the development of antiseptics, a substance applied to living tissue that stops or slows down the growth of microorganisms. In addition, by simply scrubbing hands, using rubber gloves, sterilizing clothes, and disinfecting surgical instruments before the surgery could reduce the chance of infections.



Labeled Blood Bag

By the mid-1900s, the introduction of many new medical technologies made surgery much safer than ever before. For example, blood transfusion is a potentially life-saving procedure that can help replace blood lost during major invasive surgeries. Antibiotics are also given in some surgeries as a preventive measure to reduce the risk of postoperative infections.

Medical education also evolved even further during this time. The first formal residency programs were established in the late 19th century at the Johns Hopkins Hospital, laying the foundation of post-graduate training for doctors, making medical education become more systematic where both patients' safety and medical students' quality of education can be ensured.

Conclusion

The advancement in medicine in today's world goes way beyond what our ancestors could have imagined. The word "surgery" seems to have become something very normal compared to the deadly "surgery" viewed in the past. The rate at how surgery has improved is surprisingly fast. Who knows, our descendants might once again say "This is beyond what our ancestors could have imagined!".

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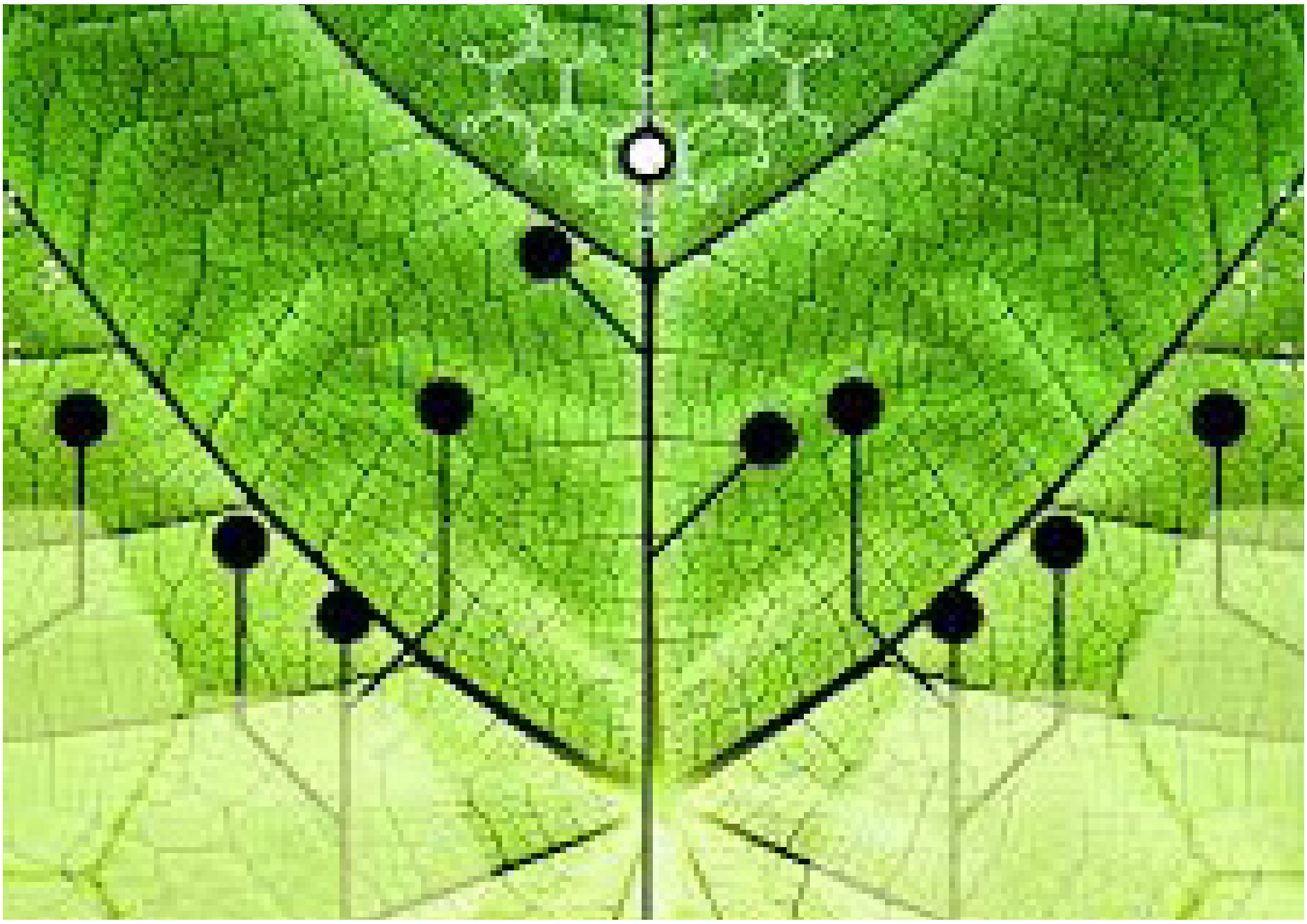

Biomimicry: The Predestination of Innovation

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Introduction

It is undeniable that the human race has thrived since the dawn of the 21st Century with the crucial inventions of 3D printing, augmented reality, capsule endoscopy and numerous other innovations. All of these incredible technological advancements have overwhelmed us with their intricate and judicious design, leading many to envision a bright future for humanity — a world full of metropolitan cities where people travel through magnetic portals, where AI-enabled Human Robots make up the workforce of the tertiary sector, where all energy can solely depend on renewable sources. Although these prognostications may very well become the reality of our distant future, they do not eradicate the dire global problems that originated from the establishment of humankind on Earth (e.g. climate change) owing to the destructive degradation of the environment. If solutions are not proposed soon, there may not even be a future to look forward to. However, the key to the future is astonishingly found at the Blue Lagoon beach, in the Amazon Rainforest and the Sahara Desert. Mother Nature is the answer. There is a false notion that any ingenious creation is artificial or man-made when in reality, it is intrinsic on the surface of our planet, which many see as primitive and forgotten. This is where biomimicry comes in.

What is Biomimicry?

Biomimicry (or biomimetics) is the technological-oriented practice of examining nature (its designs, system, processes) to emulate or take inspiration in order to solve human problems in a regenerative way. The term was coined by Otto Schmitt - an American academic and inventor - and later popularised by Janine Benyus in her book Biomimicry: Innovation Inspired by Nature (1997). The word biomimetics is derived from the Greek words ‘bio’ meaning life and ‘mimesis’ meaning to imitate. [1]

The three key components of biomimicry [1]

There are three important elements to consider wherever we are transcribing the methods into innovations. Biomimicry materialises when all three components are applied and intertwined.

1. Emulate

Emulates represent the “mimicry” in “biomimicry” in which nature’s forms, processes, principles, patterns and ecosystems are reproduced in more sustainable designs through scientific research. This is the physical act of biomimicry (innovation and design) and is often associated with “doing biomimicry”.

2. Ethos

The Greek word ethos means “character” and was first used by Aristotle, who referred to the balance between passion and caution in someone’s personality. In the context of biomimicry, it is the “philosophy of understanding how life works and creating designs that continuously support and create conditions conducive to life”[1]. Ethos forms the quintessence of our ethics and intentions when practising biomimicry; it symbolises our respect, responsibility and gratitude towards the species that live among us and our planet Earth. This is the point of intersection between biomimicry and sustainable design as the ethos element is an elaboration from the emulation of nature facilitating innovations.

3. (Re)Connect

This notion stresses the prevalent drawback of society as they fall into the societal practice of disparaging the beauty of nature. It is common to perceive humans and nature as two “separate” entities due to the dichotomy between the two, but the element of (re)connect educates others on the understanding that there is a deep interconnection between people and the environment. Only when our mindset has changed for biomimicry and biophilia to converge through observing and experiencing nature can we have a greater ethos to emulate biological strategies in our endeavour to rectify international issues.

Nature as a mentor

“Biomimicry is about valuing nature for what we can learn, not what we can extract, harvest, or domesticate. In the process, we learn about ourselves, our purpose, and our connection to each and our home” *(Source: The Biomimicry Institute: What is biomimicry? [1])*

As highlighted by the Biomimicry Institute, biomimicry allows us to finally find our place in the giant ecosystem that is Earth. As we become the apprentices of nature, we can cultivate the next generation of innovators that will guide our society to its glory. The aim of biomimicry is to produce products, processes, and policies that resolve the challenges put forward by our exceptional design in a sustainable, empathetic way in which unanimity is reached for all living organisms on this planet. Through practising biomimicry, we are gifted with the advantages of nature’s wisdom.

An advantage that biomimicry offers is assistance in relieving the stress we experience and the stress we impose on our planet as we continue to expand our civilisation, which leads to the prominent global issue of climate change. From current media coverage, we have already seen the impact of climate change, indicating that climate change is not an imminent catastrophe waiting to happen but a present circumstance that many are already experiencing. For example, the prolonged Australia bushfire incident that marked the start of 2020 resulted from the ongoing drought, heatwaves, wind speed, relative humidity that were exacerbated by the impact of climate change or the unprecedented weather phenomenon residents of Texas are facing due to the arrival of Winter Storm Uri. The irreversibility of the climate crisis and its many devastating effects on ecosystems across the world are causing people to lose hope. However, biomimicry gives us hope; our Earth is home to the solutions for our greatest challenges, accessible by humans and substantiated by the countless species still alive today. If we allow nature to become our mentor, we can experience significant healing effects through the connection to Mother Nature whilst uncovering needed relief for these problems together.

To add on, the act of altruism is promoted through biomimicry as it encourages us to design on behalf of humanity and the natural. Circularity, sustainability, and regeneration are characteristic of biomimetic designs as the creation humans make can transition to restore vegetation, water, air, soil etc. rather than degrading them for our own expense. The "great" man-made inventions utilise brute force to extract and exploit organic materials that nature has provided: mining fossil fuels, metal, rocks for commercial purposes whilst releasing a substantial amount of toxic chemicals in the process. As the world population continues to increase rapidly, our need for land, resources, and water rises dangerously. An estimated 55 billion tonnes of fossil fuels, minerals, metals and biomass are extracted from the ground annually along with the loss of 80% of the world's forest as they continue to disappear at an alarming rate of 375 km2 per day, destroying the homes of more than 1,000 species of animals. Therefore, it is imperative that we follow nature's method of creating conditions conducive to life by using structure to change functions and transit to passive forms of energy.

Furthermore, the urgent situation that our planet faces needs to be dealt with quickly as problems such as global warming, climate change, and water scarcity will continue to progress regardless of whether or not humanity is prepared to manage them. The quaternary sector of research and development is currently set up in some high-income countries such as the United States, Japan, Germany to pioneer solutions to meet the UN's 17 sustainable goals: affordable and clean energy, sustainable cities and communities, responsible consumption and production, climate action and more. Despite the high global spending equivalent to 13.2 trillion HKD with 80% of spending accounted for by 10 countries, R&D cycles are slow owing to the complexity and time-consuming nature of the progress. Instead, we should observe and learn from the biological blueprints that have been successful for millennia to catalyse trailblazing innovations. There is no need for us to devise or reinvent pre-existing strategies when we can simply adopt them from nature.

On top of all of this, the most important benefit is that biomimetics bring us the offering of a new perspective of the natural world. In the last decade, urbanisation has risen as the population has declined in many rural areas - rural-urban migration has led to 55% of the world's population living in urban areas (2018) and is expected to increase by 23.6% to 68% by 2050. The gradual shift of residence from the countryside to the cities suggests that more and more people are losing their connection with Mother Nature as they embark on a metropolitan lifestyle, forgetting their "real" home. Biomimicry has given innovators the hope of achieving a sustainable product that is efficient and effective. Not only does this teach us to appreciate and reconnect to the natural world through experiencing different viewpoints in life, but it also demonstrates the vast wisdom that nature holds and hence promotes the conservation of ecosystems and their inhabitants.

Application of Biomimicry

Biomimicry is still a relatively new technology-oriented approach in the 21st century, but it is already very much evident in different aspects of our daily life through the emulation of nature's form, process and ecosystems.

1.Engineering

One of the most monumental inventions by the Japanese is the 500 series Shinkansen bullet train — one of the world's fastest trains, travelling at the top speed of 320 km/h, which has never had a fatal crash or derailment in its 55-year history and is therefore proven to be the safest, most convenient transportation in Japan. The famous Shinkansen bullet train is named for its streamlined forefront streamlined shape and along with other structural adaptations. However, before the great success, the team of engineers at the West Japan Railway Company were presented with a problem — the noise. [2]

1. Due to the density of the residential settlement near the train track, in 1975, the Japan Environment Agency set very strict noise standards for the Shinkansen Line: a maximum of 70 dB (A) and 75(dB(A) for two zones. Although the group of engineers managed to design a train that approached the speed of 350 km/h (later named the WIN350), the problem arose due to the positive correlation between speed and level of noise. There were 3 main sources of noise[4]:
2. At a higher speed, ground vibration is generated throughout the train and supporting structures to the ground (noise was generated at twice the velocity of the train)

3. The train body and the train's pantographs that connected the overhead catenary wires with the train (at a velocity above 200 km/h, the aerodynamic noise was 6th to 8th power of the train's velocity)

4. After the train passed a tunnel at high speed, a sonic boom was created, which is a prominent issue as half the track of the 554 km Sanyo Shinkansen Line was in tunnels

The reason behind the pantograph noise was that as air passed over the linkage and structural components e.g. struts in the device, it formed Karman vortices (or a Karman vortex street). It was aerodynamic turbulence that caused most of the noise. This phenomenon occurs not only on a small scale but also at all scales, ranging from a train's aerial to patterns found on a beach. This is because it was caused whenever a body disturbed the flow of a fluid, separating into alternate and opposite eddies swirling along the line of the interference and swinging back and forth as the forces alternately dominated each other (as shown in Figure 1).

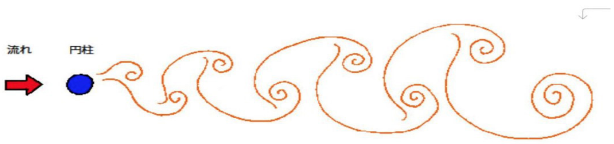

Figure 1 - A visual diagram of the Karmen Vortex in the tunnel that created a high level of noise (Source: zq02 summer 2021 edition by Tom McKeag, image courtesy of Nakatsu, Eiji)

At first, the JR West team approached the problem by decreasing the number of pantographs from eight to two, creating wind shielding covers and designing a new shape of the pantograph to reduce any fluid obstruction and thus the formation of large vortices. However, the renewed pantograph did not resolve the issue. As the new model was significantly heavier, this not only added additional weight to the train, energy and the engineering of the train tracks, but it also aggravated the ground vibration through the train body along with the supplemental pressure wave when entering a tunnel. This is when Mr Nakatsu, a man with the hobby of bird watching, noticed something crucial in bird flight during a Wild Bird Society lecture held by Mr Seichi Yakima about the physiology and anatomy of birds in aircraft design. Despite travelling at 64 km/h, being nocturnal predators, owls have several noise-dampening forms in their feathers that provide the ability of 'silent flight'. This is enabled by the flutings or fimbriae composed of "comb-like" serrations along the leading edge of the primary wing feathers, which break incoming air over the wind foil into micro-turbulence and reduce the level of sound emitted. Mr Nakatsu and his team analysed the wings of an owl specimen and emulated the curvature and serrations that form the "wing-like" component of the new prototype. (This is shown by the blue section in Figure 2.) In place of the previous double-scissors structure, they made two streamlined elements, which were the pantograph slider and a vertical aluminium pillar in 1994. [4]

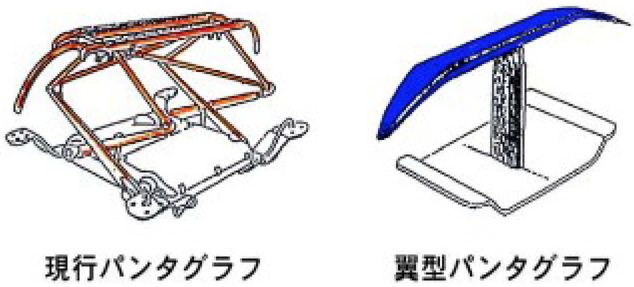

Figure 2 - A design comparison between the current pantograph in 1975 and the newly invented pantograph emulating the wing of an owl (Source: zq02 summer 2021 edition by Tom McKeag, photo courtesy of Nakatsu, Eiji)

Moving on, they had to tackle the sonic boom problem. Each time the train entered the tunnel at high velocity, low-frequency (under 20 hertz) atmospheric pressure waves were generated and propagated the tunnel at the speed equivalent to a plunger pushing into a syringe - essentially, the train was forcing air out the end of the tunnel.[8] The pressure discharged at the tunnel end was only 0.001 atmospheric pressure due to the reflection of compression waves, creating a pressure variation, the air transmitting in low-frequency waves produced a large sonic boom and aerodynamic vibrations. This is known as a Tunnel Micro Pressure Wave (as seen in Figure 3). Residents within a radius of 400 metres of the tunnel exit were affected, which pushed the engineers to find a solution. The tunnel problem was more complex than the pantograph issue due to the connection between both the geometry of the tunnel and the speed of the train - per unit increase in velocity, pressure triples - as well as the proportional relationship between the micro pressure of wave and the cross-section of the trainset compared to the tunnel. Since it would be extremely difficult and expensive to rebuild the 64 m2 tunnel, the approach was to reduce the cross-sectional area of the train and redesign its nose to prevent the building up of pressure waves.

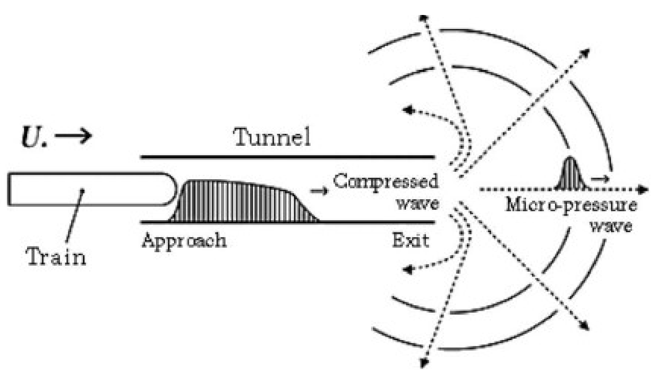

Figure 3 - A visual diagram of the Tunnel Micro Pressure Generated Mechanism which created the sonic boom (Source: zq02 summer 2021 edition by Tom McKeag, image courtesy of Nakatsu Eiji)

Once again Mr Nakatsu was able to look for inspiration in nature after a junior engineer pointed out that the test train seemed to "shrink" when entering the tunnel, suggesting that there was a sudden change in air resistance from open-air to closed air tunnel. Mr Nakatsu then realised that it was the same situation as kingfishers moving quickly from the air (a low resistance medium) to water (a high resistance medium, around 800 times denser) without creating any splash to keep its prey in their sight and avoid startling the fish. This was achieved by pushing water in front of the bill so the water would be allowed to flow past the beak. Since the train faced a similar challenge in moving from low drag open air to high drag air in the tunnel, the team decided to recreate the forefront of the Shinkansen train based on the beak of the kingfisher. The shape of the kingfisher's bill provided an almost ideal shape for this: the beak was streamlined, steadily increasing in diameter from its tip to its head in a rotational parabolic shape - the same shape formed in the diamond interstices of four perfect circles intersecting with each other. After obtaining a natural specimen of a kingfisher and analysing its dimension and materials, they recreated numerous bullets in the shape of different train nose models and tested in a pipe scaled to the model tunnel, and naturally, the bullet in the form of the kingfisher's beak generated the lowest pressure waves. Finally, on March 22, 1997, JR-West's 500-series Shinkansen bullet train was put into the commercial service, travelling 10% faster whilst remaining below the noise limit of 70 dB. The air resistance reduction also resulted in the secondary benefits of reducing energy consumption (15% less) and cost.

2. Healthcare

Although there is a huge emphasis on the maintenance of hygiene and sanitation in hospitals, there is also a rising issue of healthcare-associated infections (HAIs), which refers to infections obtained while receiving health care for other conditions. Examples of this include bloodstream infections (BSI), pneumonia, urinary tract infections (UTI) and surgical site infections (SSI) such as sepsis. According to the World Health Organisation (WHO), in every 100 hospitalised patients at any given time, 7 patients in developed and 10 in developing countries will acquire at least one healthcare infection, either leading to significant mortality rates or causing substantial financial losses for the healthcare system. Even in high-income countries, approximately 30% of patients in intensive care units (ICUs) are affected by a minimum of one HAI in spite of the extreme measures taken to keep the area as sterilised as possible for critically ill patients. This was a discernable medical vexation until a solution was accidentally discovered in 2007 by the establishment of Sharklet Technologies.

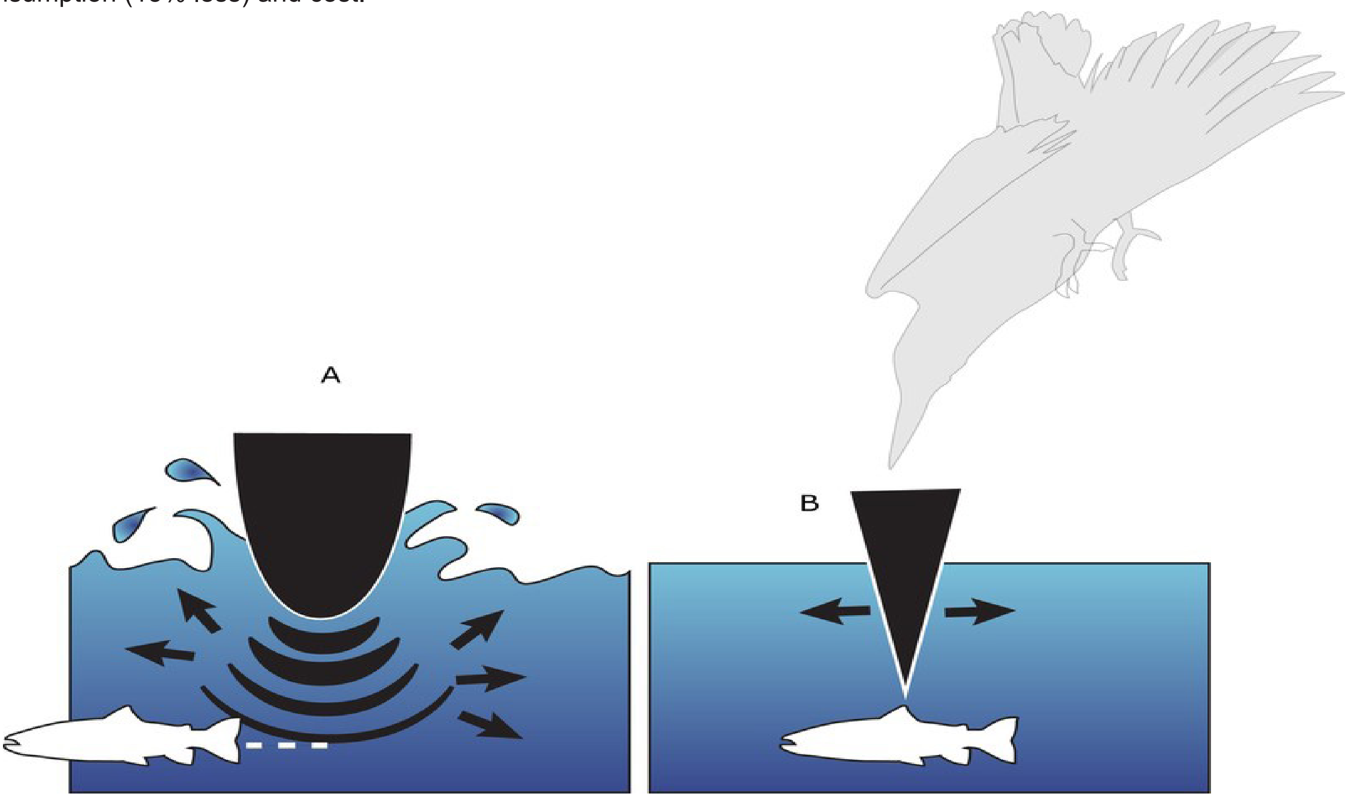

Figure 4 - The difference in drag between the two shapes. Shape A is similar to the original bullet train forefront shape and shape B resembling the beak of a kingfisher (Source: Biomimicry with 3D printing of shapes and surfaces by Max Murphy)

In 2002, Dr Anthony Brennan, the founder of Sharklet, was a materials science and engineering professor at the University of Florida. He became the pioneer of the new material called Sharklet due to his visit to the US naval base at Pearl Harbor as part of navy-sponsored research. The US office of naval research requested Dr Brennan to develop a new strategy to discourage the growth of barnacles on ship hulls to stop the use of toxic antifouling paints, as well as cutting down costs relating to dry dock and drag. He then found that Galapagos sharks, regardless of their slow movement in the water, did not suffer from the problems of being covered in algae, barnacles, and fouling.

Using scanning electron microscopy, Dr Brennan was able to observe and examine the dermal denticles of the sharkskin, which confirmed his theory that the sharkskin denticles are arranged in a specific diamond pattern with microscopic riblets that minimises drag. The first Sharklet was made after Dr Brennan's evaluation of the sharks' ability to inhibit the growth of microorganisms was proven to be antibacterial. This led to it being commercially rolled out onto the surface coverings of hospital surfaces such as countertops, bathroom sinks, computer monitors, etc, reducing the growth of microbes by an astonishing 80% and notably providing a strong advantage over drug-resistant bacteria such as MRSA and C. diff.

The Sharklet's surface is composed of millions of microscopic features organised in a distinct, uniform diamond pattern (as shown in Figure 5), which Dr Brennan had measured the width-to-height ratio of (3 microns tall and 2 microns wide). This then corresponded to his mathematical model for roughness that would discourage microorganisms from attaching, colonising and forming biofilms without the use of any toxic additives, chemicals, antibiotics or antimicrobials. Depending on its applications, the Sharklet may have positive patterns protruding from the surface, inverse patterns recessing into the surface of the material or altering the dimensions in the pattern. According to the principle of nature, organisms seek the path of least energy resistance - as a result, pathogens take root singly or in small groups with the intent to establish large colonies. The Sharklet takes advantage of this: by preventing the formation of biofilms, it would require too much energy for microorganisms to colonise. Consequently, the pathogens then move to find another place to expand their population - and since they are unable to signal each other, this eventually leads to the death of the pathogens as they are inherently programmed to die (which is referred to as programmed cell death, or PCD).

All healthcare facilities try to defend against dangerous infections through personal maintenance (e.g. washing hands regularly), the use of antibiotics, and disinfecting chemicals. These common precautions taken to combat pathogens are not always effective nor beneficial as the overuse of antibiotics creates a new generation of resistant microorganisms. To add on, the chemicals used not only have high economic costs but are also environmentally unfriendly to manufacture and may be harmful to humans such as causing skin irritations and respiratory problems. Rather than spending tens of millions of dollars on drug research to combat HAI, the answer lies within the micropattern created by evolution: By emulating the structural design into the practical Sharklet material, millions of lives can be saved.

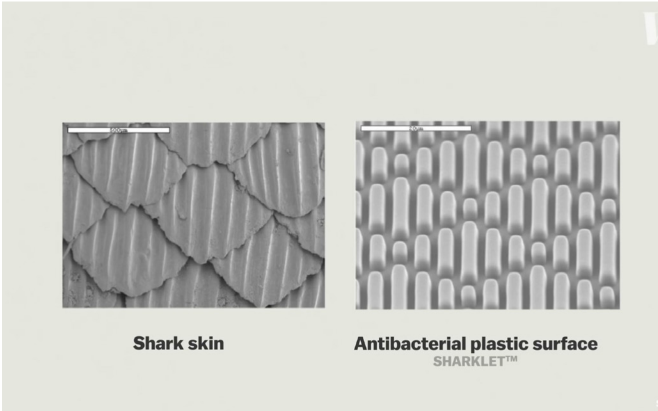

Figure 5 - Side-to-side images of the microscopic sharkskin denticles and the micropattern created by the adoption of it by Sharklet Technologies. (Source: Vox video "The world is poorly designed. But copying nature helps")

Evaluation

In conclusion, biomimicry is highly effective in enabling humans to create innovative technologies whilst also carrying out the process in an inherently sustainable way. Simply by introducing a biologist or biomimetic expert into the team of engineers, industrial and domestic life would be made easier through the imitation of nature's form, process, ecosystems. Since the idea behind biomimicry is to utilise the biological blueprint or template provided by Mother Nature without harming any organisms nor causing any environmental degradation, Janine Benyus frequently emphasised the eco-friendly nature of biomimicry. Unfortunately, this is not always the case.

Some practitioners of biomimicry in the business industry usually prioritise the production of novel technologies and maximum profit over the aim of sustainable development. For example, the most recent biomimetic research projects were designing undetectable surveillance cameras based on insects' compound eyes, creating fixed-wing, wind-propelled naval drones based on the flight of albatross, emulating DNA to create industrial nanites, etc.

Projects such as these rarely showed devotion to eco-friendly initiatives or pronounced sustainability credentials, and they could even be contributing to the ecological footprint and exacerbating the risk of environmental degradation. Owing to large corporations in the defence industry investing in these projects, it can be inferred that biomimicry is being exploited as a profitable way to take advantage of natural strategies, and this is capable of causing environmental harm instead of promoting eco-friendliness.

However, biomimicry is an intellectual movement in design and innovation, offering humanity a way to transform. Inventions by companies such as Calera - which manufacture building blocks using CO2 - or Aquaporin - which created a filtering unit for water to desalinate seawater using less electricity - have proven that biomimicry has the potential to resolve many of our current global crises, including water shortage and global warming, in a sustainable manner. This can be encouraged by the spreading of ecocentric traditions, policies and the introduction of ‘ecomimicry’, which is the emulation of nature for eco-friendly design. Ecomimicry serves as a categorisation system that allows us to identify socially or environmentally insensitive practices of replicating nature and recognise practices of emulating nature that aim to be environmentally responsible and socially just, such as encouraging decentralisation and localism, a democracy of decision-making over technological change, and the acknowledgement of the need to distribute power rather concentrate it.

Conclusion

As Janine Benyus, the co-founder of Biomimicry Institute said, “When we look at what is truly sustainable, the only real model that has worked over long periods of time is the natural world.” The Earth came into existence and survived for 4.543 billion years, with the beginning of the lives of more than 30 million species 3.8 million years ago. In stark contrast, humans only make up a small part of the history of planetary life - a mere 0.00789%. We are the latecomers, strangers to our home, and yet we are trying to change the ancient civilisation of organisms in attempts to refine our society and surpass our past, wreaking havoc and degradation to the natural world in the process. Instead of being the invaders of Earth, we should respect it by making products, systems and cities indistinguishable from the natural world and by adapting their form, process and ecosystem as animals, plants, and microbes are the consummate engineers of our world. Instead of only learning from the designs of other humans, we should become the apprentices of Mother Nature. Sustainable solutions to our globally intractable problems are intrinsic to our planet. The innovations of our future have already been predestined through the millennia of evolution. All we have to do is go outside, observe, analyse, and learn - to become the pioneers of our generation.

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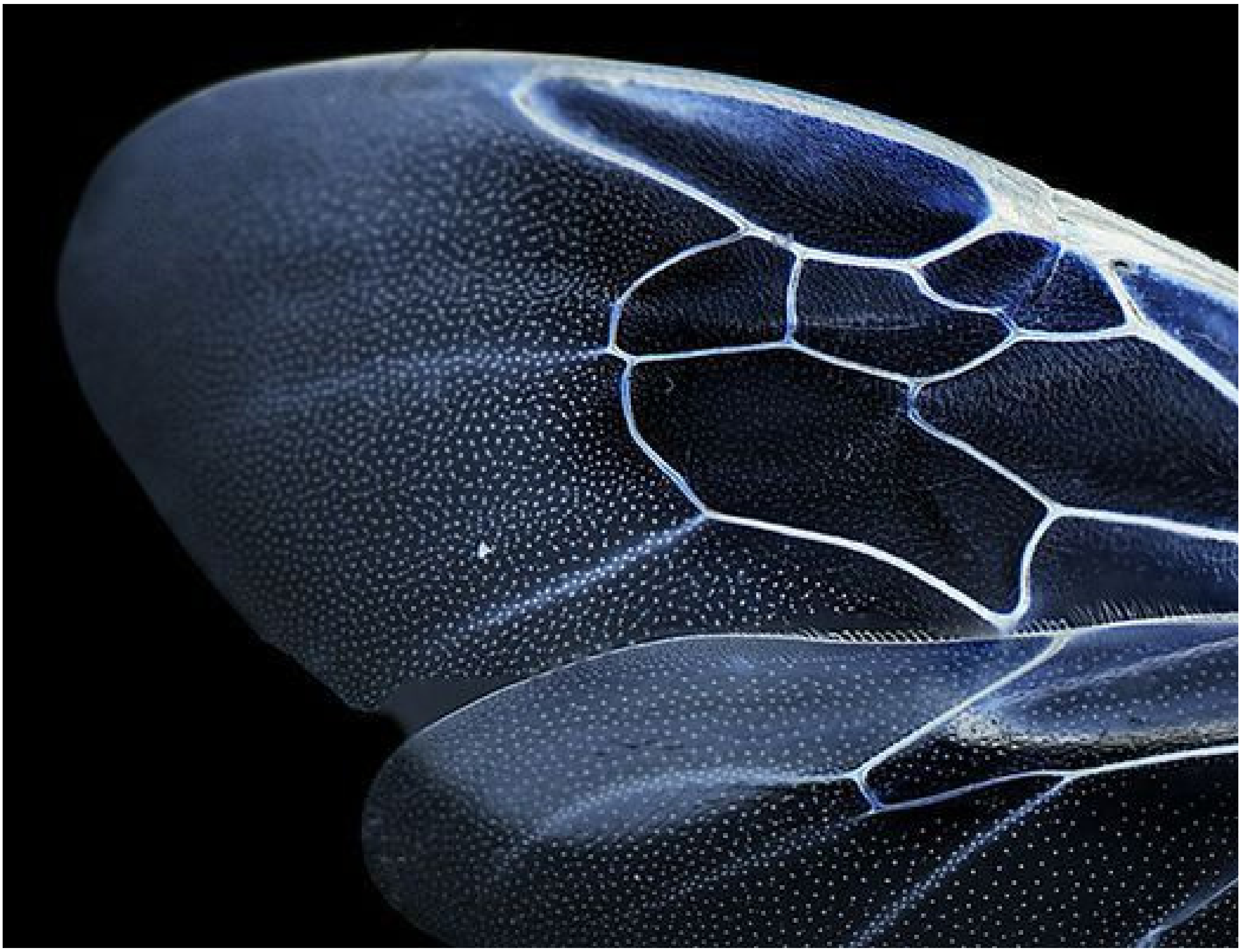

The Future of Sound Technology

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Introduction

As technology becomes more advanced, personalised and on-demand, it improves the way we listen. The growth of the live music industry and movies pushed audio technology from its origins into quite advanced systems that were used in major events. Audio systems have evolved far from being a simple speaker. Today's events are engaging, immersive and highly refined masterpieces that are played by audio artists around the world.

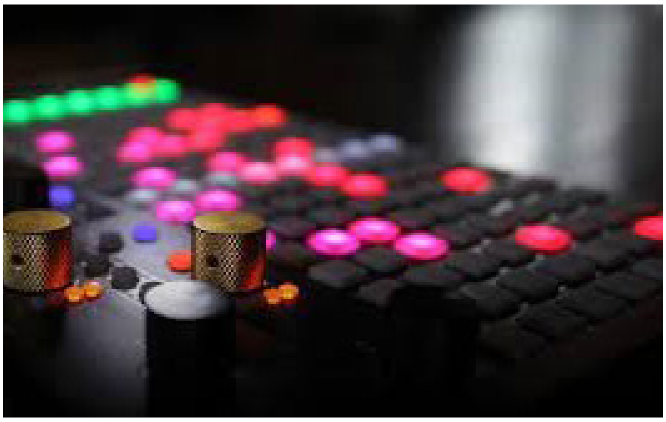
While audio technology hardware advancement appears to have slowed down, the growth will be in the software and programming that manipulates the systems to make them more flexible and allow for greater control and creativity.

Synthstrom Deluge – Portable synthesiser, and sequencer

Designed in New Zealand, this unique all-in-one synthesiser, sampler and sequencer was created with the purpose of creating and improving electronic music. It features 128 pads for sequencing, a dual-engine subtractive and FM synth and 64MB of RAM for loading samples as well as built-in effects, arpeggiator and CV outputs for external gear. This piano style instrument is already creating waves in the musical world since it requires no computer to create the music.

Decibel – Eco-friendly modular speaker

The company claims that these speakers will be "the last speaker you'll ever buy". The Decibel aims to reduce e-waste through their modular design. Rather than buying a new unit every time, Decibel encourages you to replace the components as the technology advances and you are able to be up to date. In order to open the instrument all you need is the Allen key and you can replace the part you want to with a new component that comes with a pre-paid return package. This awesome wireless Bluetooth Speaker has even more impressive features like long battery life, wireless and USB-C charging, aptX audio, and an aluminium chassis, and it is good looking too!



Olive – Next generation hearing aid

With the aim to solve the problem of cost and the social perception on the hearing impairment, Olive has come as a revolution in the hearing aid technology. Affordable and accessible to all, Olive allows the users to test the hearing aid and configure the aid to their requirement and need. The aid is cost efficient, next gen and appealing too.

4D – The future of sound

4D is here to revolutionise the way we hear the sounds by adding an extra dimension along the Y axis. This gives more depth to sound we hear. 4D is here to revolutionise the way we hear the sounds by adding an extra dimension along the Y axis. This gives more depth to sound we hear. The purpose of 4D systems is to let the electronic music producer manipulate sound so it moves in time, changes shape, and hits you from all corners of the room. The 4D system allows for 16 columns of omni directional speakers, each with three speakers per piece, and nine sub-woofers under the floor, for a total of 57 separate channels of audio. They can be easily connected through apps where the end users can manipulate the sounds in the way they want.

The way in which we experience sound has dramatically changed. Now that digital music is here for foreseeable future, it's pushing the growth of earbuds among the popular music enthusiasts. These devices, apparatus and accessories are here to give us a high quality acoustic experience for ages to come.

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Fake Trees with Real Potential

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Between the end of the ice age and the Industrial Revolution, the atmospheric concentration of CO_2 was at 280 ppm. Since the Industrial emissions have increased drastically from 0.01 billion metric tonnes in 1750 to 36.44 billion metric tonnes in 2019. This has led to an increase of CO_2 concentration to an average of 410 ppm, which is an increase of 46%. As a result, the rate of climate change and global warming has rapidly increased owing to the extreme level of pollution. Hence, as a solution, why not create artificial trees that can mimic the role and functions of a tree with increased efficiency in photosynthesis?

Reasons for the idea of the artificial tree

Carbon dioxide is an odourless and colourless greenhouse gas that makes up 0.04% of the gases in the atmosphere.

1. The Sun emits electromagnetic (EM) radiation (including gamma rays and ultraviolet waves) in the form of waves travelling through space. Most EM waves enter the Earth's atmosphere whilst some are reflected.

2. These sun rays can then take two paths:

a. Sun rays are absorbed by the earth's surface, warming its surface.
b. Some are re-emitted as longer wavelengths with lower frequencies of infra-red radiation. Most of these re-emitted waves are supposed to be reflected back into space. However, excessive volumes of greenhouse gases absorb the infrared photons

When infrared photons hit the carbon dioxide molecule, it causes the covalent bonds between the carbon and oxygen molecules to vibrate in one of three ways (modes): symmetrical stretching, asymmetrical stretching and bending. This is due to the natural frequency at which the bonds in CO_2 molecules vibrate, which corresponds to the specific frequency of infrared radiation. When infrared active photons (energy) reaches CO_2, the infrared radiation is transferred to kinetic energy causing the asymmetrical stretching or bending of carbon dioxide.

This produces a change in the dipole moment of CO_2, causing CO_2 to be temporarily polarised as the linear shape of carbon dioxide is distorted (Figure 1). The V shape of the carbon dioxide molecule and the asymmetry in asymmetrical stretching means that vectors do not cancel out. This results in a higher temperature since the temperature of the gas is a measure of the average kinetic energy per particle. Hence, diatomic molecules such as nitrogen molecules only have one mode (stretching and compressing their bonds) and are identical and symmetrical in the distribution of charges. As a result, this inhibits the molecules from creating a change in dipole moment and therefore cannot absorb infrared radiation.

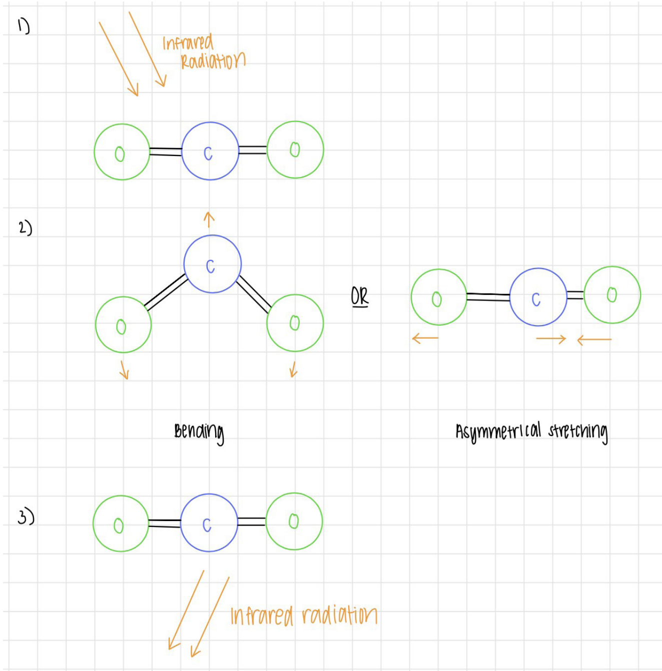

Figure 1: A demonstration of the movement of carbon dioxide molecule when it absorbs infrared radiation

Additionally, collisions between carbon dioxide molecules also cause a transfer of energy from the energised molecules to other molecules. The faster the motion of a molecule, the greater the increase in thermal energy and the greater the earth's surface temperature.

The increasing volume of carbon dioxide in the atmosphere has caused serious concerns for the environment, as the increase in global temperature has caused the melting of glaciers and hence the rise in sea levels. This poses a danger not only to countries located on low lying coastlines such as Hong Kong but also to organisms that thrive off of shallow water. It can cause catastrophic destruction including imbalances in ecosystems as a result of damaged habitats from flooding or drought leading to animal migration.

There have been various attempts to reduce carbon emissions and their footprint:

1. The use of Scrubber devices that have been fitted to the chimneys in different pilot projects around the world so that the greenhouse gas produced during fossil fuel burning can be removed from the exhaust emissions;

2. The Climate Change Act 2008;

3. Specific brands attempting to reduce their carbon footprint (e.g. Levis is using recycled plastic to make jeans, resulting in reduced waste and plastic in oceans as well as reducing the volume of water used to manufacture a pair of jeans by up to 96%, saving more than 1 billion litres of water in product manufacturing)

As a result of the excess emission of carbon dioxide globally, the rate of photosynthesis of plants can no longer keep up with the rate of carbon production by humans. This, therefore, has acted as a catalyst for the development of artificial trees.

The idea of artificial mechanical trees

Professor Klaus Lackner, director of Arizona State University's Center for Negative Carbon Emissions, announced the commercialisation of carbon-capture technology. The idea behind his synthetic trees came from his early observation of the build-up of carbon dioxide in the atmosphere. He believed that the technology needed to deal with this problem does exist; however, because nobody ever had enough incentive to create it, it has not been made. Dr Lackner wanted to treat the root cause of climate change using direct air capture.

According to an article written by Arizona State University, Lackner's technology is thousands of times more efficient at removing CO2 from the air per artificial tree than a regular tree. It captures carbon dioxide from the atmosphere through the movement of the wind blowing into the device, which then emulates a tree's ability to photosynthesise. Carbon dioxide can also be sequestered and sold in the form of synthetic fuels as it gets buried or used as an industrial gas. This system separates itself from other carbon-capture technology:

1. It is a passive process and,
2. It allows for lower costs whilst allowing it to be a scalable and commercially viable solution.

How does it work?

The mechanical tree prototype is made of 12 columns which can remove a minimum of 1 metric ton of carbon dioxide per day. When the tree extends its 'branches', the white sorbent-filled disks in the 'leaves', which is an ion-exchange resin (IER) and polyvinyl chloride (the binding agent), absorb the carbon dioxide. In this case, the ion exchange resin is sodium carbonate. It is able to do this as it is an anionic (positively charged) exchange resin that has a strong affinity to bind with carbon dioxide (which has partial negative charges from oxygen) as a bicarbonate ion when in a dry state.

Stage 1: Capture the Carbon

1. Tiles on the 'tree' extend upwards from a compre
2. ssed position to 10 metres high and become saturated with flue gas from ambient air carried by the wind.
3. Tiles are lowered mechanically into a chamber at the base.

Stage 2: Carbonator

1. Flue gas contains a mixture of gases for example nitrogen dioxide and sulfur dioxide, which make it impure. This restricts the carbon capture to directly capture carbon dioxide and sequester it.
2. The white sorbent and water from the atmosphere are therefore required in order to isolate carbon dioxide later. This forms the sodium bicarbonate (white solid), which is collected on a disk and moved towards the section of thermal regeneration as other gases such as sulfur dioxide is sucked out using a vacuum.

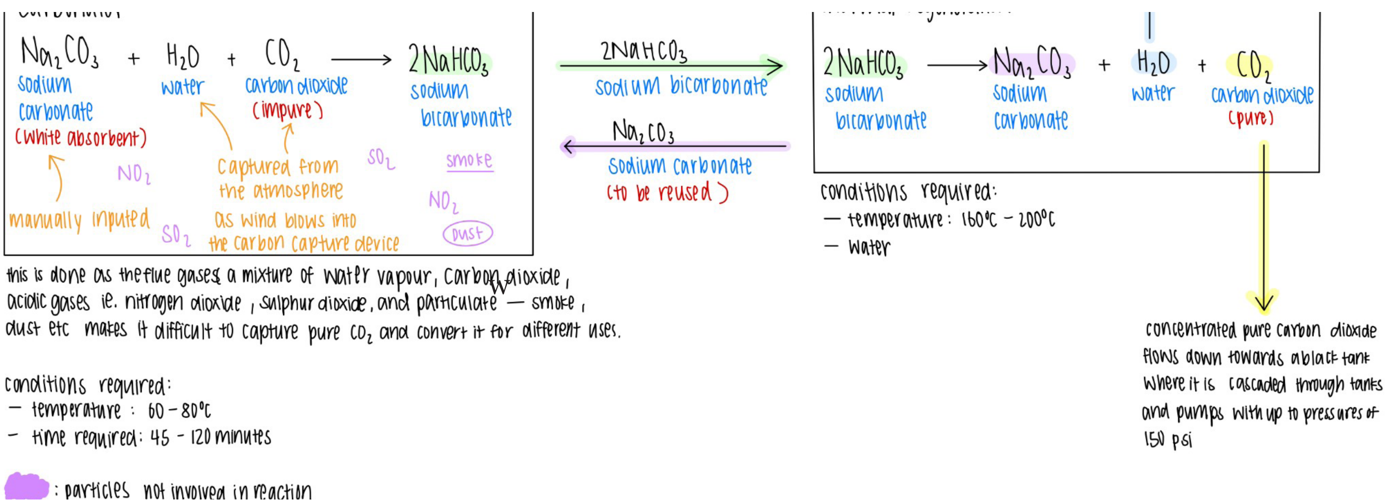

Figure 2: A visual representation of what happens in the two steps

Step 3: Thermal Regeneration

1. The disks with sodium bicarbonate are lowered into the heated wet container where the carbon dioxide is released.
2. Carbon dioxide is then heated to evaporation to separate from H2O in order to obtain a 95% pure sample.
3. It is then condensed and flows down towards a black tank where it is cascaded through tanks and pumps with up to pressures of 150 psi in order to convert pure carbon dioxide for other purposes.
4. 1% of the total gas inputted will be carbon dioxide, of which only 90% can currently be extracted.

Step 4: The process repeats as the mechanical tree extends upwards again.

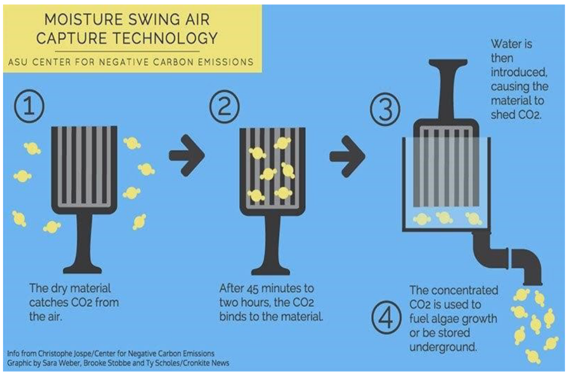

Figure 3: A visual representation of what the Carbon-Capture technology does when coming in contact with carbon dioxide (source: Cronkite News by Sara Weber, Brooke Stobbe and Ty Scholes)

Problems that arise with artificial mechanical trees

1. The Social Cost:

There is not enough space to store it securely in saline aquifers or oil wells.
Solution: Geologists have come up with an alternative. Rock peridotite (which can absorb large volumes of carbon dioxide) can seal the absorbed gas as a stable magnesium carbonate mineral, but despite its potential, it could potentially damage more natural resources. Lackner believed the gas should be petrified and used for transport vehicles. Carbon dioxide can react with water to produce carbon monoxide and hydrogen (syngas) because it can be readily turned into hydrocarbon fuels such as methanol or diesel. The process requires an energy input, but this could be provided by renewable sources such as wind energy.

2. The Moral Cost:

Because of the invention of technology, more people are more susceptible to becoming less conscientious to curb their emissions. Although more carbon is being offset by the fake trees, people may potentially produce more carbon dioxide, creating a vicious cycle. Furthermore, there is also the fear of playing with natural systems. Geoengineering could cause certain natural processes such as weather patterns and rainfall to change: these effects cannot be reversed or offset, making it dangerous to use fake trees.

3. The Carbon Cost:

Each synthetic tree requires energy to operate; it generates some carbon itself if plugged into the power grid. Lackner calculated that, for every 1000 kg of carbon dioxide the synthetic tree collects, it emits 200 kg, so that 800 kg are considered the true collection. [3]

4. The Economic Cost:

Not all countries have the financial resources or capability to shift to more sustainable energy sources, let alone invest in an expensive project. For example, because of the UK's geological position, it is able to rely more on wind-generated energy. It has a natural advantage when it comes to offshore wind power because of the North Sea. The economic resources of the UK have also allowed for a series of subsidies to build new wind farms. However, countries such as India have other issues, such as social unrest and high rates of poverty, that need immediate attention, so reducing carbon emissions within a country may not be considered a priority.

Application of Fake Tree

As previously covered, artificial trees are said to be thousands of times more efficient than natural trees at removing CO2 from the atmosphere. Dr Lackner's team based in Arizona, known as Carbon Collect Limited, is working on providing unlimited, low cost and clean solar energy for direct air capture. They plan to begin deploying small-scale Mechanical Trees in preparation for the mass production of large-scale direct carbon capture devices.

Additionally, to combat the urban heat island effect, many scientists have invented solutions building on Professor Lackner's ideas. Designs such as the TREEPOD and CLECanopy were devised with the intent to enhance and maximise the benefits of trees.

Specifically, designers Mario Caceres and Cristian Canonico designed the TREEPOD for the SHIFTboston Urban Intervention contest. It is able to remove carbon dioxide and release oxygen using a carbon dioxide removal process by Lackner's technology called 'humidity swing'. It is powered using solar energy panels and an interactive seesaw that children can play on and convert kinetic energy into electrical energy. This energy can then be used to power the air filtration and night lights for increased safety. They plan to build the TREEPOD out of only recyclable plastic from drink bottles, which has added advantages of reducing pollution through using plastic in the sea. This design harnesses the biomimicry of both the Dragon Blood tree, imitating its umbrella shape to optimise shading surface, wind flow and solar energy panel surface area and the human lung filled with the resin in which is able to absorb CO2. The large surface area of the branches allows for higher efficiency of 'gas exchange'. [10]

Conclusion

For the future of the world, money should not be the reason limiting these innovative ideas and projects, as fake trees can help reduce the effects of carbon emissions and restore (to an extent) some balance into the world again. However, we still should not be overly reliant on fake trees as natural trees bring other beneficial aspects, such as providing shade and food for wildlife. Creating fake trees alongside the continuous plantation of real trees could be a more sustainable way of slowing down the climate crisis.

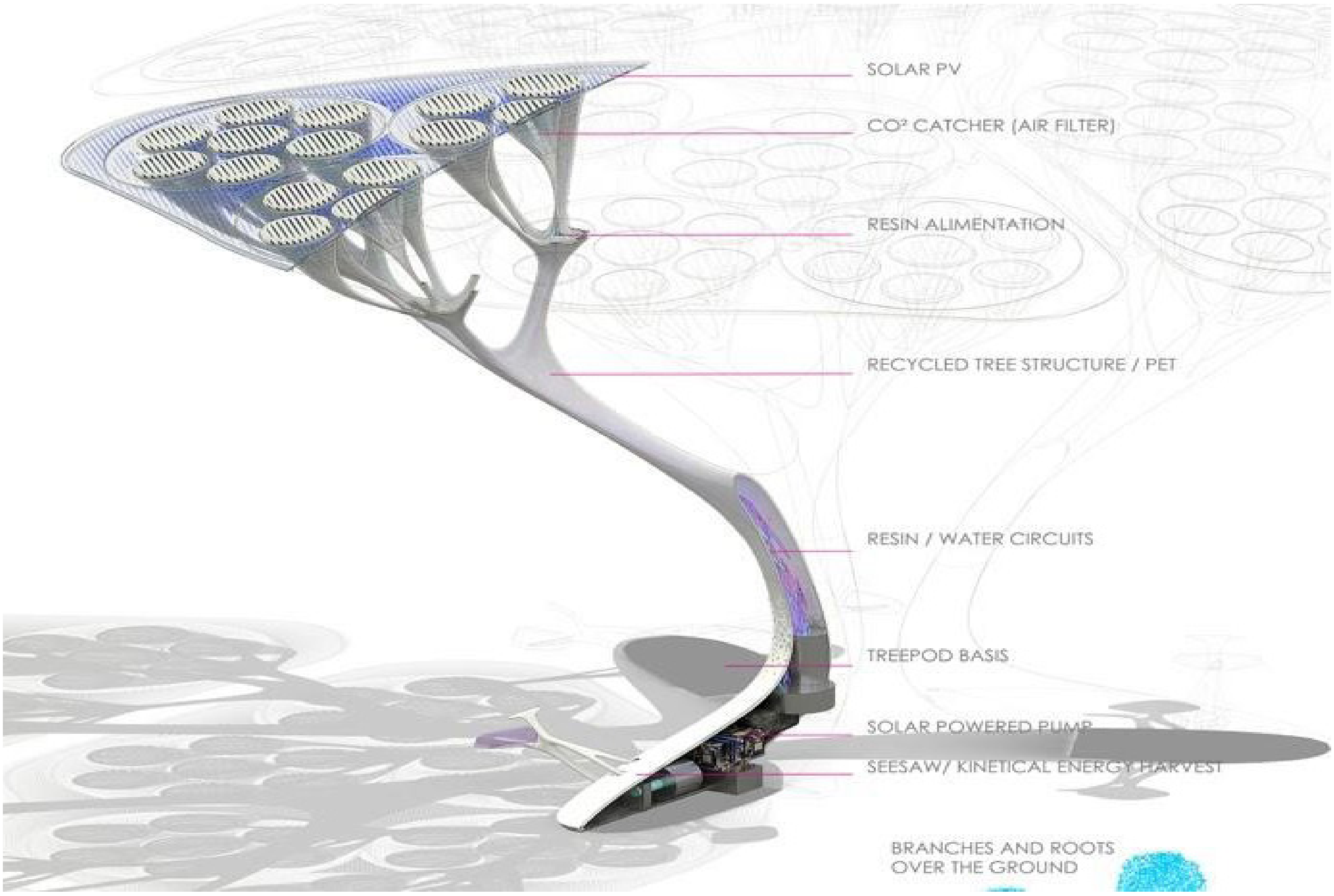

Figure 4: A picture showing the cross-section of the TREEPOD design (Source: Inhabitat, image courtesy of Mario Caceres and Cristian Canonico)

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Artificial Synthesis Of Starch From Carbon Dioxide

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Researchers have been searching for ways to artificially synthesise starch to reduce reliance on food sources such as maize (corn) crops. Cai et al. from the Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences, have developed an artificial pathway to synthesise starch by combining chemical and chemoenzymatic catalysis. This new pathway has the aim to imitate the two main stages of photosynthesis, with a slightly modified approach. Overall, the aforementioned Artificial Starch Anabolic Pathway (ASAP) has no reliance on using biological cells as a medium and has shown to be more efficient than photosynthesis in many aspects. This breakthrough is a milestone achievement in industrial biotechnology, though there are still major challenges before ASAP can be expanded onto an industrial scale.

Photosynthesis

Photosynthesis, in essence, is the process in plants where CO2 and water react to form sugars and release oxygen in the presence of light. Key steps in photosynthesis must be understood before trying to develop a better alternative witbiotechnology. During the light-dependent stage, photolysis of water allows energy from sunlight to be transferred to high energy electrons and the energy is gradually released. Using the energy released, ADP is converted to ATP and NADP+ to NADPH. Light energy from the sun is now converted into chemical energy and stored in these high energy molecules.

Progressing onto the Calvin cycle, carbon fixation and reduction reactions occur. This involves fixing a molecule of CO2 onto a five-carbon sugar, RuBP, forming a six-carbon sugar which immediately breaks down and forms the three-carbon sugar glyeraldehyde-3-phosphate (G3P) as the final product. One out of six G3Ps produced from every three RuBPs is used to synthesise carbohydrates, including starch.

Photosynthesis allows the transfer of light energy to chemical energy and stored as starch in plants. Although the entire process contains numerous enzymatic reactions and has a low energy efficiency of 2%, all of the products are recycled or reused in some way. The only major byproduct is oxygen, which is still breathed in by other living organisms. Finally, enzymatic reactions in photosynthesis do not contain components that will inhibit one another. This is dissimilar to the Krebs cycle in cellular respiration where the build-up of ATP will inhibit enzymes in earlier steps of the cycle, to name an example. Therefore, photosynthesis is slow and steady.

Designing the ASAP

In photosynthesis, energy from the photolysis of water is converted to a chemical form as ATP and NADPH. To do this artificially, solar panels are used to harness sunlight energy and transform it into electricity. The electrical energy is then used to hydrolyse water to gaseous hydrogen and oxygen. Hydrogen is reacted with carbon dioxide to form methanol, also called 'liquid sunshine' as it stores the energy from the sun. This methanol has similar roles to ATP and NADPH in photosynthesis.

The second step is to design a pathway similar to that of the Calvin cycle. A blueprint was designed from around 7,000 biochemical reactions using computer algorithms to find the optimal combination of reactions for a synthetic pathway. However, due to the lack of millions of years of natural evolution, the chosen enzymatic reactions in ASAP were often incompatible where one enzyme could inhibit the activity of another. To overcome this, the research team modified the enzymes or re-slected new enzymes to resolve problems with substrate competition and product inhibition.

The compositions of starch produced by the ASAP has shown to be in the same proportions as natural starch in terms of ratios of amylose to amylopectin by using nuclear magnetic resonance spectroscopy (NMR), meaning that the nutritional values are practically the same as naturally synthesised starch.

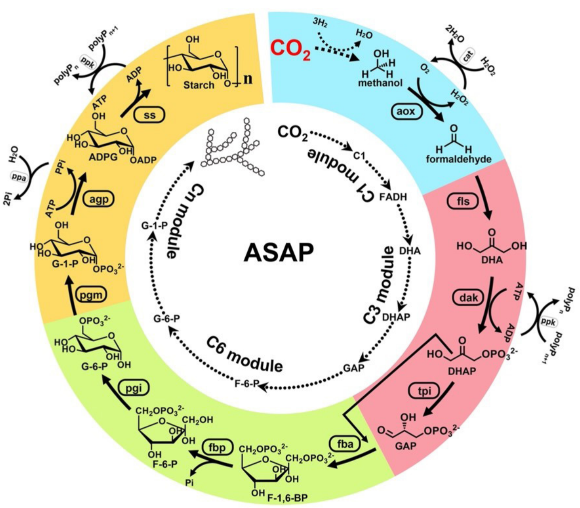

Figure 1: The ASAP [1]

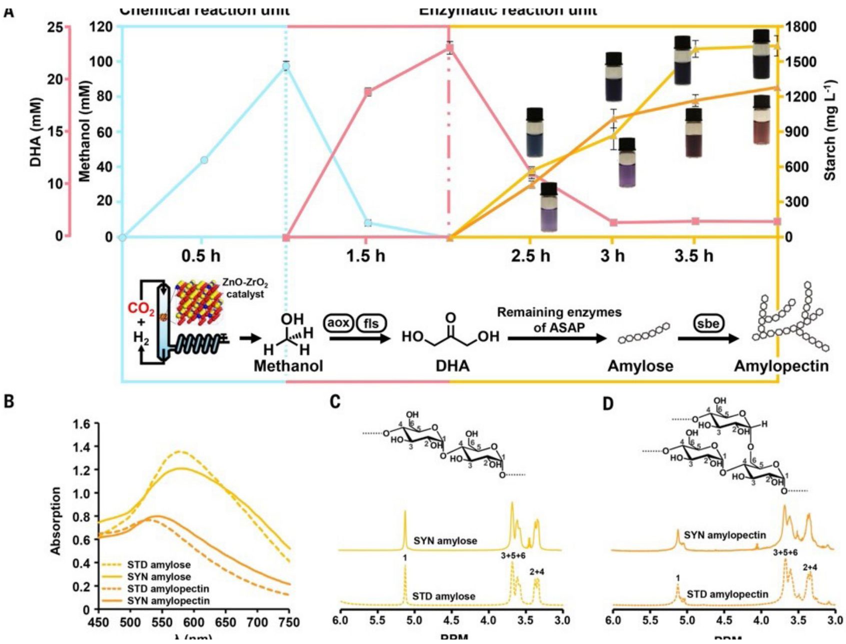

Figure 2: Products of ASAP visualised [1]

ASAP vs. Photosynthesis

Overall, the ASAP consists of one chemical catalysis reaction and ten enzymatic reactions. The conversion of carbon dioxide to methanol to dihydroxyacetone (DHA) takes two hours and involves two enzymes. In the final stages, eight enzymes are used to convert DHA to glucose then to starch, which takes two more hours.

Maize, however, requires 120 days to mature, after which each hectare can yield around 300kg of starch in maize crops, simplifying down to 2.5kg per hectare per day. With ASAP, a container with a volume of 1m3 can produce 10kg of starch per day, which is 4 times faster than maize. In addition, ASAP is much more energy efficient. Photosynthesis has an efficiency of 2% where ASAP has a 7% overall efficiency, which is 3.5 times greater. Finally, in terms of carbon fixation, the combined carbon fixation rate of all the enzymes in ASAP is 22 nmolmin-1mg-1. The number for photosynthesis is 2.58, which means ASAP fixes carbon 8.5 times more efficiently.

Prospects

Just because ASAP is much more efficient than photosynthesis, there are still some major hurdles to its widespread adoption outside of the laboratory. The current ASAP must be done under non-standard conditions. High concentrations of CO2 and H2 under high temperature and pressure are required during the synthesis of methanol. Moreover, the need for manual monitoring and addition of enzymes at each stage of the pathway does not allow scalable production. The synthesis of the enzymes required in ASAP is another major problem. Enzymes cannot be synthesised artificially yet because they are proteins with complicated structures, meaning that it is only plausible to use bacteria with recombinant DNA containing genes coding for the required enzymes as a production method, meaning the process still relies on biological cells to produce the molecular machinery needed.

This technology is a zero to one breakthrough, and the journey from one to one hundred has just begun.

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Why are enzymes so much bigger than their active site?

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The largest enzyme within the human body is titin, named after the Greek word 'Titan' for humongous giants. Indeed, the name fits this molecule well: it is a giant enzyme with over 27,000 amino acids and a molecular weight of 3,000,000Da (Da, or Dalton, is a unit of mass equal to a twelfth of the mass of a Carbon-12 atom) (Sela, 2002). Only a fraction of these 27,000 amino acids is directly involved in the active site – despite titin's enormous size, it only has one catalytic site (Mayans, et al., 1998).

In most enzymes, only 3-5 amino acids usually make up the active site, while the full primary structure is tens or hundreds of amino acids longer. Given that stop codons can appear randomly after the start codon, smaller proteins should be more prevalent than longer ones, yet the smallest protein is at least 62 amino acids long (Tiessen, et al., 2012; Chen, et al., 1992). It also cannot be coincidental that in all enzymes, the active site constitutes only around 3% of the entire molecule: the remaining >97% of the enzyme must hold important functions for enzyme catalysis as well.

In this article, I will not focus on the active site – often the main character in enzyme-catalysed biological reactions. Instead, I will explore some interesting examples where the rest of the long polypeptide chain has important and prominent roles in the catalysis mechanism of the enzyme, giving good reason for enzymes to be many times larger than their active site.

Adenylate kinase

Nucleoside monophosphate kinases are a group of enzymes which catalyse the transfer of phosphryl groups between nucleoside triphosphates and monophosphates. One example is adenylate kinase (AK) which specifically regulates adenine nucleotides (Solaroli, et al., 2009).

It is an important enzyme with implications in cell signalling and homeostasis by catalysing the phosphoryl exchange between AMP and ATP and two ADP molecules:

2ADP <-> ATP + AMP

Without AK, this reaction would take 8000 years under physiological temperature and pH (Kerns, et al., 2015).

It is a monomeric protein, comprising a polypeptide chain which is 194 amino acids long, made up of three major domains: CORE, LID, and NMP. AK has two binding sites made of just five to seven amino acids each – the active residues therefore make up slightly over 3.5% of the enzyme (Von Zabern, et al., 1976).

During catalysis, AK undergoes interesting and very large conformational changes of the LID and NMP domains as shown in Figure 1, transitioning eversibly between the open and closed states. ATP binding closes the LID domain to a partially closed, unstable transition state. Then AMP binding closes the NMP domain, reaching a fully closed state for phosphoryl transfer. Release of each ADP in turn opens the LID, then NMP domains, thus restoring the open state.

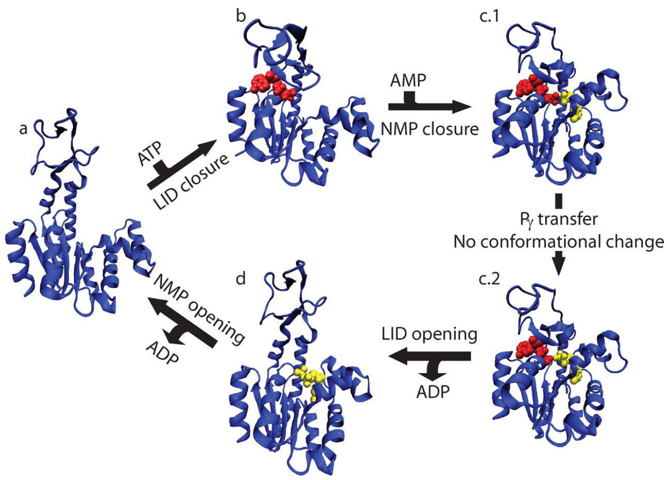

Figure 1: Proposed mechanism for AK catalysis. (a) open, unligated AK, (b) ATP binds while the LID domain closes, (c.1) closure is followed by AMP binding and NMP domain closure, (c.2) phosphoryl transfer occurs, resulting in two bound ADPs, (d) thermal fluctuations open LID domain and one ADP is released, (a) loss of LID-CORE interactions induces opening of NMP domain, loss of second ADP, and return to the open, unligated conformation. (Whitford, et al., 2008)

Despite high strain energy which occurs during transitions, there is localised unfolding of non-active-site residues which allows the large conformational change to occur (Whitford, et al., 2007). Moreover, in the ligated state, the closed conformation is most energetically favoured; the conformational changes allow the enzyme to reach a more stable form (Arora & Brooks, 2007)

The long amino acid chain facilitates these large and unique conformational changes. The flexibility of the long chain allows the domains to rotate and bring the substrates and cofactor closer together to allow the reaction to proceed. This is why the chain of 194 amino acids is necessary for AK's function as a catalyst, despite only a very small number of amino acids actually binding to the substrates.

Alcohol Dehydrogenase

Alcohol dehydrogenase (AD) is an oxidoreductase enzyme, oxidising alcohol to aldehyde, coupled with the reduction of the NAD+ cofactor to NADH. It is homodimeric – both the alpha and beta polypeptide chains are identical 374 residue long chains of 80,000Da. More importantly, AD is the primary detoxification mechanism following ethanol consumption on a night out (Crabb, et al., 2004; Goodsell, 2001).

AD has multiple cofactors which are key to its function. The active site contains a Zn2+ cofactor and an NAD+ cofactor which have implicit functions in the oxidation of alcohol. AD has a second Zn2+ cofactor with a structural function, not located in the active site.

Let's take the example of AD deprotonating ethanol to ethanal.

CH3CH2OH + NAD+ → CH3CHO + NADH + H+

The tertiary structure of AD has an important role in correctly positioning the cofactors involved in catalysis.

For example, the catalytic Zn2+ cofactor is used to position ethanol correctly. The Zn2+ cofactor must be held by three residues in the active site: bonding with the sulfur atom of Cys-174 and Cys-46, and with the nitrogen atom of His-67. The numbering on these residues (46, 67, 174) show that these amino acids are not next to each other, or even close to each other, within the primary structure of AD. However, as the protein folds up into its tertiary structure, winding and bending its long amino acid chain, these residues are brought close to each other into the spatial region of the active site (Anon., 2021). These amino acids do not bind directly to the substrate, but the precise coiling of the tertiary structure enables these residues to suspend the Zn2+ cofactor in its correct and precise location. Only then can Zn2+ bind ethanol and position it near the NAD+ analogue for reaction in the active site.

In addition, Zn2+ lowers the activation energy in the transfer of the hydride group to Ser-48 to reach an ethoxide intermediate (Figure 2) so its position next to Ser-48 (the 48th amino acid in the polypeptide chain, Serine) is crucial for the reaction mechanism (Agarwal, et al., 2000).

Hence, the long chain of amino acids is necessary to situate the Zn2+ cofactor within the enzyme correctly, important for binding ethanol and lowering the activation energy (EMBL-EBI, 2021).

This is similar for the NAD+ cofactor which is held by five non-active-site amino acids.

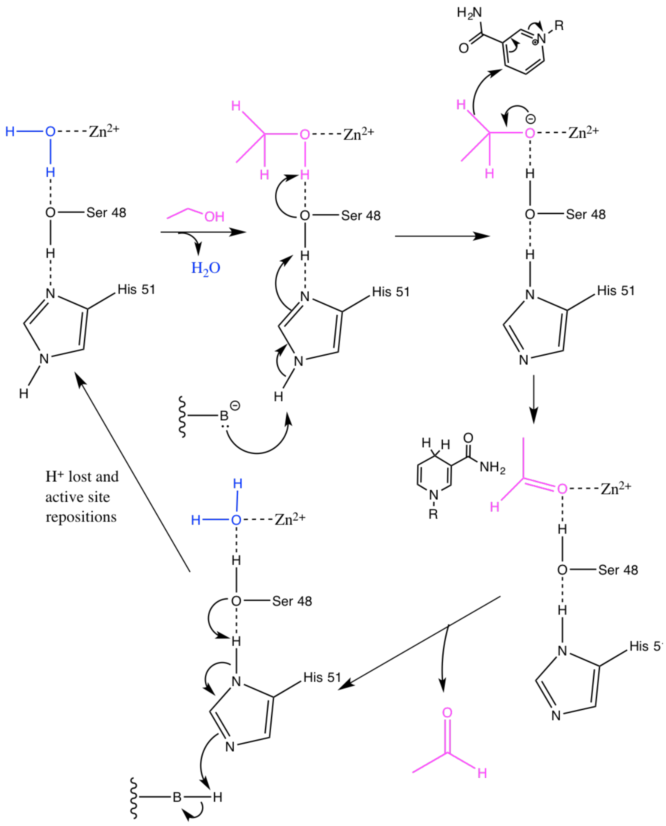

Figure 2: Mechanism of alcohol dehydrogenase. Amino acids coordinating the Zinc ion are not included. (Anon., 2021)

Therefore, for AD, the precise tertiary structure enables the oxidation reaction to proceed by positioning the cofactors and substrate in its precise location. This precision can only be achieved by the flexibility that comes with a long amino acid chain. So, the enzyme has to be much bigger than the active site residues in this second example as well.

Rubisco

Ribulose-1,5-bisphosphate carboxylase/oxygenase, or Rubisco, is the single most abundant enzyme known to exist. It is present in every plant as a key player in photosynthesis and photorespiration – it is also extremely inefficient and therefore must be present in large numbers to reach a sufficient rate of photosynthesis (Andrews & Lorimer, 1987).

Rubisco is a very large enzyme made of eight large subunits (470 amino acids and 55,000Da each) and eight small subunits (over 100 amino acids and 15,000Da each). In total they add up to a massive molecule of around 550,000Da (Valegard, et al., 2018).

Rubisco's small subunits provide an environment that causes CO2 to accumulate in the regions near the active sites to a greater extent than O2. This is due to a high density of amino acids with small, hydrophobic side chains (Ala, Val, Leu, Iso) and sulfur-containing amino acids (Cys) which interact with CO2 preferentially compared to O2. The tertiary structure coils the amino acid chains in such a way that positions these amino acids near the active site and accumulates CO2. (van Lun, et al., 2014).

These binding areas also act as entry points for CO2 to drift into the active site. They are subsurface grooves with a continuous interface to the active site, providing a direct and short route for CO2 to move into the active site (van Lun, et al., 2014)

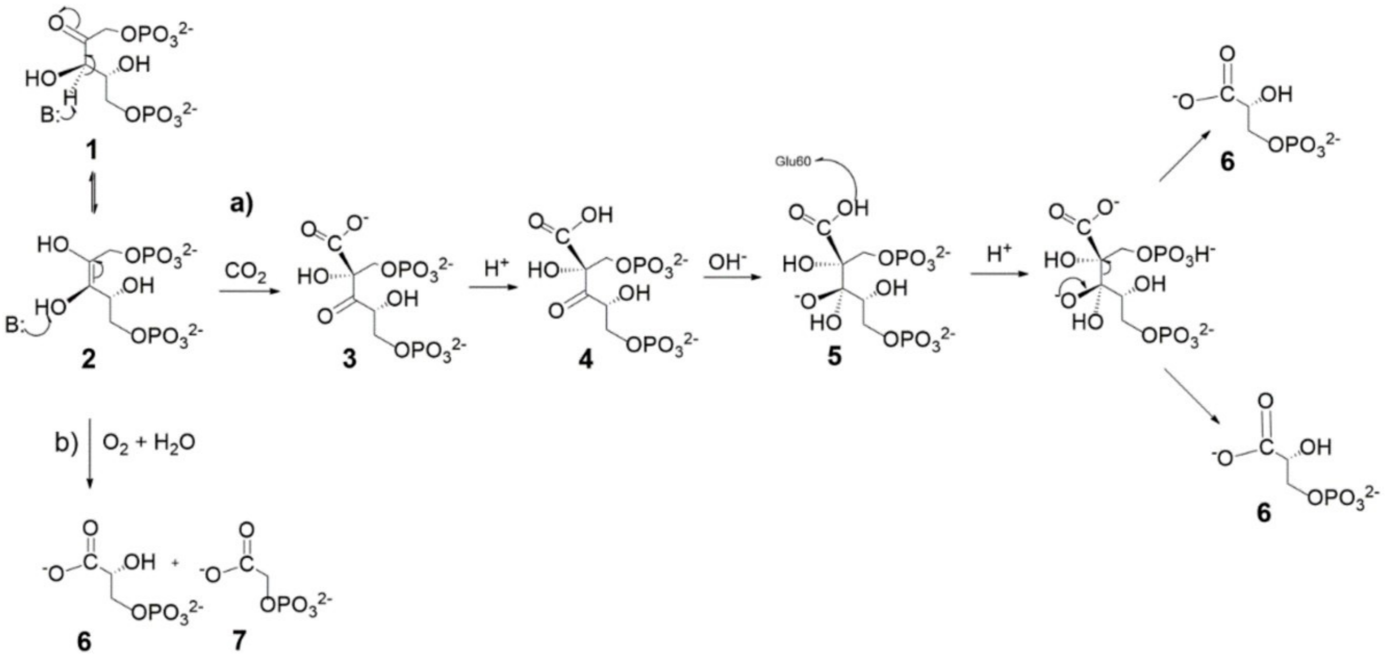

Figure 3: RuBP conversion by Rubisco through carboxylase (a) and oxygenase (b) reactions. (Tommasi, 2021)

As its full name suggests, Rubisco catalyses the opposing carboxylase and oxygenase reactions of ribulose-1,5-bisphosphate (RuBP), reacting with CO2 or O2 respectively, as shown in Figure 3 (Bathellier, et al., 2018). About 20% of the time, rubisco binds to O2 to produce 2-phopsphoglycerate. Apart from some used in photorespiration, it is a largely unusable molecule (Angersson, 2008). Its inefficiency can be attributed to its affinity for both CO2 and O2 which compete to bind to Rubisco.

Surprisingly, despite Rubisco's inefficiency, it has adaptations to attract CO2 more strongly than O2: it utilises the rest of the enzyme body to increase affinity for CO2 rather than O2 (Tommasi, 2021).

These modifications and the difference in cumulation of CO2 and O2 on the Rubisco surface are simulated in Figure 4.

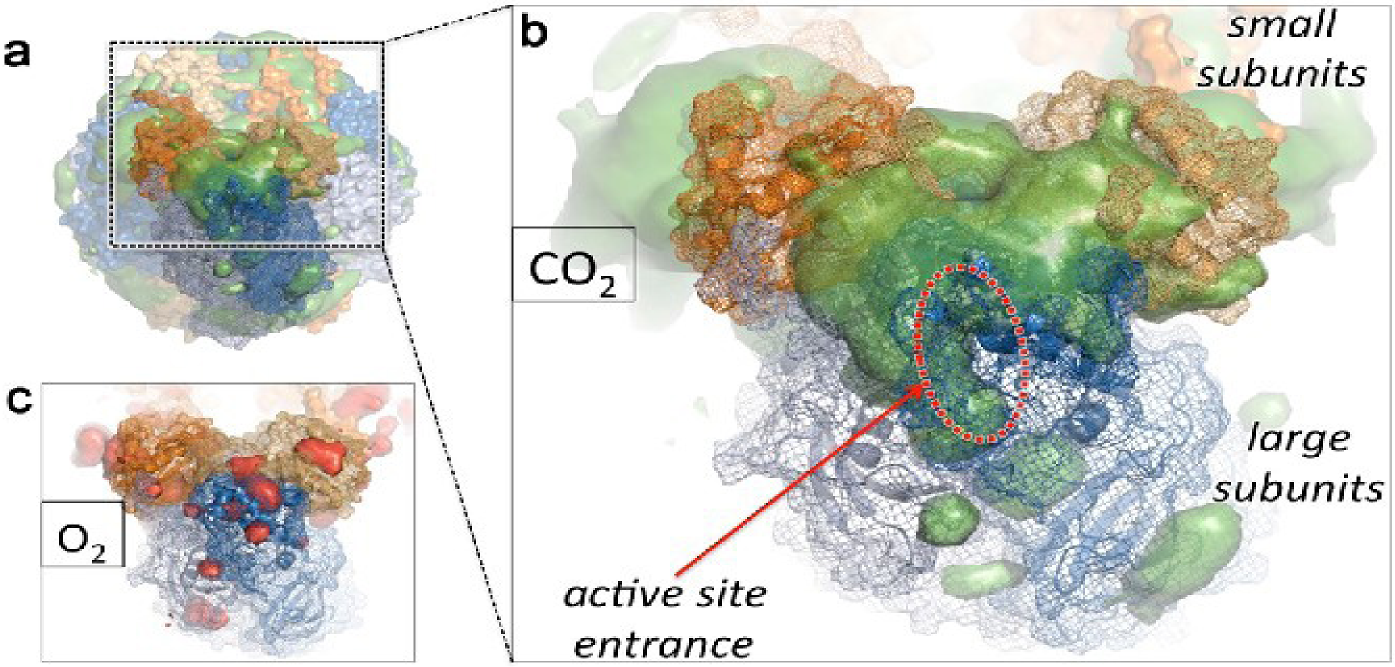

Figure 4: Cumulative CO2 and O2 density around the active site of Rubisco. Large subunits are shown in blue and small subunits in orange. Cumulative CO2 density is shown as smooth surface in green, cumulative O2 density in orange: both are predictions by simulation after 20 ns at equal concentrations of each gas. (a) Hexadecameric enzyme (C. reinhardtii Rubisco closed complex, PDB code 1gk8) showing subunits. (b) Close-up around active site with residues from large and small subunits represented as a mesh. CO2 density has a direct connection between the subunits that may aid in attracting and guiding CO2 toward the active site. Active site is circled in red. (c) Cumulative O2 density in same orientation as (b). (van Lun, et al., 2014)

Despite Rubisco (unhelpfully) binding both CO2 and O2, it has used its massive enzyme body and multiple subunits in this way to increase the chance of binding CO2 over O2. The non-active-site residues increase the rate of photosynthesis in plants, which clearly has far-reaching and crucial implications for the plant. In this third and final example, the enzyme needs a much larger body than its active sites to reduce the frequency of the unhelpful competing reaction.

Conclusion

In this article I gave three examples of enzymes with interesting uses for their long amino acid chains. Adenylate kinase undergoes large conformational changes, moving two domains for the reaction to proceed, then to release the two products. Alcohol dehydrogenase uses its precise coiling and folding to position the cofactors, NAD+ and Zn2+, needed for the reaction mechanism. And finally, Rubisco increases its affinity for CO2 by arranging certain non-catalytic amino acids around the active site.

The non-active-site residues are often underacknowledged yet have crucial and diverse roles in the role of nzymes as biological catalysts. This is why enzymes are so much larger than their active site: without the length of the polypeptide chain, an enzyme would have much more limited possibilities for coiling and conformational changes. It could not arrange its residues to improve catalysis, nor allow the reaction to proceed.

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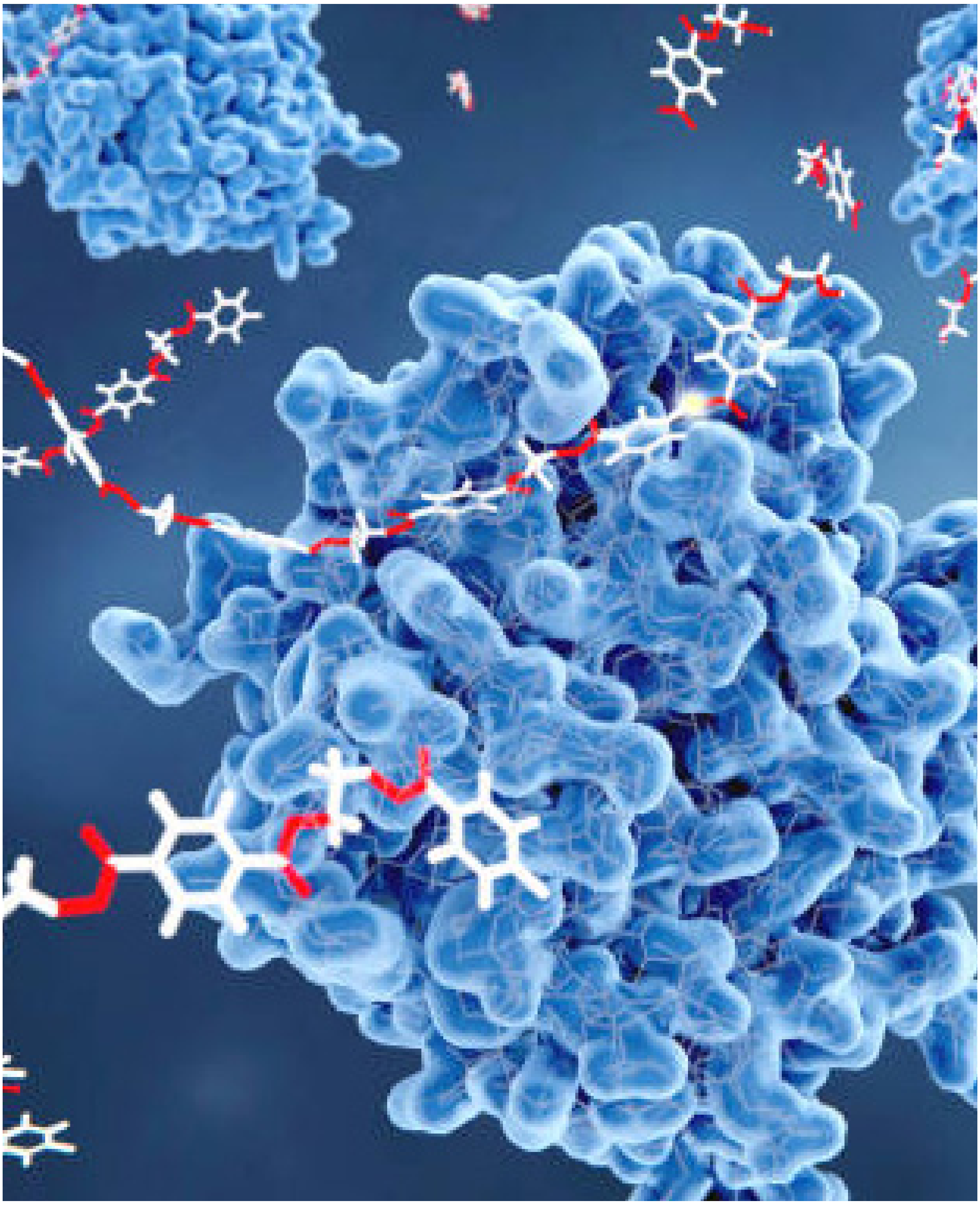

The 7 Bridges of Königsberg
The Birth of Graph Theory

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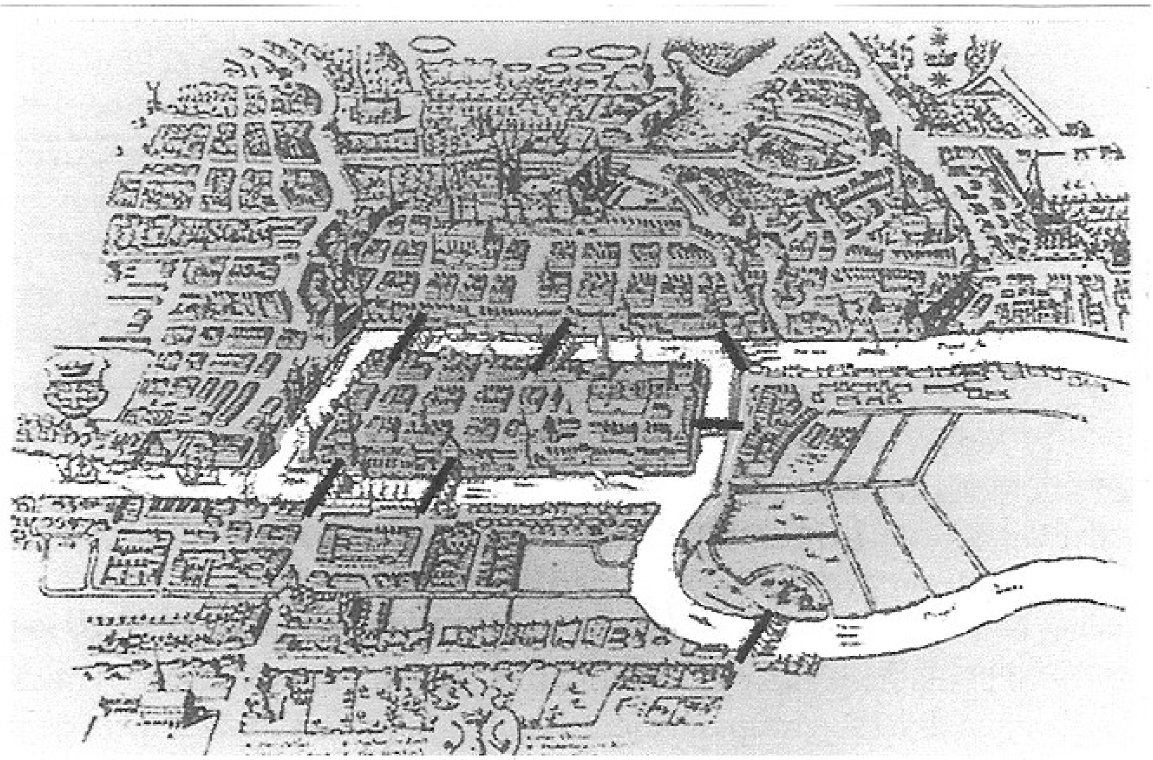


Königsberg was a Prussian city (presently Kalingrad, Russia) in the 18th century. The city had seven bridges connecting four landmasses as shown in the diagram.

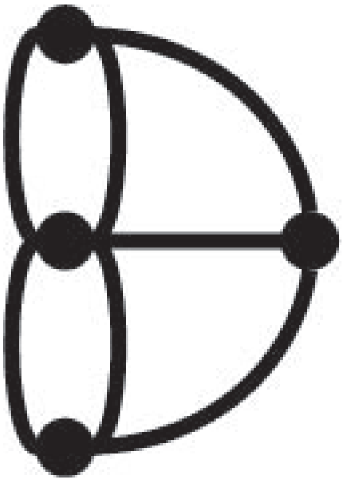
According to folklore, the following question was a popular mathematical puzzle at the time:

Could one take a walk through the city in such a way that each bridge would be crossed once?

Though many had attempted the problem, they could not prove that their answer was indeed correct. Enter Euler. Euler tackled this problem in 1735, proving exactly why his answer was correct and subsequently creating the field of graph theory.

Leonhard Euler (1707-1783) was an extremely prolific mathematician. Most people will know of his constant e, from high school mathematics as well as his multitude of other accomplishments. Euler had such a huge mathematical influence that Pierre-Simon Laplace quoted " Lisez Euler, lisez Euler, c'est notre maître à tous." Which some of you French learners/speakers will know roughly translates to "Read Euler, read Euler, he is the master of us all".

Euler represented the city and its bridges as a series of vertices and edges as shown in the diagram below. Each landmass is represented by a vertex and each bridge by an edge.



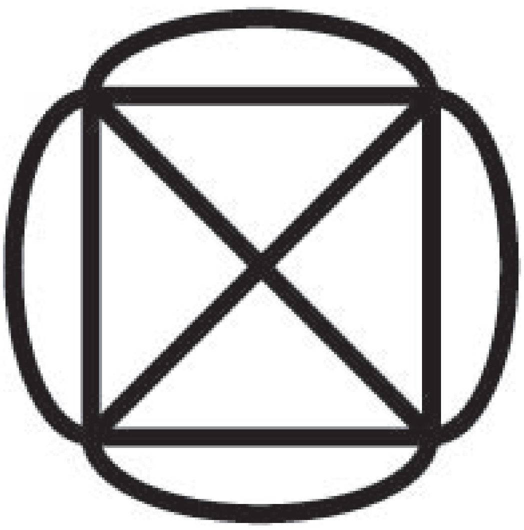
Each vertex has a degree which is the number of edges that enter or exit from it. A path that travels along each edge exactly once is called an EULER WALK. A path which travels along each edge exactly once and ends up on the same vertex as it started on is called an EULER CIRCUIT. The Königsberg bridge problem can be restated to whether or not an Euler Walk on the graph is possible.

The answer is no. For an Euler Walk to exist, there must exist at most two vertices of odd degree. This is because for the middle vertices, there must be a path to enter and to exit. The one or two vertices with an odd degree are the start and end points of the path. Examining the Königsberg bridge graph, we can see that this is not the case and therefore, an Euler Walk is not possible. So it is not possible for one to take a walk through the city in such a way that each bridge would be crossed once.

For an Euler Circuit to exist, each vertex must have an even degree. Again, this is because there must be a path to enter and to exit each vertex.

Now you too can wield the power of Euler's graph theory the next time someone presents you with a little puzzle like this one:

Can you draw this shape without lifting your pen up from the page?



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Geoengineering and its Effects on the Environment

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What is Geoengineering?

Geoengineering refers to ways of cooling down our planet and could be a solution to help tackle rapid climate change. There are many ideas for geoengineering, but I will just talk about the main ones, for example we could send a giant mirror into space to reduce the amount of solar radiation into our atmosphere. Almost all heat on Earth comes from the Sun and so reducing the amount that comes into it in the first place could be a good idea. About 71% of the solar radiation that hits Earth is absorbed by the Earth's surface and atmosphere, the rest of it (29%) is redirected back to space by bright surfaces such as ice, desert, snow and even clouds. More reflection, less energy, less warming. It's simple, right? Well not really.

The Climate Crisis and how Industry Hides it
To understand geoengineering properly you need to understand what is happening with the climate and how it works, not just scientifically but politically and economically as well. Although most people know what climate change is, they don't tend to fully understand the cause of it. Cars are widely believed to have a large environmental impact, but this is not true. We live in a time where information is very powerful and is easily accessible and because of this a lot of misinformation is given to many people. Blame is shifted from major industry and government to YOU! This means that we are encouraged to switch to low carbon emission technology such as buying a new electric car, swapping your gas stove for an electric one, or just turning off the lights. Modern industry has made society believe that if we do not have the money or time for these things, we should feel bad and that it is all our fault that the planet is warming up. But yet again it is just part of the problem.

We have just experienced a global experiment by staying at home and banning travel during the pandemic. All of this has reduced carbon emissions by just 7% compared to 2019. This shows us that whilst the average person can switch off their lights, the impact is dwarfed by the reality of current industry emissions. So then why don't we just stop major carbon polluters? Well, it's complicated. The emissions produced when making a new car are as much as building just two meters of road. Solutions to reduce emissions from other high polluters have not been found yet due to lack of funding. A lot more research needs to be done and this research is expensive. Even where solutions do exist it doesn't mean that people are ready to adopt them. To have the necessary funding to support the development of new solutions, tax would need to go up to unprecedented levels. Countless businesses will go bankrupt, including ones that are very big today, such as BP, unless they make a sustainable transition that is accepted by governments.

What if we Started Geoengineering Today?

There are many potential ways to geoengineer but what are they? What are the possible outcomes and how much do we just not know yet? First let's talk about how industry and politicians may use geoengineering to delay the switch to a carbon neutral economy. One possible way to geoengineer is to reduce the amount of heat that comes from the Sun in the first place. This method will be the cheapest and the easiest but there are some downsides. For example, this method of geoengineering will not stop carbon from being trapped in the atmosphere, which is still harmful to countless ecosystems that are necessary to us for our survival. An example of this is coral. Most of the Earth's surface is covered by ocean and it provides us with a large amount of oxygen. The oceans absorb a lot of carbon from the atmosphere, but this makes them more acidic. Coral reefs help to regulate this, however coral reefs are very hard to maintain because they need a specific environment, a little bit more acidity will kill them all. The accumulated carbon will result in countless ecosystems being affected or destroyed. If one is destroyed, then this will have a knock-on effect on other ecosystems. This will change the world so much that organisms will not be able to adapt fast enough. Humans may survive but the survivors will inhabit an unfamiliar world that is constantly trying to kill them.

One potential way to geoengineer is by spraying gases into the atmosphere - stratospheric aerosol injection. However, this may be damaging to the ozone layer and because it is such a controversial topic, scientists haven't been able to do the necessary experiments to see if it will work. Ok, but is stratospheric aerosol injection really an option? What might be the impacts if it goes wrong? Stratospheric aerosol injection will be feasible according to projections and it is more feasible than dealing with rapid climate change. There is a very big problem with this though. Global warming wouldn't be an issue anymore but there will still be too much carbon in the atmosphere. Carbon is still very bad for many organisms and millions of organisms, humans and animals would die of air pollution and so this is not an option to solve climate change.

This is not the only problem with aerosol injections, there are others such as rainfall patterns may change leading to unusually poor harvests which would affect billions of people. Also, because we are stopping solar radiation from coming in it heats up the stratosphere. Ok, but what will aerosol injections use, how much does it cost and why is it that it is damaging for the ozone layer? As mentioned before, geoengineering is a controversial topic and scientists haven't been able to do the necessary research to see exactly what will happen.

We could use Sulphur Dioxide which will react with the atmosphere to create Sulfuric Acid which will reflect radiation back out to space stopping it from warming the planet in the first place. As it turns out acid is very bad for the ozone layer and doing this over decades could negatively affect the planet. On the flip side though, the project is very feasible with projections estimating about 8 Billion (USD) per year. Scientists have also suggested other chemicals, but not enough research has been done yet.

Ok, so we have looked at reducing the amount of solar radiation that comes into the atmosphere but what else can we do? Well luckily there is something, reducing the amount of carbon dioxide in the atmosphere. There are many different ways of doing this, for example, we could fertilise the oceans with iron to speed up the growth of trillions of algae cells which would take lots of carbon out of the atmosphere, but it would require a lot of funding.

In conclusion, climate change is complex problem that cannot be solved by the average person. Industry and governments need to change their ways and Geoengineering could buy us a crucial decade or two. It will not however solve climate change as a whole.

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The Future of Food

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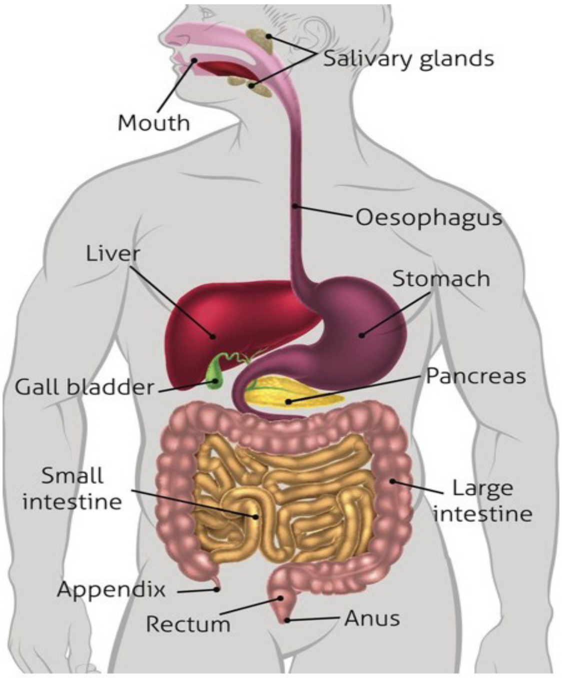
Leyland Tractor on a farm

Food and the human body

We need food to survive. Food contains nutrients to help us survive whilst giving us the energy required by our body to carry out our daily activities. Each type of food contains a different number of categories needed. For example, dairy products such as milk contain calcium whilst meat such as chicken contains protein. There are also vegetarian options such as Quorn which can provide a source of protein. These are just some of the various types of food we need for a balanced diet to contribute to a healthy lifestyle.

The effect of farming and food on global emissions

Farming and the food we eat have a big impact on the climate and on our planet, for example one cow can produce up to 200kg of methane a year and each household produces approximately 48 tons of carbon emissions per year, just from food. Small impacts like this can cause damage on a greater scale. The way farming is carried out is also a large factor in the effects of climate change. For example, tractors are now common sight in a farm, and one tractor's carbon emissions is equivalent to 150 cars per year. Finally, we are left with deforestation. This leads to a greater impact since the homes of local species are destroyed and due to a lack of plants there is a greater amount of carbon dioxide in the air.



Human digestive system shows that nutrients are essential for our body

Ways of Sustainable Farming

Shows agriculture being grown in an urban landscape

Sustainable farming is the only way we will be able to keep our planet and us healthy and safe. There are many different options for sustainable farming

Examples include:

- Lab created meat
- Biodynamic farming
- Agricultural development in urban areas
- Natural animal raising

A bit more detail…

Lab created meat

- Lab created meat consists of cultured cells that are grown in a lab. This would allow people to eat and enjoy food like meat, whilst knowing that they are not harming animals. It is also better for the environment as methane is not released and factories are not emitting dangerous emissions when using the machines that cull the animals.

Biodynamic farming

- Biodynamic farming is the process of raising animals in a farm where all animals support each other. The goal is the creation of an ecosystem where only farm animals help each other, the soil, and the plants around them to grow. An example of this is composting.

Agricultural development in urban areas:

- Agricultural development in urban areas cuts down on tall buildings and limits deforestation whilst also lowering carbon emissions. Trucks and transport would emit less as shops and farms are closer. Finally, carbon dioxide levels will decrease due to the creation of more plants.

Natural animal raising

- Natural animal raising is raising animals in their own habitat, where they can help each other through biodynamic farming. This can also lead to happy animals, and therefore tastier meat (though not so helpful for vegans or vegetarians!).

Steps already being taken

Local eating

In many small towns and cities people are opting to buy produce from local farmers. This increases the economyoftheareawhilstalsolimitingthecarbonemissions produced whilst food is transported around the globe.

More home cooking

With the recent pandemic, many people have opted out of eating at restaurants, and instead have tried new and wonderful recipes at home. This can help to create a healthier population.

Cooking at home

Aquaponics

Aquaponics is a new type of method for farming where plants and fish are all in the same ecosystem. This can also help the reduction of soil overcropping because aquaponic plants grow in the water instead of in soil, by nesting on the fish faeces.

Aquaponics

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