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MARCH 2026 ISSUE 106

3D-PRINTING BUILDINGS

SECOND LIVES FOR SOLAR PANELS

ENGINEERING THE WINTER OLYMPICS

FUTURE-PROOFING OUR CROPS

Royal Academy of Engineering

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WELCOME

As ever, this issue of *Ingenia* brings together a compelling collection of stories that highlight how innovative engineering is improving people's lives and shaping a greener and cleaner future.

On page 10, our feature on the engineering behind the Winter Olympics showcases the precision technologies and material innovations enabling athletes to perform at their limits while staying safe in extreme conditions. Alongside this, our profile of Dr Josh Macabuag OBE FREng highlights a career dedicated to disaster resilience and humanitarian engineering – an inspiring reminder of how engineering expertise can transform outcomes for vulnerable communities.

We also explore how engineering is helping to create a more sustainable world. On page 16, we examine advances in 3D printed concrete construction, a technology reshaping how we build with reduced waste and lower emissions. We also turn to the future of renewable energy materials with our feature on recycling and re-engineering solar panels and our article on page 22 looks at how engineers are helping rewrite biological systems to address global challenges, from medicine to materials.

Finally, and on a personal note, this issue marks the end of my 12-year-long membership of the *Ingenia* Editorial Board including five years as Deputy Editor. It has been a marvellous time giving me the chance not just to observe the breadth of modern engineering but to meet with many of the amazing individuals who are actually delivering this work! I must also thank all the other members of the Editorial Board in that time and the fantastic editorial team at the Academy who have made the whole period so enjoyable. I know that *Ingenia* will continue to cover the exciting developments in engineering and help inspire its readers to want to join the people who really do 'build the world'.

Professor David Delpy CBE FREng FRS FMedSci
Interim Editor-in-Chief

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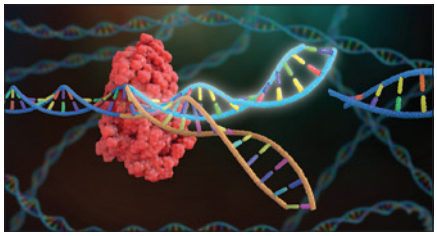


IN BRIEF

NEURAL INTERFACE PIONEERS WIN THE 2026 QEPRIZE

Eight of the 2026 QEPrize winners (left to right): Professor Grégoire Courtine, Professor Jocelyne Bloch, Professor Pierre Pollak, Professor Alim Louis Benabid, Professor John Donoghue, Professor Graeme Clark, Dr Ingeborg Hochmair, Professor Dr Erwin Hochmair © Jason Alden

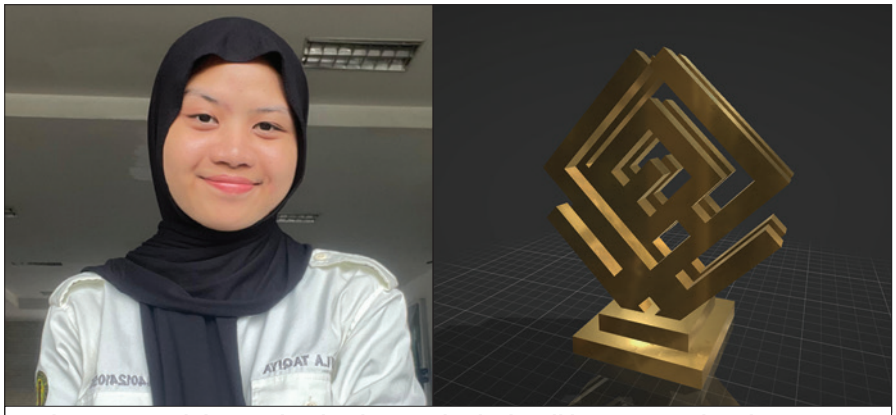
On 3 February, the 2026 Queen Elizabeth Prize for Engineering (QEPrize) was awarded to the nine engineers whose work on modern neural interfaces is restoring human function and improving quality of life worldwide. The advances by the nine winners enable technology to interface directly with the brain and nervous system to help people hear, move and communicate after sensory loss and paralysis, and alleviate symptoms of neurological conditions.

Spanning several decades of research and clinical translation, the winners' contributions define a new frontier where engineering and medicine converge. In cochlear implants, Professor Graeme Clark AC FRS, Professor Dr Erwin Hochmair, Dr Ingeborg Hochmair, and Professor Blake Wilson are recognised for transforming the technology from experimental devices into reliable neural prostheses now used by over a million people, through innovations in multi-channel stimulation, miniaturisation and sound processing.

In brain–computer interfaces, Professor John Donoghue is honoured for his leadership in decoding neural activity from the motor cortex to restore movement and communication, establishing core engineering principles for the field. In deep brain stimulation, Professor Alim Louis Benabid and Professor Pierre Pollak pioneered targeted electrical stimulation and advances in electrode design and programmable systems to alleviate symptoms of movement disorders such as Parkinson's. In electronic spinal stimulation, Professor Jocelyne Bloch and Professor Grégoire Courtine developed approaches that reactivate neural circuits controlling locomotion, enabling individuals with spinal cord injuries to regain voluntary movement through targeted stimulation and advanced rehabilitation.

What made this year's award stand out, according to the chair of the judging panel, Professor Dame Lynn Gladden DBE FRS FREng, is the clear impact on people's lives, demonstrating the power of engineering to translate deep scientific understanding into practical solutions.

The announcement took place at the Science Museum by Lord Vallance of Balham KCB FRS FMedSci HonFREng, Chair of the QEPrize Foundation. The Laureates will share the £500,000 QEPrize and will be honoured at a presentation ceremony at a later date, where they will receive a unique trophy designed by the 2026 Create the Trophy winner, Kayla Taqiya, aged 21, from Indonesia. The Create the Trophy competition invites young people aged 14 to 24 to test their design skills using the latest 3D design technology; two 14-year-old entrants were also highly commended this year, Laura Smith from Scotland and Hafsa Tanveer Hassan from Pakistan.



Kayla Taqiya and the trophy she designed, which will be presented to the winners at a later date

MOTORSPORT SCHOLARSHIP BACKED BY SIR LEWIS HAMILTON EXPANDED

Sir Lewis Hamilton MBE HonFREng (fifth from left) with the second cohort of MSc Motorsport scholars at Silverstone

An MSc Motorsport Scholarship Programme to increase diversity in motorsport engineering, backed by Sir Lewis Hamilton MBE HonFREng and run by the Royal Academy of Engineering, has been relaunched in a new and expanded form. The new programme will have more scholarships of up to £43,000, target a wider range of candidates and will be supported by two extra delivery partners.

Funded by Sir Lewis's charitable foundation, Mission 44, the pilot programme has already run for two years, providing financial and career support to two cohorts of young engineering graduates from a Black or mixed Black ethnic background undertaking a Master's degree in a motorsport or engineering discipline. Of the 13 people awarded scholarships during the pilot – five in the first cohort in the 2023–24 academic year and eight in the following academic year – five are now working in Formula 1 teams, two in the motorsport sector, and one in engineering more broadly.

The expanded programme will increase the number of scholarships from 8 to 12, and eligibility has been extended to include women and those from a less advantaged socioeconomic background. The two new partners to join the programme, Driven By Us and the Association for Black & Minority Ethnic Engineers, will help to deliver networking and career training and mentoring.

The programme was launched in 2022, following a recommendation from The Hamilton Commission, set up by Sir Lewis Hamilton to investigate the underrepresentation of Black people in UK motorsport and the STEM sector.

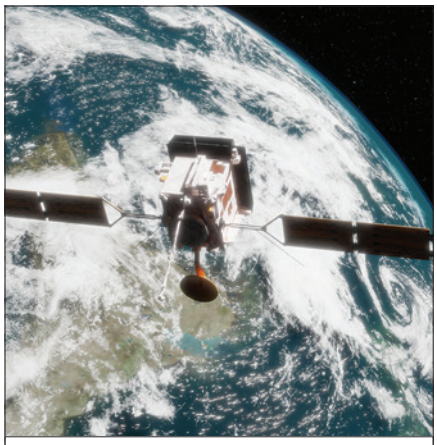
ALUMINIUM BREAKTHROUGH COULD MAKE SHIPS ALMOST UNSINKABLE

Researchers have found a way to make ordinary aluminium tubes float indefinitely, even when submerged for long periods or punched full of holes. By engineering the metal's surface to repel water, the tubes trap air inside and refuse to sink, even in rough conditions.

The researchers, from the University of Rochester in the US, found that this trapped air allows the tubes to float indefinitely, offering a simple and durable way to keep structures buoyant. The technology could eventually be scaled up into floating platforms, ships, or even wave-powered energy systems, leading to safer marine equipment, new types of life-saving devices and more resilient ocean-monitoring technologies.

By rethinking a familiar material, the team has shown how a small design change can have a big real-world impact – and open the door to new engineering applications in challenging environments.

SPACE HUB OPENS TO ACCELERATE UK SPACE INNOVATION



© Pixabay/Adis Resic

A new £20 million space hub has opened in Buckinghamshire, marking a major step forward for the UK's growing space sector. Backed by a £5.8 million from the UK Space Agency, the facility provides state-of-the-art testing, training and commercial space designed to help space businesses develop new technologies and bring them to market more quickly.

The new hub is located at Westcott Venture Park, which has more than 50 years of rocket engine testing heritage, and offers flexible laboratories and workshops, a 150-seat training auditorium, and advanced propulsion testing facilities, including one of the UK's largest vacuum chambers for electric propulsion engines.

Space Minister Liz Lloyd said the opening represents "another exciting milestone for the UK's space ambitions", highlighting the hub's role in attracting private investment and supporting home-grown innovation. The development, led by URA Thrusters with several industry partners and Buckinghamshire Council, is expected to create up to 300 skilled jobs across the region.

SMART T-SHIRT COULD TRANSFORM DIAGNOSIS OF HEART CONDITIONS

A new smart T-shirt developed by researchers at Imperial College London could help detect dangerous inherited heart conditions that often go unnoticed using standard tests. The project, supported by the British Heart Foundation, aims to make long term heart monitoring easier and more comfortable by embedding up to 50 sensors into sportswear style fabric. These sensors mirror the function of an ECG but allow people to go about their daily lives while the shirt continuously records their heart's electrical activity.

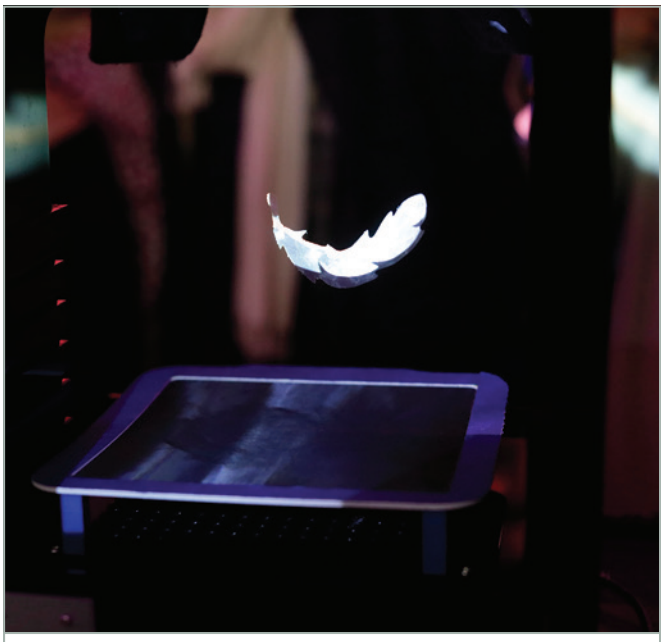
At present, people with symptoms such as dizziness or chest pain are sent home with portable ECG monitors that use sticky electrodes and wires. These can be uncomfortable and are typically worn for only 24 to 48 hours, meaning irregular heart rhythms may be missed. In contrast, the smart T-shirt can be worn for up to a week, giving it a greater chance of detecting rare rhythm disorders.

The T-shirt aims to make heart monitoring far more comfortable, accessible and accurate. Its soft, sensor embedded fabric avoids the discomfort and inconvenience of sticky electrodes and wires, making long term monitoring easier to manage in everyday life. For families affected by inherited conditions such as Brugada syndrome, earlier detection could reduce anxiety and improve access to timely treatment.

The technology is being tested with patients including 38-year-old teacher Carly Benge, whose diagnosis of Brugada syndrome followed her sister's experience with the same inherited condition. Researchers are now training an AI system on data from more than 1,000 people to identify subtle abnormalities earlier and more accurately.

Carly Benge (right) with a member of the research team © British Heart Foundation

GET INVOLVED IN ENGINEERING



© Innovation Late / Professor Sriram Subramaniam FREng

DISCOURSE: HOLOGRAPHY AND LEVITATION – ADVANCES IN MULTISENSORY SOUND

27 March 2026, 7.20pm to 8.45pm
The Royal Institution, London, or online
Drawing on advances in acoustic holography and levitation, Professor Sriram Subramanian FREng will show how sound waves can be computed and controlled to lift and guide tiny objects, forming dynamic three-dimensional shapes that can be both seen and felt. These demonstrations reveal how sound can enable the contact-free handling of materials ranging from solids and liquids to powders and gases. To book tickets, head to **www.rigb.org/whats-on**

EDINBURGH SCIENCE FESTIVAL: GOING GLOBAL

4 to 19 April 2026
Various venues
This year's festival includes tech-and-data installations, family engineering shows and headline talks from astronaut Helen Sharman and civil engineer Professor Gordon Masterton FREng. The theme Going Global, Edinburgh Science Festival 2026 will showcase the research and innovation created through international partnerships that address shared challenges, directly aligning with the UN Sustainable Development Goals (SDGs). To find out more, visit **www.edinburghscience.co.uk**

© Unsplash/K. Mitch Hodge

TITANIC SOCIETY TALKS

14 April 2026
Olympic Suite, Titanic Belfast
Join the Belfast Titanic Society in the Olympic Suite for two in-person talks exploring engineering innovation and the human stories behind Titanic. Delivered by members of the Belfast Titanic Society, these talks delve into the vision that shaped Belfast's shipbuilding legacy.
Visit **titanicbelfast.com** for more information

BIOELECTRONICS – TECHNOLOGY INTERFACES WITH THE HUMAN BODY

12 May 2026
The Royal Society, London, or online
Professor John Rogers FRS will deliver this Royal Society prize lecture on engineering devices that talk to biology, to accelerate biomedical research and provide new foundations for monitoring and treating diseases. Book tickets at **royalsociety.org/science-events-and-lectures**

THE FUTURE OF RAIL – YOUNG ENGINEERS' NATIONAL FINAL

13 May
Institution of Mechanical Engineers, London, or online
Each year, the Institution of Mechanical Engineers' Railway Division holds a competition of technical presentations. The competition is open to all young railway engineers including apprentices, undergraduates and those in the early stages of their career. Entrants will present to a panel of judges and other attendees. Winners of the regional heats will compete for a prize of £1,000 at the final. The winning presentations will give a fascinating insight on work going on within the rail industry across the country, by talented young engineers. Find out more at **www.imeche.org/events**

HOW I GOT HERE

Q&A

RACHEL CHIU
PRINCIPAL SYSTEMS ARCHITECTURE ENGINEER

HRH The Princess Royal (left) with Rachel (right), receiving the 2025 Smeaton Medal. The award recognises engineers in the early- or mid-stage of their careers who have demonstrated outstanding engineering achievements in hostile environments, such as space and in the deep ocean

Rachel Chiu has built a career around tackling complex challenges in spacecraft systems engineering. She received the 2025 Smeaton Medal for accelerating a major satellite constellation launch – despite plans being derailed by Russia's invasion of Ukraine.

WHY DID YOU BECOME INTERESTED IN SCIENCE AND ENGINEERING?

It started when I was super young, about six, when I was first introduced to Lego and got the hands-on experience to build things (and from time to time, stepping on it and questioning my life decisions). But overall, it was inspiring, because I saw when things come together, they work. I was fortunate to travel with my parents to visit places like the Kennedy Space Centre and the Airbus A380 line at Toulouse. Seeing these huge structures in person, I was impressed, and eventually that steered me towards aerospace.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I decided to specialise in aerospace, just because from a simple physics point of view, making metal fly in the air is impossible. That led me to go to Imperial College London to study aeronautical engineering. I started my career with Dyson, focusing on multi-physics simulation. I did everything from fluid dynamics, to electrical [and] thermal modelling, and much more.

Soon I was bored by the challenge of a small system, so looked for a bigger system, and found my way into satellite communication systems. It spans from the ground to space, 1,200 kilometres above us. You don't really have any systems bigger than that, in terms of physically covering a huge space, it's challenging.

I joined Eutelsat [formerly OneWeb] as a systems modelling engineer. I needed to understand the entire system to model it: how our satellite constellation is moving around, how our network is operated, and how the links work between different parts of the network. Now I'm a systems architecture engineer, leading cross-functional projects and designing the upcoming features for our next satellite constellation and ground assets.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

Driving forward our constellation deployment timeline, which is the main factor supporting the award citation. It's quite rare because usually engineering dates are delayed. I'm pretty proud of that – how I managed to use a small one-off demonstration to drive a major system completion deadline ahead of schedule and recover from other delays.

One was the Black Swan event, when Russia invaded Ukraine and all of the launches through Russian territory were scrapped. The entire launch campaign was completely scrapped. If I didn't make some adventurous last-minute changes, it would probably

Rachel as a teenager visiting the Kennedy Space Centre in Florida

have cost us over a year to recover from that. I decided to propose some crazy ideas that sped up our completion by a year. It gave us more commercial flexibility while we let the geopolitical situation unfold and see what's our next step, who's our new launch partner, that kind of thing.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

I think being an engineer in industry is more interesting because I get to both interact with other technical parties and see it from the customer's (non-technical) point of view. It gives me an appreciation of why we shouldn't over engineer things. From university education, we want to come up with the most brilliant engineering solution. But once I started working in the industry, I realised there's more to it, it's actually about getting to use the system correctly, getting customers engaged.

I now enjoy that part of the challenge, which is less about developing very engineering-centric solutions, and really about making things work for everyone – not just for the few people with the technical understanding. I really enjoy seeing someone non-technical figuring out how to use the system because we make it simple and possible.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

It depends on the project. Usually I'm juggling three to four things. I supervise some of the technical work from other junior members, giving them technical feedback and sense checking their work. Other times I'm discussing more strategic long-term projects with senior management and then I spend a bit of time documenting some of my knowledge or training other people with my system knowledge.

I do systems training for everyone. I write up some documentation and training material and generally do some of that knowledge transfer to other teams who might be designing something new. So even if I'm not directly supporting their project, I help everyone to work off our collective experience, so I usually spend my time juggling between these kind of tasks. At this point I spend very little time doing numerical or coding analysis by myself. I used to do that quite a lot, but right now it's usually me supervising more.

WHAT WOULD BE YOUR ADVICE TO YOUNG PEOPLE LOOKING TO PURSUE A CAREER IN ENGINEERING?

I would say you don't really need permission to try, just try it and then eventually, that willingness to try will pay off. If you're too scared to try, if you're always waiting for permission to innovate, you will never get anywhere. I think the benefit of having young voices in the room is that we can bring in some good questions, make everyone rethink the status quo. Young people should always see their contribution as a refreshing voice in the room. Don't be scared to ask questions.

We've managed to push forward some unorthodox solutions that no one else considered from this. I just asked the simple question, why do we have to do it this way?

So simple things like that. That's why I managed to change our launch sequence and everything. I think it's something younger engineers should try, just questioning the simple things and you never know, that might be what you need for a breakthrough.

WHAT'S NEXT FOR YOU?

I am currently moving towards more senior technical advisory roles so that I can contribute to more projects, rather than just focusing on one. That's kind of what I enjoy, I can then have a better view across multiple projects. That's another aspect I'm enjoying – instead of seeing people working in a silo, little pockets of excellence, I'm now trying to align everyone's direction so that in the medium- to long-term there's more technical synergy.

QUICK-FIRE FACTS

Age: **28**

Qualifications: **aeronautical engineering, Imperial College London; Chartered Engineer from the Institution of Mechanical Engineers**

Biggest engineering inspiration: **Lego**

Most-used technology: **WD40 and duct tape**

Three words that describe you: **loud, opinionated, technical**

OPINION

ENGINEERING BIOLOGY NEEDS ETHICS BUILT IN

To unlock the gains of engineering biology, engineers must bake ethics into the field, through open debate, clear safeguards and engaging with the public, says Professor David Bogle FREng, Professor Emeritus of Chemical Engineering at UCL.

Professor David Bogle FREng

It is said that while the 20th century was the century of physics, the 21st century is the century of biology. With more powerful computers to model and better understand complex biological systems, engineers have been able to turn our skills in quantification, computation and the problem-solving design mindset to engineering biology.

The UK government defines engineering biology as "the design, scaling and commercialisation of biology-derived products and services that can transform sectors or produce existing products more sustainably". But the field goes beyond this, touching many aspects of our lives in health, agriculture and food, new chemicals and materials, the environment, and even national security and the resilience and preparedness of our society for the unexpected.

In February 2026, the Royal Academy of Engineering and the Engineering Council issued a revised *Statement of Ethical Principles*, which emphasises the need to ensure engineers' work is in the wider public interest. For engineering biology, as in all fields of engineering, this means embedding ethics from conception through to rollout.

Many of the potential impacts from the field are hugely beneficial, but there is also potential for harm. With such a wide-ranging scope for impact, it is important that the ethical dilemmas that engineering biology throws up are discussed openly, both within our technical community and with wider society. We need to ensure that potential risks are well understood and mitigations well explained. Without this, there is a danger that society will lose their trust in engineers.

Healthcare is perhaps the area with the greatest potential impact, and the least controversy so far. Already, drugs are made using engineering biology with general acceptance. Take the COVID-19 mRNA vaccine. In the face of a global pandemic, this brought to light the urgent need for effective treatments and for rapid development and rollout. Combining modelling and AI with growing data sources may help us replace animal testing, speed up drug discovery and develop new approaches to treatment. However, a big barrier is

With such a wide-ranging scope for impact, it is important that the ethical dilemmas that engineering biology throws up are discussed openly, both within our technical community and with wider society

that the interests of the pharmaceutical industry are skewed towards new medicines sold in high volumes. Yet, the bigger challenges are in treatments needed for very small patient groups, such as those affected by rare or orphan diseases, and to diseases prevalent in the developing world where funds are limited. These pose an ethical dilemma for pharmaceutical companies and their investors.

Engineering biology as applied to agriculture and food may be more controversial, although there are many potential benefits in terms of efficiency and quality. To some extent, new engineering biology approaches are 'industrialising' cross-breeding that has been practised for centuries. Yet they are also more sophisticated and certainly perceived as having the potential for harmful effects, both known and unknown. How do we ensure that society is broadly on side when biological adjustments are made? Are they made to benefit everyone, including those often excluded from the benefits through cost or accessibility? Is labelling adequate and are people sufficiently well informed?

Biofuels are often proposed as a significant source of energy but there are ethical concerns about the need for agricultural land to support food production. Would enhancements to biology make this more efficient, to an extent that all land needs are satisfied?

Industrial biotechnology – where engineered microbes produce useful chemicals and materials – increasingly uses genetically modified organisms. As yet, public scrutiny and awareness seems to have been limited. Textiles could also be an area where new materials are made from biologically altered organisms – but how would the public respond to these?

Looking to the defence sector, engineering biology can be considered dual use, like many technologies that have the potential to bring benefits. Biological weapons have a long history, resulting in international agreements to control their use. The propensity for sophisticated offensive or defensive weapons based on engineering biology is considered widely by security forces, with most research and development inevitably in secret. This is an area that raises concerns with the public, so engineers in the spaces where they are developed must continue to scrutinise them, and engage with government-appointed task forces, such as the UK Biosecurity Leadership Council. So what must the engineering community do?

- Hold open debates on the benefits and risks of engineering biology, bringing in diverse voices from beyond engineering.
- Insist that it is a funding requirement for engineers to consider and communicate the potential ethical consequences of new research.
- Scan emerging engineering biology research for early indications of new technologies that could pose ethical challenges.
- Promote engineers' involvement in regulation, particularly of healthcare, agriculture and food, based on up-to-date engineering knowledge.
- Back continued engineering biology research and development, both for prosperity and to understand potential consequences.
- Ensure that there is strong support for longer-term fundamental research, which needs infrastructure, collaboration and patience. There is a constant push towards short-term success and quick translation of semi-ready technologies. Focusing seriously on establishing the foundational bases would ensure new technologies are grounded in solid engineering foundations.

We should also ensure that when we train new engineers, we encourage vibrant debate about ethical issues in all areas, including engineering biology. Engineers must consider ethical consequences of their work and be well-prepared to discuss with friends, neighbours and the wider public. Where appropriate, they should even challenge their managers to justify investments, and sometimes even argue against developments.

This is a technology area with huge potential but also one that raises many ethical issues. To ensure that we get the benefits, identify and mitigate the key risks, and maintain our society's trust in the engineering community, we need to be open with the public and encourage transparent ethical debate.

BIOGRAPHY

Professor David Bogle FREng is known for developing computer-aided process design and control engineering methods, enabling their application to biochemical and pharmaceutical processes, and in applying systems engineering methods to physiology and medicine. He has been actively engaged across engineering, including as President of the Institution of Chemical Engineers from 2022 to 2023; Scientific Vice-President of the European Federation of Chemical Engineers from 2018 to 2022 and chairing the 2005 World Congress of Chemical Engineering. Until recently he was chair of the Royal Academy of Engineering and Engineering Council's Engineering Ethics Reference Group.

This article was adapted from the Royal Academy of Engineering's 'Engineering ethics' blog series. Read the original and others in the series at raeng.org.uk/ethics.

Marco Odermatt of Switzerland competes in the men's team combined downhill skiing at the 2026 Milan-Cortina Olympics. Alpine racing courses such as this rely on machine-made, tightly packed snow to handle repeated high-speed runs

HOW TO PREPARE THE MOUNTAINS FOR THE WINTER OLYMPICS

Did you know?

- Snow, but not snowflakes: machine-made snow starts life as tiny ice 'nuclides'. These grow into spherical beads, rather than the snowflakes we usually think of, and this influences the snow's macroscale properties
- A hidden waterworks: new reservoirs and underground pipelines feed over 1,000 snow guns; in Livigno two pump rooms can push up to 369 litres of water a second, helping lay about 1.6 million cubic metres of snow before the first start
- Tuning dial: snowmakers can tune the snow from drier to wetter on a one to nine scale and even 'water' the piste so moisture soaks in and freezes into a hardened layer that withstands the stresses of racing

Because of climate change, the Winter Olympic Games can no longer depend on natural snowfall. Behind the scenes, and thanks to many months of infrastructure preparation, ski racing courses at the 2026 Milano-Cortina Olympics have been highly engineered to ensure fairness for competitors, writes Chau-Jean Lin.

Cast your mind back to the second week of January 2026. Across the slopes of Cortina d'Ampezzo and Bormio, a white blanket covers the mountains. The local New Year's celebrations have finished, and 1.6 million cubic metres of machine-made snow is ready for the upcoming Winter Olympics. The only signs that the snow is machine-made are the bright yellow snow guns that appear like a connect-the-dots puzzle alongside the ski slope.

Snow is critical to the Winter Olympics, but climate change is making conditions less favourable. Alpine landscapes that historically accumulated one to two metres of natural snowfall each season are now increasingly rare. In 2023, the former International Olympic Committee President, Thomas Bach, noted that it's likely that only 10 to 12 countries will be able to host the Winter Olympics by 2050.

Warming winters and a push for a more sustainable infrastructure mean hosts such as Italy must now find solutions to this challenge. Working in the background, engineers from around the world have come up with ways to ensure consistent amounts of snow are available during the games, while athletes adapt their performance and training to the conditions of the engineered snow.

THE IDEAL SKI RACING SLOPE

Like a high-budget film set, Winter Olympic ski slopes are highly constructed environments, shaped through land-forming, grooming, and snowmaking. Slope design is important to ensure that competitions run smoothly.

Competition courses require dense, compacted, strong snow that won't break up when over 100 skiers launch themselves down the slope, to ensure consistency throughout the competition.

"It's always good to have quite a hard slope," says Nemanja Dogo, who has worked at TechnoAlpin, the maker of the snow guns for the Milan and Beijing Winter Olympics Games, since 2018. "If the slope is harder, then the conditions for the first athlete and the 150th are more or less than same."

The secret to a hardened slope is a process called watering, where (unsurprisingly) water is sprayed or injected into the top layer of snow. Rather than forming a dangerous icy crust, the idea is for it to percolate into the snow, mixing, bonding and freezing into a resistant layer.

Of course, before slope managers can get to that resistant layer, they first need a foundation of snow.

HOW TO MAKE SNOW

When natural snow falls short, snow fan guns and their smaller equivalents, snow lances, come to the rescue. Fan guns are well-suited for wide slopes that require a lot more snow over a large area. Lances, on the other hand, are better for narrow cross-country trails

Down a slope or trail, the surface depends on the sport – and its intensity. Leisure skiers need 'grippier' slopes than ski racers, who are better-equipped for the hardened conditions that resist breaking up from repeated high-speed runs. (Right) Cross-country skiers glide on smooth, homogenous trails to improve balance and manoeuvrability. However, competition trails must still be made of significantly stronger snow than ordinary trails

that require more accuracy as to where the snow lands.

Machine-made snow requires water, from a reservoir or a natural source, to be cooled and pumped into the gun. For the Milan-Cortina Olympics, organisers constructed a lake in Bormio, the site of the men's ski races, to hold 88 million litres of water for snowmaking. For the Livigno freestyle and snowboarding events, they built a 200-million-litre basin, and two machine rooms that can pump up to 369 litres of water per second to the system of snow guns via underground pipelines.

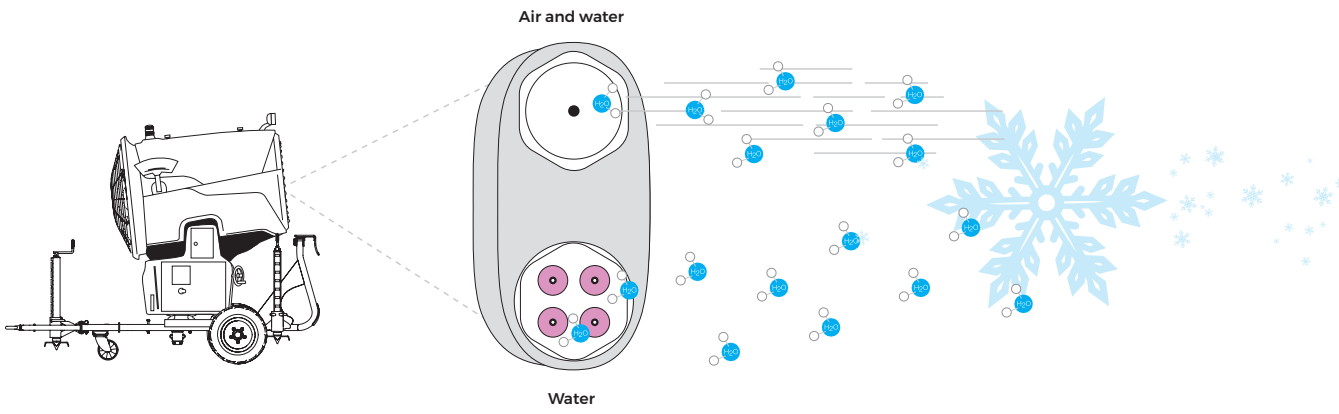
To bring it to the right temperature for snowmaking, the water travels via cooling towers before being pumped into the fan guns. Tiny ice crystals or snow nuclei, known as nuclides, are produced when the water is injected into compressed air and expands from the pressure difference.

At the same time, water nozzles produce a mist of finely atomised water droplets. The mist and nuclides are blown into the air by a fan, and as the water droplets attach to the nuclides in the air, they form 'ice beads', rather than snowflakes. As they subsequently fall onto the ground, they pack neatly like small spherical balls with small pore spaces in between them. This uniform structure makes its mechanical properties less variable than natural snow.

Snowmakers can finely tune the properties of machine-made snow. "You can change the snow quality from one to nine," says Dogo. A higher number indicates wetter snow, although he points out that external temperature and humidity are important constraints.

To improve their efficiency, snow guns are usually run at night, when temperatures are cooler. Luckily for the organisers of the Milan-Cortina Olympics, a cold spell throughout Europe after Christmas enabled them to run the systems during the day too, says Dogo.

But conditions are not always this ideal. At temperatures above -8°C or in relatively high humidity, snowmakers can introduce nucleating agents (see 'Natural vs machine-made'), such as aluminosilicate minerals, known as feldspar, or sometimes bacteria. These nucleating agents help snow guns become more efficient – using less water and energy to produce snow.



Inside a snow gun: snow nuclei, also called 'nuclides', form as water injected into compressed air expands from the pressure difference (top). It accumulates droplets from the mist of water (bottom) and grows into 'ice beads'. These ice beads resemble natural snow on a macroscale level but are spherical, rather than snowflake-shaped © TechnoAlpin

Piste groomers come out each night after racing finishes for the day. They mix fresh and old snow, then compact it into a consistent, load bearing layer © CEphoto, Uwe Aranas, CC BY-SA 3.0

MAINTAINING SLOPES DURING THE OLYMPIC GAMES

After an eventful day of competitive skiing, mountains, like athletes, need rest and repair. The slope management team of the Olympics sets to work every night after the slopes close. Their job is to repair slope damage, redistribute snow, and regenerate a trail's surface – a process known as 'grooming'.

The ideal conditions to groom the slope is when the snow is highly deformable – slightly wet and pushed to the bottom of the slope – and the temperature is close to zero. This is usually shortly after a slope closes, when the snow is still warm and easy to process. There is also enough time for the snow to consolidate, known as the respite period.

The snow groomers used in the Olympics are more advanced than those put to work on commercial ski slopes. Advanced GPS systems and software on the Olympic-grade machinery can determine how much snow is needed and where to put it. These tracked vehicles usually have a tiller to break up the snow and a blade to cut and shape the snow, so they can collect snow, redistribute it, and smooth surfaces.

ADVANCES IN SNOWMAKING

As global snowfall continues to decline, researchers have been developing ways to make and store snow in more efficient ways, to ensure leisure skiing can continue and competitions can go ahead. In countries with cooler climates, such as Norway, snow storage has been an effective strategy for preserving snow. It is conserved in insulating materials, such as sawdust, between April and the end of September.

Meanwhile, at Spain's oldest ski resort, La Molina, Dr Albert Verdaguer and researchers from the Institut de Ciencia de Materials de Barcelona are testing whether feldspar will boost ice crystal nucleation when temperatures are on the warmer side. So far, the group's research indicates this approach could enable snow production at temperatures 1 to 1.5°C higher than traditional approaches, and reduce energy costs by 30%.

At the Olympics, advanced weather forecasting software integrated into snowmaking tools will prevent overproduction of snow. For a system that has over 1,000 snow guns, the efficiency and accuracy of snowmaking is vital, as changing weather conditions during snowmaking can change where the snow falls. "We can predict which side the wind is coming, so we can change the position of the snow guns," Dogo explains, "[to ensure] the snow falls on the trails." And when needed, the machines can also stop snow production to prevent wasting water and energy. "It's important to switch off the whole system immediately in warm temperatures to prevent spreading water."

NATURAL VS MACHINE-MADE

Natural snow, in contrast to machine-made snow, depends partly on the presence of a nucleating agent, such as dirt or dust – even at very low temperatures. "You can supercool water to -38°C, but it won't make snow without particles," says Carla Molteni, a professor of physics at King's College London, who has worked on computer simulations of ice crystals.

Natural snow most commonly appears as the branching, hexagonal structures we recognise in snowflakes, although water can crystallise into different structures to form ice. "When snow crystals are made in nature and become larger, they become more reactive and less stable," Molteni explains. This is why natural snow is less homogenous and stable than machine-made snow.

For athletes, the two feel different – so it's key to train on competition-like courses, made from machine-made snow. Many national teams head to the southern hemisphere to do so. They can then mirror the conditions they will face in the competitions and test their equipment on similar snow. However, some athletes, their coaches and researchers have claimed snow sports are becoming more dangerous and less predictable because of the increasing use of machine-made snow.

The ice track at Cortina d'Ampezzo © Michael Kristen

Cortina d'Ampezzo's luge and bobsled track, once featured in a James Bond film, is the first in Europe cooled by glycol instead of ammonia. It opened ready for training runs in November 2025 © Michael Kristen

BEYOND SNOW: THE BOBSLEIGH, SKELETON AND LUGE TRACK

Cortina d'Ampezzo's 'Eugenio Monti' Bobsleigh and Luge Sliding Centre is a modern engineering phenomenon. It stands at 1,730 metres long, with 16 curves, rebuilt over a historical track that appeared in the 1981 James Bond film, *For Your Eyes Only*.

The track is the first in Europe and second in the world to use glycol as a refrigerant, reducing the use of ammonia by 96%. Ammonia is commonly used as a track coolant, but is highly toxic: a leak in 2003 at France's La Plagne bobsleigh track resulted in World Cup events being cancelled (and spooked track operators).

Despite construction delays, the track at Cortina d'Ampezzo was ready for international training runs in Novembe 2025r. Markus Aschauer, a track expert for the International Luge Federation (FIL) was there during the trials. He has consulted on every track since the Nagano Olympics in 1998.

"The ice is the same. The only thing which is different is the construction inside the track. We have a bigger refrigeration pipe than an ammonia system, so we need much more energy to pump the glycol." This is because glycol has a lower coefficient of heat transfer than ammonia, so a much greater volume of glycol than ammonia is needed for the same cooling effect. In turn, the energy required for a glycol system will be greater than that for ammonia: the trade-off for a safer system.

Experts worked tirelessly to finish the track for the Olympics. The engineering design team, Jörg Penseler and Mike Richter of IBG+Partner, calculated the velocity, G-forces, and trajectories that the athletes will face. Speeds can reach 135 kilometres per hour and their calculations usually fall within 1% of the speeds obtained.

"The most interesting result of our calculations is the trajectories and pre-calculations for a curve. When you see the athletes have similar trajectories, that's quite cool," Richter explains.

And when asked if the new track will affect an athlete's performance?

Richter nods. "There's no influence."

How it works

- Glycol is cooled in a refrigeration plant and pumped throughout the track via steel pipes embedded in the concrete below the track. The pipes cool the concrete along the route.
- As temperatures drop – to about -21°C in the centre of the track, and about -15 to -18°C along the edge of the track – water sprayed on the track freezes.
- Ice makers shape the ice to create a uniform, smooth track. The ideal ice layer is four centimetres thick.
- The track temperature is controlled by 33 pumping stations. The waste heat is recovered and used to heat buildings located along the track.

A freshly groomed piste at Cortina d'Ampezzo © Ale Zesta

However, advances in snow gun and snow grooming software and technology notwithstanding, the snowmaker has the final say on how to achieve the optimal quality of snow on the slope. "Every snowmaker has their own idea … on how they want to make the snow," says Dogo. In the eyes of a snowmaker, preparing an Olympic slope is a combination of engineering, science, and art.

For athletes, the conditions of the slope require adaptivity. Caryn Davies, a former US Olympic and Paralympic alumni president, a three-time gold medallist in rowing and former competitive skier, explains the need to respond to different snow conditions. "You have to adjust your equipment: different types of snow require different wax. You also have to adjust your technique, since your skis will respond differently to pressure if the snow is soft or hard, powdery or granular."

As an elite athlete, Davies says, "I always looked at the conditions with equanimity: variable conditions are part of the sport. It's all how you handle it."

WAX ON, WAX OFF

Ski waxes, made from materials produced from petroleum or synthetic processes, are used to reduce the friction between the surface of skis with snow. Gliding across snow on skis creates friction, which produces heat and melts the snow. Waxes can improve or worsen the glide from the film of water that is produced as the snow melts.

The type of wax needed depends on the temperature, as well as how wet and dry the snow conditions are:

- Hydrophobic, or water-repelling, waxes are more suitable for wet snow. In these conditions, the layer of water underneath the ski becomes thick enough to create resistance.
- For drier, powder-like conditions, hydrocarbon waxes that prevent dry friction are needed.
- Machine-made snow requires waxing more often, since the particles of snow are more abrasive and harder.

BIOGRAPHIES

Markus Aschauer is Chair of the Track Construction Commission of the International Luge Federation (FIL) and provides consulting services for the construction and operation of artificial ice tracks for bobsleigh, skeleton, and luge under his company, SCA GmBH.

Mike Richter and **Jörg Penseler** are civil engineers and track designers. They are owners of IBG+Partner and have worked on eight Olympic bobsleigh, skeleton, and luge tracks.

Nemanja Dogo is an executive sales manager at TechnoAlpin based in Italy. He is also CEO of TechnoAlpin Middle East.

Caryn Davies is a three-time gold medallist in Olympic rowing. She is the former president of the US Olympians and Paralympians Association (USOPA).

SETTING NEW STANDARDS IN CONSTRUCTION

© Shutterstock

3D-printed concrete is increasingly being employed on building sites around the world, resulting in significant time and labour savings. Neil Cumins spoke to two engineers at the forefront of concrete printing technology, Professor Paul Shepherd at the University of Bath, and Luyten 3D founder Ahmed Mahil, about how the approach is transforming the construction sector.

Did you know?

- Traditional concrete can be tricky to shape as it relies on rigid moulds, meaning it is less suitable for complex structures
- This also often means concrete construction uses more material than necessary, creating waste
- 3D concrete printing can cut construction waste and lower labour costs compared with traditional poured or moulded methods
- Researchers have 3D printed vaulted floors that carry the same loads while using only a quarter of the concrete needed for a conventional solid slab

Concrete has been used in construction for thousands of years, from Assyrian aqueducts to floors in ancient Greece. The Colosseum and Pantheon served as early showcases of concrete's potential, yet it has always been a challenging material to work with. This is because it requires moulds to adopt its final form, offering limited scope for sculpting or shaping. Its widespread adoption in post-war British housebuilding saw it quickly fall from grace, as it experienced structural failures and became associated with unattractive and poorly built high-rise housing. Today, concrete tends to be used for floors and foundations rather than visible external finishes. It can be used for load-bearing walls, but as it is weak in tension, it must be reinforced with steel (rebar) to absorb tensile forces and avoid structural failure. Concrete is also a major source of carbon dioxide, generating about 8% of all emissions globally ('Concrete foundations for net zero', *Ingenia* 102).

These longstanding challenges have opened the door to new approaches, particularly 3D-printed concrete. As a construction method, 3D printing concrete uses automated, computer controlled machines to build structures by extruding a specially formulated concrete mix in layers. Instead of relying on traditional formwork, the printer follows a digital design to place material precisely where it is needed. Not only is this more efficient and sustainable, but it allows for the creation of complex shapes that would be difficult or costly to achieve using conventional techniques.

MALLEABLE YET SOLID

Compared to poured or moulded concrete, 3D-printed concrete can reduce construction waste by up to 60%, production time by 70% and labour costs by 80%, demonstrated in 3D printing projects carried out in Australia by manufacturer Luyten. These savings could be transformative for a housebuilding industry with ambitious national completion targets to meet, just as prefabrication techniques revolutionised post-war residential construction. Professor Paul Shepherd, of the University of Bath's Department of Architecture and Civil Engineering, explains: "When 3D printing, you can easily put material only where it's needed."

Shepherd has been instrumental in the university's Automating Concrete Construction project (ACORN). This aims to make concrete construction much more sustainable and efficient, to address the fact that many concrete parts in buildings use more material than needed because they're made with old, flat moulds. For example, it has 3D printed load-bearing floors using a quarter of the volume of concrete

A concrete structure 3D-printed by ACORN © John Orr

that would be required to support the same load using a traditional solid-slab, mould-poured floor.

The idea of spraying concrete through printer nozzles might seem odd, but as Shepherd explains, concrete can be held in liquid form for just long enough to be sufficiently malleable. "Materials need to be liquid enough to flow through the printer, while setting quickly enough to support the weight of the next layer when it is printed on top. Chemical additives include retarders, which delay the setting period of the concrete and makes sure it stays liquid while waiting to be printed, and accelerators to speed up the setting process once it's output. There is a lot of research being done to optimise the concrete mix for 3D printing, including investigations into whether new materials such as nanoparticles and graphene can help."

Another way is modifying the material properties between layers to gradually change the microstructure and makeup. "Changing the proportions of cement and aggregate allows different material stiffnesses and strengths to match requirements in different parts of the structure," adds Shepherd. "This is known as 'functionally graded' material."

The precise composition of concrete has varied enormously over the centuries, so this isn't anything new – but the ability to have different mixes in different parts of the same structure is. However, 3D printing is introducing new challenges in construction projects. "Concrete is great in compression but poor at resisting tension," explains Shepherd. "In ACORN, we tackled this by using geometry – our floors were vaulted, like a gothic cathedral roof or an arch bridge, so that almost all of the material was in compression. But since structures need to withstand different loads like horizontal wind or vertical snow, some sort of reinforcement is generally needed using a material that is good at resisting tension. Traditional floors use steel reinforcement meshes, but ACORN used short glass-fibre strands added into the concrete mix just before printing." These are applied in situ rather than installed separately, as reinforcement meshes are. It is a simpler process and their ratios can be optimised for greater efficiency and strength. The challenge of providing 3D-printed concrete structures with the required strength is ongoing, according to Shepherd. ACORN tested the robotic placement of carbon fibre tapes but chopped glass fibre proved to be a simpler solution.

Luyten's Platypus X2 printer printing a parametric self-shading wall using concrete
© Luyten

While ACORN didn't need to print temporary support for concrete during printing, another project that Shepherd was involved in did. He was part of a team of researchers from Imperial College London and University College London that used a swarm of several drones to create large 3D-printed structures made of foam or cement. Taking inspiration from nature, the drones worked together – with one or two builder drones equipped with a 3D printer flying in circles while depositing the material to build up the structures one layer at a time, while another used a depth-sensing camera to develop a 3D map of the structure as it progressed. This technique could help construct tall or complex buildings and structures, without relying on support scaffolding or heavy construction equipment.

SCALING UP PRINTING

While 3D-printed concrete has proved to be efficient, conventional industrial 3D printers would clearly be inadequate for construction work, as they are far too small. Manufacturer Luyten was founded to address the need for purpose-built construction

The company's X12 printer can be assembled on site in just 20 minutes using standard hand tools, and can print structures up to six metres high and 12 metres wide, as well as producing varying object lengths, which could theoretically enable a whole terrace of houses to be constructed

robots as opposed to repurposed ones, as traditionally used in 3D concrete printing.

The company started out manufacturing printers to use in academia, which permitted controlled experimentation with printable cementitious materials and has now developed gantry and crane-based systems that can undertake full-scale residential construction. The company's X12 printer can be assembled on site in just 20 minutes using standard hand tools, and can print structures up to 6 metres high and 12 metres wide, as well as producing varying object lengths, which could theoretically enable a whole terrace of houses to be constructed. Designs are typically modelled in BIM (building information modelling) or CAD (computer-aided design), before being imported to the printer using three-dimensional surface geometry file formats such as STL, a widely used file format for 3D printing and CAD that represents 3D object surfaces using a mesh of triangles.

Before launch, Luyten's printers are subjected to extended continuous and cyclic loading, repeated calibration and intentional de-calibration sequences to test their positional recovery and robustness. They are tested across temperature gradients with varying humidity and moisture regimes to determine their restart behaviour, fault tolerance and controlled degradation. According to the company's CEO Ahmed Mahil, "reliability in construction is defined as much by predictable recovery as by nominal precision."

JUDGEMENT CALL

Controlling a 3D printer is a hugely complex task, particularly in unpredictable real-world conditions. Mahil explains that human oversight remains crucial to effective deployment: "Luyten's control software is developed in-house to address the distinctive demands of construction-scale additive manufacturing. The software provides real-time monitoring of key operational parameters, including motion stability, extrusion consistency, and system status across the full build envelope. This monitoring capability is not passive; it is designed to inform operator decision-making as conditions evolve on site."

Operators use an interactive control panel to adjust print speed, extrusion rate, offsets and recovery protocols in real time. They can also respond to field variables and manage pauses or restarts without compromising structural continuity. Unlike small-format printers or lightweight robotic arms, construction-scale printing operates within open, variable environments where informed human judgement remains essential. "The emphasis is on operator authority and adaptability, enabling intelligent intervention grounded in engineering understanding," Mahil adds.

Despite recent rapid developments in AI software, Luyten uses it in an assistive capacity rather than granting it decision-making autonomy. AI-enabled tools are used to monitor print consistency, analyse sensor data related to material flow and motion stability, and support quality assurance and predictive maintenance.

UK UNIVERSITIES LEADING THE WAY

Several pioneering 3D printing projects are being developed at universities across the UK, showcasing why future construction sites might echo to the whirr of printers rather than the rumble of cement mixers.

Luyten installed a printer in Northumbria University's Mechanical and Construction Engineering department in 2024, to support the testing and validation of sustainable infrastructure. Experiments are underway involving eco-friendly concrete mixes reinforced with corrosion-resistant composite materials, seeking to optimise weight-to-strength ratios while minimising concrete usage. Meanwhile, experiments involving free-form construction have been taking place at Loughborough University since 2006. It was here that the world's first reinforced concrete printed component was produced.

At the University of Cambridge, researchers recently developed the first 3D-printed concrete infrastructure to be used by National Highways – a retaining headwall installed on the A30 in Cornwall. This 3.5-metre shape was fully printed off site in one hour without needing any reinforcement, while it also incorporates Cambridge-designed smart sensors which provide real-time measurements on factors including ambient temperature, strain and pressure. The resulting digital twin could potentially identify faults in the structure before they occur, enabling pre-emptive repairs to take place.

Meanwhile, a team at Loughborough University are combining concrete 3D printing with robotic milling, printing an approximation of the shape and then drilling away excess material to achieve precise results. This resolves key structural challenges during the printing process, allowing assembly components, joints, and channels for lighting and cables to be integrated, and offers an alternative approach to achieving precise finishes.

3D-printed concrete offers the opportunity for construction of more interesting structures, as the concrete can be applied precisely and is not limited by moulds © Shutterstock

Human oversight is maintained for all structurally consequential decisions.

THE DIFFERENCE BETWEEN OFF AND ON

There are clear differences between on-site and off-site printing – and benefits to both. While the former underpins ground-up construction projects, off-site modular printing can be used to preprint complex shapes for assembly later. Central to ACORN's plans is building concrete components off site using automation and robotics to create better-shaped moulds. This allows beams, columns and floors to use only the material needed, reducing waste and emissions. "Off-site allows better quality control of the finished products, plus easy waste recovery, which can be reintegrated into the manufacturing process," says Shepherd. "Off-site also means faster construction times on site, since the site becomes a place to assemble rather than manufacture. Some parts of buildings are being delivered to site with all the plumbing, electrics and interior decorations already in place." This couldn't be done with concrete poured on site, extending a benefit to concrete construction already associated with other prefabricated building methods.

While off-site concrete printing has its advantages, Shepherd acknowledges that there are limitations. "Off-site requires the parts to be transported from factory to the site. This puts limits on the size of each part, so a design that necessitates a large all-in-one concrete pour would need significant redesign if it were to be made off site."

However, the divide between on- and off-site doesn't have to be binary, as Shepherd points out. "Some projects have used a concrete 3D printer inside a shipping container, delivered to site so the parts could be made locally and then assembled. Others have lorry-based 3D printers that drive to site and 3D print in situ."

THE FUTURE OF CONSTRUCTION?

3D concrete printing is an area where Shepherd sees potential, once significant barriers are overcome: "We can already design complex shapes and render them physical, either by laying down layers of concrete one on top of another, or by spraying concrete onto a shaped mould. Getting tension-resisting reinforcement into those complex shapes is more of a challenge, so I believe the win-win comes when we optimise the shapes to minimise their need for reinforcement – using concrete for what it is good for, by resisting compression." However, he says that, like any new technology, in the short term 3D concrete printing will need to fit into an existing design process, legal framework and supply-chain that was not created with it in mind. "More insights are needed into the structural performance of 3D-printed concrete, not least its long-

3D-PRINTED HOUSEBUILDING

The first multistorey 3D-printed house in the southern hemisphere

With ambitious national housebuilding targets being challenged by affordability issues, net zero commitments and a lack of experienced construction personnel, 3D printing concrete could offer rapid, cost-effective and largely automated solutions to the UK's housing crisis. In the Lancashire town of Accrington, a community interest company recently signed a 'print partner' agreement that will see 46 affordable new homes created using 3D printing services. This is the UK's first 3D housing construction project, mirroring the principles of Luyten's Geode properties – the first 3D-printed multistorey homes anywhere in the southern hemisphere.

Each customisable Geode house is constructed in situ. A solitary Platypus X12 machine prints everything from a lift core to sound-cancelling walls, creating 350 square metres of living space within a five-week period, complete with elegantly curved exterior walls that would be extremely difficult to achieve using traditional poured concrete. This compares favourably to the eight-month construction window for a similarly sized house using traditional methods. Not only is construction quicker, but consistent output can shorten project timelines and enable precise replication of approved designs elsewhere.

While on-site supervision remains essential as each Geode home is being printed, the level of manual labour is significantly reduced compared to conventional construction. Treating buildings as machines rather than hand-crafted sculptures could help to revolutionise a traditionally conservative industry. The prospect of new homes being built more accurately and quickly, while requiring fewer on-site personnel and weather-related delays, is likely to galvanise support for 3D construction techniques.

term fatigue behaviour, and its ability to resist earthquakes and fire. This is an area I am keen to explore as part of my ongoing research."

Construction has lagged behind other engineering disciplines in the adoption of automation and targeted printing. While the need for minimising material usage has driven huge efficiencies in aerospace manufacture, the buildings and construction sector still accounts for 37% of global greenhouse gas emissions, according to the UN Environment Programme. Using concrete more sparingly (and efficiently) could play a significant role in the pursuit of net zero targets around the world, as well as bringing construction in line with more efficient manufacturing sectors.

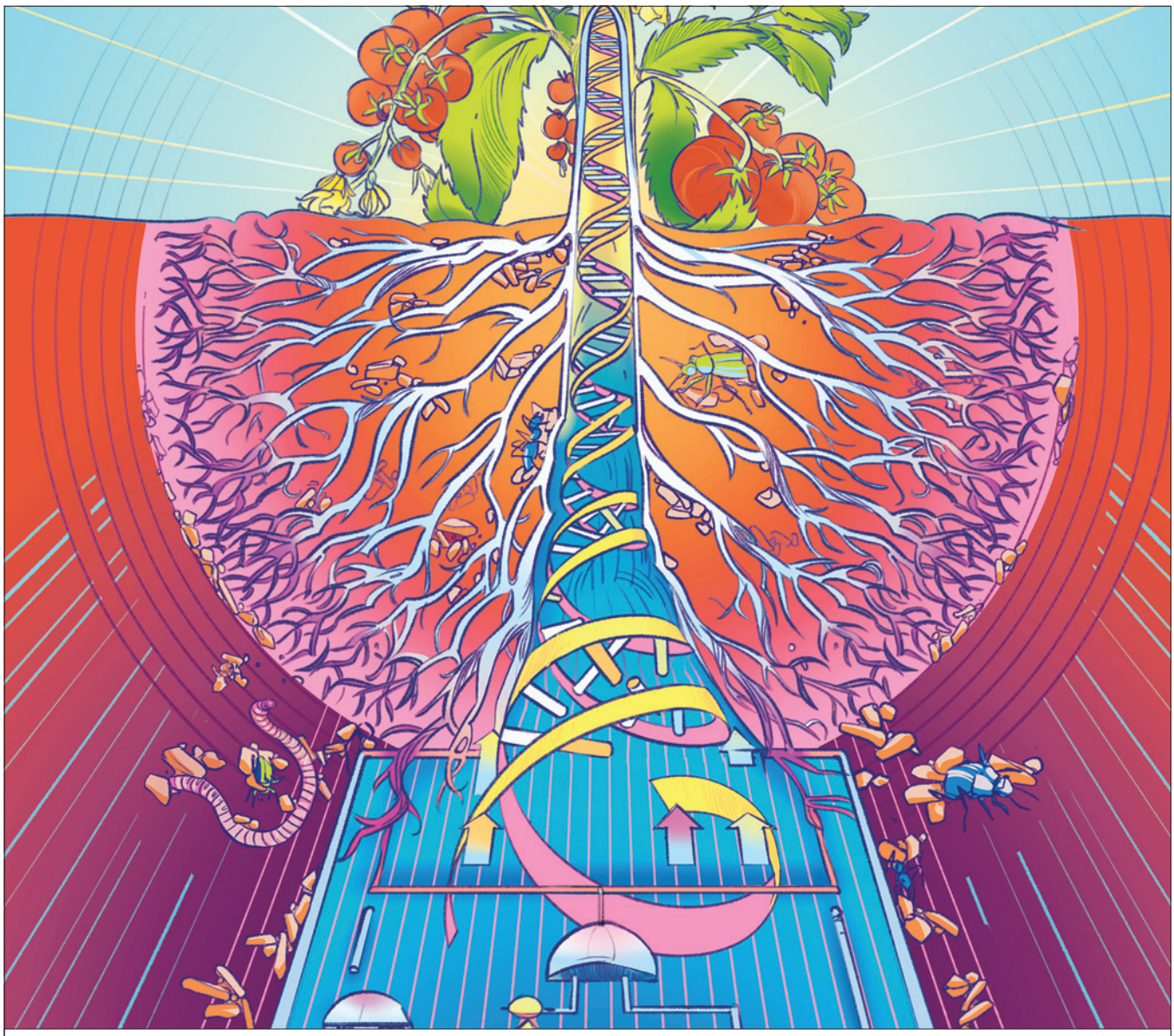
BIOGRAPHIES

Professor Paul Shepherd is a chartered mathematician, scientist and engineer with over 30 years' experience in the construction industry. As Professor of Computational Design in the Department of Architecture and Civil Engineering at the University of Bath, he is an internationally recognised expert in the use of computers to improve the built environment. He also spent time as Deputy Director of the Bath Institute for Mathematical Innovation, and is now Co-Director of The Foundry: Centre for Digital Manufacturing & Design.

Ahmed Mahil is a robotics and aerospace academic, industrial technologist, and the Founder, Chief Executive Officer and Global President of Luyten, a global manufacturer of large-scale construction robotics systems. In parallel with his industrial role, Mahil serves as an Adjunct Professor across multiple universities, contributing to research and postgraduate supervision in robotics, architecture, materials engineering, and business schools.

COULD ENGINEERING CROPS SAVE OUR FOOD SYSTEMS?

Synthetic biology is making waves in manufacturing and medicine. Could its tools help us re-engineer plants to cope with the harsh reality of a changing climate? Amy Lyall reports on the UK researchers harnessing synthetic biology in plants.



Did you know?

- Synthetic biologists have engineered plants to make insect sex pheromones that scramble pests' mating signals, potentially reducing our need for chemical pesticides
- Crops are being fitted with genetic 'circuits' so their roots can sense drought and reshape themselves to reach more water
- Some traits can be modified by tweaking just one gene. Others require entire networks or modules of genes to be re-engineered

Modern agriculture faces unprecedented challenges. Climate change is bringing longer droughts and greater risks from pests and diseases. At the same time soil degradation, fertiliser run-off and rising global demand are stretching food systems to their limits. Traditional breeding can't alter crops fast enough to match the pace.

Crop plants originally evolved to grow in different wild environments and are not optimised for agriculture. But what if the innate ability of plants to alter their growth and metabolism in response to their environment could be tuned? Can we enhance their ability to take in nutrients, to improve fertiliser uptake and reduce run-off? Could we strengthen their capacity to produce defensive compounds to ward off pathogens and pests?

Enter the rapidly maturing field of synthetic biology. Synthetic biology aims to precisely program living organisms with predictable functions, applying engineering principles such as modularity and standardisation to speed up the design-build-test cycle.

With synthetic biology products now beginning to appear in manufacturing and medicine, UK researchers are making strides in applying the field's approaches and techniques to plants to address some of the challenges facing agriculture.

THE PROMISE AND CHALLENGE OF SYNTHETIC BIOLOGY

Humans have been engineering the natural world for millennia, ever since we started farming seed-producing grasses and eventually bred wheat. We chose the best varieties of apple to crossbreed for size and sweetness. We bred miniature dachshunds to go down rabbit holes and Great Danes to hunt bears. We domesticated yeast to ferment bread and beer.

But last century, we made huge technical advances, building bioreactors to make antibiotics, vaccines and insulin. We discovered the structure of DNA and how to read its sequences and copy it.

Armed with this knowledge, in the 1990s, researchers began swapping genes into crops, bringing pest resistance to cotton and herbicide tolerance to soybeans and corn. Sometimes this had unintended consequences, such as when these plants bred with wild relatives or weeds developed resistance to herbicides.

Now these powerful but imprecise techniques have been augmented by genome editing tools – hallmarks of this era of synthetic biology. These techniques, such as CRISPR, allow us to precisely target sections of DNA, to modify, remove or insert individual DNA 'letters'.

Professor Jim Haseloff at the University of Cambridge is one of the UK's leading figures in synthetic biology. He believes the future depends on engineering biological systems in ways that let us coexist sustainably with the planet – not just in food production, but also in materials, chemicals and energy.

As Haseloff puts it, biological systems are "inherently modular." Every gene is made up of four chemicals, bases, that are the 'letters' of DNA. "[Evolution] happens through tweaks and changes," he says. "Step by step, base change by base change." It is this modularity that allows genes to be rewritten – and in turn the proteins and biological pathways they code for – without collapsing the whole system.

Living systems evolved to work in this compartmentalised way because it has many advantages. Modules can evolve independently, be repurposed, combined, or even sustain damage without necessarily affecting the overall system.

For a synthetic biologist, a module is any self-contained, functional unit that performs a specific task. This could be a gene, a network, a metabolic pathway, or even an organ.

These elements can – in principle – be treated similarly to inanimate modular elements such as those used when constructing a bridge. But while biological systems can be designed, built, tested and learned from, there are caveats to engineering them.

THE SYNTHETIC BIOLOGY TOOLKIT

Key synthetic biology approaches include:

- biocircuits: tools to build new logic-based circuits that program new cell behaviours or tune the function of natural gene circuits
- metabolic engineering: rewiring organisms to produce valuable chemicals or medicines
- creating new biological modules: synthetic genes, circuits, metabolic pathways, chromosomes, or genomes
- engineering cells: to sense signals and respond in predictable ways.

"Most engineering projects outside biology will be driven by a blueprint, where you've got a master plan," says Haseloff. "The connection between components is much more straightforward."

Biology, on the other hand, is complex and dynamic, with unpredictable obstacles. Because biological systems adapt and evolve, the module a researcher is working with can change unexpectedly. This is, says Haseloff, "the big challenge" of engineering biology.

"If we want to take advantage of the power of biological systems, harness the ability to grow the most complicated structures that we know from simple ingredients like glucose, those are the kinds of problems we have to grapple with."

SYSTEMS CHALLENGES

The past decade has seen the first precision-edited crops made commercially available. In the US, there is a soybean gene-edited to produce no trans fats in its oil, and the Sicilian Rouge High GABA tomato, sold in Japan, promises higher levels of the neurotransmitter GABA (which some claim boosts relaxation).

But as yet, no gene-edited crops on the market are designed to tackle large-scale agricultural challenges. Dr Nicola Patron, a plant synthetic biologist at the University of Cambridge, wants to change this. As well as working to improve the existing abilities of crops to produce antifungal agents in response to infection and growth in response to nutrients, her group is also engineering plants as factories to produce novel products for agriculture.

Patron aims for her work to result in products, "that genuinely [reduce] the environmental impact of food production, whether that's a crop that needs fewer fertilisers or a natural product that replaces chemical pesticides."

In 2023, Patron and colleagues engineered a wild relative of tobacco

An Australian relative of tobacco is a widely used model organism in synthetic plant biology, making it an ideal platform with which to develop new crop engineering approaches © Shutterstock

(a model organism in plant biology) to produce insect sex pheromones. These chemicals disrupt the breeding behaviour of pests, so could reduce pest numbers on crops, and in turn, reduce our reliance on pesticides that also harm pollinators and predators. Insect pheromones have been used in organic farming practices for several decades, but are currently only available for a small number of insects. Production from living cells could expand this to a wider range of crop pests.

The group has also set its sights on trickier systems engineering problems, such as modifying key traits that are decided by many genes wired into complex networks.

Patron's team is rewiring a network in lettuce, the UK's most valuable leafy vegetable crop, to help the plant fight fungal diseases. In an ordinary year, farmers lose about 1 in 10 lettuces to fungal disease. Sometimes the loss can be as much as 50% of their crop. The group is fine tuning the plant's response system, so that lettuce can eliminate disease quickly and easily, without the need for human intervention.

But Patron believes the analogy of genetic circuits being like electronic circuits can be pushed too far.

"The caveat with synthetic biology is we are putting engineered parts into a biological system. So yes, in some cases, things behave as we expect them to. But inevitably, if you do anything else to that system or to that circuit, your predictions will go off."

This can happen even in simpler systems such as bacteria, she says. "A circuit will perform at lab scale. But once you start scaling up the growth, the stresses and environmental conditions change the metabolism of that cell. We need new information to be able to predict how cells behave in a wider range of conditions.

"It can be frustrating from an engineering perspective. But as a biologist, it's actually valuable. When the circuit behaves differently, that tells you something about the system. If you've controlled and standardised everything else, any unexpected change helps narrow down the factors influencing the biology."

With the ultimate goal for the plants to grow either outside or in a controlled greenhouse, all of this information is critical to ensuring the engineering is robust. It allows synthetic biologists to build up a picture of how the new genes might affect the plant under different conditions – for example, if it was grown in a field and subject to weather variations.

PROGRAMMING PLANTS

The Advanced Research + Invention Agency (ARIA) is a UK funding agency set up in 2023 to fund high-risk, high-reward ideas. Its Synthetic Plants programme is funding an array of early-stage research projects, many aiming to address challenges in agriculture and food systems.

ARIA's programme thesis is that while synthetic biology is bringing

Teams funded by ARIA aim to eventually engineer the potato plant, which is economically important and seen as comparatively easy to transform © Shutterstock

new ways of producing drugs and potentially game-changing new therapeutic treatments, it has so far been underfunded and undervalued for the impact it could have in agriculture.

But the organisation sees now as the time to change this. "With advances in genome editing and synthetic biology, it's now possible to predict and design plant traits more precisely," says Fabrizio Ticchiarelli-Marjot, a technical specialist in ARIA's Synthetic Plants programme.

"Plants make up 80% of Earth's biomass," he says. "They're self-replicating, self-healing and can be deployed at massive scale. We see them as an ideal platform technology – the 'hardware' of the natural world."

One project ARIA is funding aims to insert complex traits, such as disease resistance and resilience to changing climates, into plants' genomes by building synthetic chromosomes. Chromosomes are long, tightly wound-up DNA strands found in cell nuclei. Depending on the species, plant chromosomes contain hundreds to tens of thousands of genes, plus a lot of baggage.

Building chromosomes from scratch would give synthetic biologists the ability to deliver multiple genes into a plant at once. And not only that: without all the baggage, they would also theoretically have a greater understanding of and control over the chromosome.

With a team including researchers at the University of Cambridge and startup Phytoform, this project will be the first attempt to create and deploy a functional synthetic chromosome in a plant. The team will use an easy-to-engineer moss as a development platform to build and test the synthetic chromosome. If the project is successful, the next stage will be transferring the chromosome into the potato plant.

ASSESSING THE RISKS

These projects are designed to help humanity and the natural world. It's important to ensure they don't have any deleterious effects such as uncontrolled breeding with wild plants or escape of an unwanted dominant gene.

Like all the researchers, Ticchiarelli-Marjot takes biosafety very seriously. "All our ARIA teams work on biocontainment strategies," he says. "One of the most effective methods is genome recoding."

Genome recoding is one way to reduce the chance that engineered genes would function in a wild plant. Synthetic biologists do this by rewriting the genetic code that maps DNA to proteins. The result is that the engineered gene will be unlikely to produce a functioning protein in a wild plant.

In the UK, plant products of synthetic biology are likely to be classed as either genetically modified (GM) or gene-edited (precision-bred) plants, depending on the type of modification. GM plants have been grown commercially for more than two decades. Overall, more than 190 million hectares of biotech crops were planted worldwide in 2019.

Gene-edited crops are not yet grown commercially in the UK. The Genetic Technology (Precision Breeding) Act 2023 does allow their commercial cultivation, but research trials are still in the early stages.

Engineered plants are bred and tested in controlled environment rooms under strict regulations and monitoring. Environmental impact assessments must be carried out before release to measure any potential effects on wild relatives.

But if the changes made could have been created through classical selective breeding, no fail-safes are needed.

For example, if the DNA of an apple variety has a gene from a different apple added to improve sweetness it would not be considered to be genetically modified, because the same result could have occurred through natural cross breeding.

WHAT'S NEXT?

Biology is not steel or silicon. It adapts, evolves and responds to context in ways that can frustrate tidy assumptions. However, these uncertainties are integral to the field. Synthetic biology is about learning to collaborate with nature, rather than control it.

This means unexpected behaviour can become a source of insight, instead of a failure. As Patron and fellow synthetic plant biologist, Dr Sarah Guiziou both note, when engineered systems behave differently under real-world conditions, they often reveal new biological principles.

As techniques mature and scale, we will see increasing emphasis on robustness, manufacturability and real-world deployment. At a moment when climate change, biodiversity loss and food insecurity are placing unprecedented strain on planetary systems, combining engineering discipline with biological insight offers a way to expand what is possible.

SIGNALLING FOR HELP

Many desert plants, such as the Saguaro cactus, develop shallow lateral root networks to capture limited rainfall, while sending a long taproot deep underground © Shutterstock

Dr Sarah Guiziou researches plant root development and plant – microbiota interactions at the Earlham Institute.

Plants shape their root networks in response to their environment, with desert plants developing wide, shallow lateral networks to capture limited rainfall, while sending a deep main root searching for underground water. By redesigning root structure and strengthening the relationship between roots and their microbiome, Guiziou hopes to support more sustainable crop production. Integrases, enzymes that add or remove DNA segments, are a key tool. They can be used to build genetic circuits that respond to environmental cues. One such cue could be an excess or shortage of water, to prompt an alteration in root architecture.

"The main challenge for synthetic biologists is that we don't understand the principles as well," says Guiziou. "In physics, we understand the fundamental principles. In biology, there are a lot of fundamental rules that we don't understand. When we are building modules, they might not behave the same way depending on external conditions. But that's part of what makes it exciting. These circuits can help us understand what we don't know."

Dr Guiziou says that a biology background is not essential to succeed in synthetic biology. "Engineers can bring different resources and principles; we're able to look at biological questions slightly differently and bring insights and solutions that some other people with more traditional biology backgrounds might not see."

BIOGRAPHIES

Dr Sarah Guizou is a group leader at the Earlham Institute in Norwich. She is interested in engineering plant root architecture and microbial interactions for sustainable agriculture. She earned her PhD in synthetic biology at the University of Montpellier and followed it with postdoctoral work at the University of Washington before joining the Earlham Institute in 2023.

Professor Jim Haseloff is Head of Synthetic Biology for Engineering Plant Growth at the University of Cambridge. His research interests have included plant viroids, RNA enzymes and engineering approaches to plant development. He is currently interested in simple open systems for engineering plant growth.

Dr Nicola Patron is Head of the Plant Molecular Engineering Group at the University of Cambridge. She completed a PhD in plant molecular biotechnology and did postdoctoral research at the John Innes Centre and the University of British Columbia on plastid evolution and metabolism. She is also a co-founder of Black in Plant Science.

Dr Fabrizio Ticchiarelli-Marjot is a plant scientist with a PhD from the University of Cambridge. He has spent 10 years advancing plant biology knowledge and its translation to products. Before ARIA, he spent five years working in early-stage tech startups.

GIVING SOLAR PANELS A SECOND LIFE

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As millions of solar panels reach the end of their useful lives, the question of what to do with them is set to become pressing. Stuart Nathan looks at how reuse and recycling are the first step in a circular solar panel economy.

Did you know?

- By 2030, the UK is expected to generate 1.2 million tonnes of waste solar panels each year, forming part of a much wider e-waste challenge
- Used solar panels can often be repaired or reused, and in some cases still have a decade of useful life left, reducing waste and extending their value
- Advanced recycling processes can recover high-value materials such as silver, copper, aluminium, silicon, and clean glass from spent solar panels, allowing them to re-enter manufacturing supply chains

The sun is setting on a generation of solar panels. Since the late 1990s, the need to find ways of generating electricity without burning fossil fuels has led to rapid growth in the use of photovoltaic panels, both on a domestic scale (on rooftops) and industrial (generally in fields). Their use has increased significantly since 2010, when financial incentives came into force to encourage their uptake. This included energy companies offering free panels to homeowners under the Feed-in-Tariff scheme, where they would be paid for electricity generated.

In the UK, total installed capacity for photovoltaic solar power reached 18.9 GW peak capacity in May 2025, according to the Department for Energy Security and Net Zero, providing just over 5% of total electricity generation – a proportion that has risen from just 0.01% in 2008. In terms of area, the government estimates that 21,200 hectares of land were covered by solar panels in the UK in September 2024 (2,120 million square metres) – about 0.1% of the total land area in the country. Worldwide, solar generation capacity reached 1062 GW in 2022.

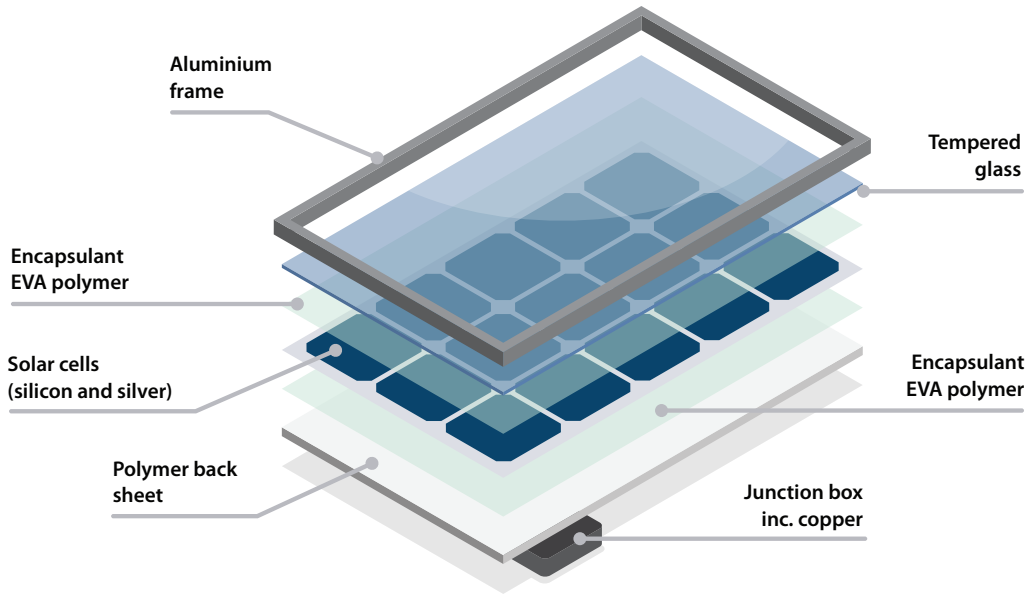
But these impressive figures mask a looming problem. Solar panels' performance declines over time, due to factors such as long-term exposure to UV rays and weather, with most having a 25- to 30-year useful lifespan. This means that a substantial proportion of the installed panels across the country are approaching the end of their life.

In the UK, end-of-life solar panels are not automatically treated as hazardous waste, but they are regulated. Under UK law, they are classified as electrical and electronic equipment (EEE), which means that once they reach end of life, they fall under the Waste Electrical and Electronic Equipment (WEEE) Regulations. This classification places legal duties on producers and waste handlers to ensure they are properly collected, assessed and recycled.

As their use continues to grow, solar panels are forming part of a rapidly increasing e-waste stream and without coordinated regulation and treatment capacity, valuable materials could be lost and environmental risks could rise.

This has focused attention on the possibility of recovering valuable materials from discarded solar panels and recycling or reusing them. In 2024, the Exeter Centre for Circular Economy (ECCE) at the University of Exeter produced a report, *From Linear to Circular: Evidence from the UK solar sector*, that explored the continued use of solar panels and their component materials after they reach end of life. One of the report's co-authors, Professor Peter Hopkinson, sees the issue as part of a wider problem of e-waste: the UK needs better systems for collecting, testing and recycling end-of-life solar panels at scale. "We are facing, yet again, another challenge with products, components and materials that have been placed on the market where we don't have infrastructure or regulations that can manage end of life in a coordinated way. So, we're not capturing the maximum value from those products. Rather like electronic components generally, we're facing a messy and complex situation, and it's going to get worse."

By 2030, according to ECCE, an estimated 82 million tonnes of e-waste per year will require safe disposal in the UK, of which some 30,000 to 200,000 tonnes will be solar panels – potentially reaching 1.2 million tonnes by 2050. The materials that make up the majority of a typical panel's mass are aluminium, used in the frames; critical minerals such as copper and silver, used in the electronics; and the glass that comprises the panels' outer surface. If these materials can be extracted from the solar panels and purified, they can be sold to manufacturers for reuse in new products: copper and silver are in high demand for electronics, although are difficult to recover because of the small percentages; aluminium is used in many sectors, notably aerospace and general manufacturing; and clean glass is, of course, readily recycled. Despite this, however, some of the concern over solar panels focuses on materials used in their electronics and the photovoltaic cells themselves, such as crystalline silicon and rare earth minerals, which have limited global supply.



The constituent parts of a solar panel that can be recycled when disassembled © Shutterstock

ECCE sees making solar panels part of a circular economy largely as being a matter of design, ensuring that the components of panels can be separated easily for repair (if possible) or disassembly to recycle their constituent materials. "Modularity is the first thing to think about," says Diego Bermudez, a research and impact fellow at ECCE who has worked on data modelling for several circular economy projects. "But you also have to think about the materials you use and minimise those that are difficult to recycle or reuse."

EXTRACTING THE MATERIALS

In cases where the solar panels cannot be repaired or reused, engineers are working on ways to extract and recycle the material components. One such process is flashlight delamination, which uses short pulses of high-intensity light to separate the layers of polymer composite: the light pulses heat up the materials, causing their layers to separate. The process, along with disassembly steps, separates solar panels into glass, aluminium, polymers, silicon, and metals such as silver, in a form that can be sold to manufacturers and reused in other products. Dresden-based Flaxres is one company using this technique. Its mobile recycling plant for solar panels travels to where

MAKING THE MOST OF EXISTING PANELS

Cornwall-based ReSolar is taking a different approach to recycling used panels. Billed as the UK's first organisation to research and develop solutions to tackle waste from solar panels, ReSolar has already teamed up with Hammersmith and Fulham Council in London to keep discarded solar panels in use. In 2023, 700 panels were removed from a housing estate because of changes in building regulations. Determining that 50 of the panels still had 10 years of useful life left, ReSolar transported them to Ukraine and assisted with their installation. They are now supplying decentralised power to clinics, independent from the country's electricity infrastructure, which is unstable because of the ongoing conflict in the country.

ReSolar is also investigating repairing damaged solar panels, looking at using resin, silicone glue and acrylics to repair cracked glass. It has employed its techniques on 204 panels that had been damaged in transit to a large solar farm in Southwest England and is also working with the University of Birmingham to investigate the possibility of using AI to automate the repair and reuse process, analysing performance data and images of damaged panels to identify specific faults.

A recovered solar panel being tested © ReSolar

According to project coordinator Claire Agraffeil, one of the project's biggest achievements was coping with the diversity of design in the solar industry and across several different countries. "It may seem easy, but there are over 150,000 models of photovoltaic devices, with their own design specifications, so it is very complex to find a universal way of disassembling them"

the panels are decommissioned, saving on transportation costs. With a capacity of 10 tonnes per day, Flaxres claims the plant can recycle 95% of materials in the panels.

Photorama, an EU-funded project that involved companies from Spain, France, the Netherlands, Sweden, Germany, and Italy, concluded in early 2025 with the opening of a pilot plant in Tangermunde, Germany. Similarly to Flaxres, the plant incorporates flashlight delamination, alongside processes such as diamond wire cutting; water jets to separate polymers and solar cells; solvent extraction with an ethylene glycol/calcium chloride mixture followed by electrolysis to recover silver and silicon; and a similar extraction/electrolysis process with methane sulfonic acid for indium and gallium. According to project coordinator Claire Agraffeil, one of the project's biggest achievements was coping with the diversity of design in the solar industry and across several different countries. "It may seem easy, but there are over 150,000 models of photovoltaic devices, with their own design specifications, so it is very complex to find a universal way of disassembling them. We had to design and develop a whole system, flexible enough to treat any kind of photovoltaic waste. It is very important, because recycling is about throughput and high-volume treatment."

Although recovered glass, aluminium and silicon can be readily reused across a range of applications, it is the conductive metals that represent the most valuable resources contained within end-of-life solar panels. These essential materials are crucial for clean energy technologies, yet their supply remains constrained and vulnerable to disruption. By recycling spent panels and recovering these critical metals, the industry can help to mitigate supply risks, reduce reliance on raw material extraction, and support a more resilient supply chain for renewable energy technologies.

France-based ROSI Solar, claims to have developed the first process to recover pure silver from spent solar panels. It uses a thermal delamination process – high heat in the absence of oxygen that breaks materials down into a mix of gas, liquid and solid char, often used in plastic recycling – to separate the constituent materials, then further treats the products of pyrolysis with water-based chemistry to extract and purify copper and silver for sale and reuse. Its plant can process 10,000 tonnes of panels per year and although the mass of metals recovered is small – a little over 40 tonnes of copper and 8 tonnes of silver per year – this represents a large fraction of the value of the panels, where over 60% of the material value is embodied in just 3% of the total mass.

The possibility for recycling doesn't just stop with the panels themselves; the solar sector can also be a customer for recycled material – including those recovered from spent panels – making it a potential contributor for a wider circular economy. Researchers at Newcastle University are working with the Ministry of Defence and a Norwegian company, Wastefront, to use carbon black, a pigment that can be made from waste tyres, in printable light-absorbing inks that can be used in photovoltaics. The project found that the ink performed as well as a product made with virgin carbon black.

HOW RECOVERED SOLAR PANEL MATERIALS ARE USED

Recycling end-of-life photovoltaic panels yields a mix of high-value materials that can re-enter manufacturing supply chains across several industries.

Glass typically makes up the largest share of a solar panel's mass. Once recovered and cleaned, it can be reused in new solar panels as glass sheets or the protective layer between the glass and the backing; used in construction materials, such as tiles, abrasives or other glass-based building products; or made into new glass products.

The aluminium frames are easily separated and 100% recyclable. These are often remanufactured into new solar panel frames or used in wider aluminium-product manufacturing, including industrial components and consumer goods.

Silicon is the main semiconductor material that converts sunlight into electricity. Silicon that is recovered can be purified and reused in new solar cells or used in electronics manufacturing to create new semiconductors. In some cases, it is reprocessed into silicon feedstock for various industrial silicon products (where purity thresholds are lower).

The conductive metals are among the most valuable reclaimed materials. Silver can be reused in electronics and new photovoltaic contacts. Copper can be returned to electrical wiring and other conductive applications. Rare elements, such as indium, gallium, and tellurium in thin film panels, are often reused in high-tech electronics, specialist coatings and semiconductor applications.

STEPS TOWARDS A CIRCULAR ECONOMY

While innovative ways of recycling and reusing solar panels are paving the

way towards a more sustainable and circular economy, it is clear that further action is needed from both industry and government. Stronger policies, increased investment, and collaborative efforts are essential to scale up such solutions and ensure their widespread adoption, ultimately maximising the environmental and economic benefits for society.

Recycling is a first step and to make it more efficient, the ECCE report encourages manufacturers to publish lists of all the materials in their products, highlighting anything hazardous and making it easier to track the impact of the products on the environment. Government policy should also encourage investment in developing recycling facilities specifically for solar equipment, while industry should establish testing facilities to identify equipment that can be reused rather than scrapped and formulate standards for photovoltaic reuse.

Business models that extend the lifespan of functional panels through repair, maintenance and reuse, and improved data collection on system performance and failure cases can also help to effectively manage the growing challenge of solar waste. Such insights will be crucial for refining panel design, shaping better regulations and supporting the shift to a more circular economy in the industry.

The future sustainability of the UK solar industry depends on embracing circular economy strategies that prioritise ongoing use, robust repair, and effective recycling of the materials that make up the panels, supported by transparent information and progressive policies. This approach will help retain the value of solar technologies, reduce environmental impact and ensure the sector's continued growth.

AN AI-ENABLED APPROACH

Shortlisted for the Manchester Prize – an initiative funded by the Department for Science, Innovation and Technology to reward UK-led developments in AI for the public good – Green Loops, from the University of Birmingham, is using AI to analyse the optical properties of materials recovered from spent solar panels and to predict how they can be recombined into new materials. It is specifically looking into their use in a class of substances known as metamaterials, which interact with light in ways not found in nature. Green Loops claims that these engineered substances, in this case, made from a layered structure of metals and organic materials, can be used in new electronic products, including flexible solar cells – thin, lightweight, bendable panels that can be attached to curved or uneven surfaces.

Dr Kiran Gulia, who is lead developer of Green Loops, explains that the lack of access to raw materials for electronic components is key to the thinking behind the project. "We figured out that the critical materials themselves are absolutely vital in everything we do in this sector," she says. "But we are dependent on East Asia for all these materials – they have to be mined, and the UK does not have the mining. Essentially, we need to secure all the material that is floating around in our economy."

AI plays multiple roles in Green Loops' technology, Gulia explains: "It literally sits at the heart of the process." First, it helps define the properties of materials recovered from solar cells. Secondly, it uses properties such as bandgap (the energy needed to make current flow in a semiconductor), carrier mobility (how easily the current flows), optical absorption, and defect states in the materials' crystal structure, taken from a database of seven million materials, to predict how silicon, copper, aluminium, other metals including cadmium, tellurium, silver, and ethylene vinyl acetate (EVA) – a polymer used in and recoverable from solar panels – could be recombined into metamaterials. "We have generated a green extraction process that will also bring in electronic waste from laptops, computers and mobile phones, so that widens the critical material range to include gallium, gallium arsenide and gold," Gulia says. Notably, the system, called ECOMAT AI, predicts how the materials can be used "as is", without any need for further refining or purification. Thirdly, it gives methods for the metamaterials to be synthesised. Finally, it tells the researchers the energy efficiency of the whole process from extraction to synthesis.

Green Loops is working on a portfolio of solar and energy storage products that reintegrates the extracted materials from e-waste and end-of-life solar panels. The ECOMAT AI software is currently beta tested and will soon be ready for commercialisation.

BIOGRAPHIES

Diego Bermudez is part of the Digital Innovation and Circular Economy (DICE) Network+ at the University of Exeter. Previously a Senior Analyst at the Ellen MacArthur Foundation, Diego led AI-driven circular economy initiatives and brings over 15 years of expertise in systems thinking and data analytics across finance, IT and policy. He holds a PhD in Digital Business Systems Resilience from Cardiff University.

Peter Hopkinson is Professor for Circular Economy at the University of Exeter Business School where he established and leads the Centre for Circular Economy. He also leads a Global Masterclass on implementing the circular economy developed with the Ellen MacArthur Foundation. Peter is a founding Director of the UN-backed Global Centre of Excellence for Sustainable Resource Management and Circular Economy, and currently leads the development of a National Circular Economy Data Observatory.

Stuart Nathan would like to thank Ananda Nidhi, the lead researcher of the From Linear to Circular report; Dr Kiran Gulia of Green Loops; Claire Agraffeil of Photorama; and Pablo Dias from SolarCycle for their help in producing this article.

THE HUMANITARIAN FACE OF ENGINEERING

Dr Josh Macabuag OBE FREng

When disasters strike and buildings collapse, Dr Josh Macabuag OBE FREng is one of the engineers who runs towards the danger. A volunteer with a UK search and rescue team, he has helped locate and free people trapped after earthquakes, and is now leading renewables risk analytics company Renew Risk as co-founder and CEO. He talks to Beverley D'Silva about bringing technical expertise and calm precision to some of the world's most harrowing crises.

There is more than one professional title to describe Dr Josh Macabuag OBE FREng and what he does because his career is multifaceted. He's a structural engineer with a background in building design whose day job for the past 12 years has been in catastrophe risk modelling, quantifying the risks and costs of natural disasters. In early 2026, this role took on another facet as he was made CEO of Renew Risk – a company he co-founded in 2021 to revolutionise risk management for renewable energy by building software and other solutions for insurers, banks and developers of renewable infrastructure assets such as windfarms and solar farms.

Natural disasters are also central to his second life, through his role as an urban search and rescue engineer with Search and Rescue Assistance in Disasters (SARAID), which entails finding and extricating people trapped in collapsed buildings. Macabuag has been deployed as a volunteer engineer to many humanitarian missions abroad, including the earthquakes in Nepal in 2015 and Turkey in 2023.

"And at some point, I decided to call myself a disaster risk engineer," he adds. "It's a made-up term because all three words are important to me."

However, another of Macabuag's titles came as a big surprise, at least to him: OBE, which he received in HM The King's 2025 Birthday Honours list. He's happy the award acknowledges his long-held goal "to use engineering as a vocation for humanitarian purposes." But it is not his alone, it belongs to his fellow search and rescue engineers and others too, he insists.

EARLY INFLUENCES AND NINJA TURTLES

Macabuag recalls where his interest in engineering started, during his childhood, "growing up on a council estate in Romford in Essex. There were no engineers in my family, but my father was a car mechanic. He used to call himself a mechanical engineer, and I used to argue with him about that," he grins. "I don't know anything about cars myself, I wish I did, it would be useful. But my dad's job did have an influence on my interests, I'm sure."

Another influence on his career is perhaps more surprising: an animated cartoon series about four martial arts loving turtles. "As a kid in the 1990s I watched *Teenage Mutant Ninja Turtles* on TV a lot. My favourite was Donatello, the engineer. He has all the gadgets and fixes things." That character was also smart, calm and clear-headed – essential qualities in a disaster response engineer? "Well, I'm not saying ninja turtles decided my career," he laughs, "but I did always admire technical ability. Like on *Star Trek*, it was the guys down in engineering who got everything working."

Like those turtles, the young Macabuag was a dab-hand at martial arts, good for developing fast reactions and coordination. But it was his talents in maths, science and technology that were really flourishing. "I guess I discovered engineering through maths and physics … It was almost accidental, more a case of what I was interested in."

While reading a careers manual he discovered structural engineering. "It was about making stadiums, buildings and bridges, and I remember thinking: now that *is* interesting." He was fascinated by structural engineering's part in designing other large structures such as wind turbines and rollercoasters, ensuring they are technically safe and stable;

QUICK Q&A

What is your favourite project you've worked on?
On the search and rescue side, I led engineering coordination during the Albania 2019 earthquake, where a team of over 180 engineers from more than 20 countries helped the Albanian government establish a damage assessment centre, supporting the evaluation of over 39,000 buildings and assisting hundreds of thousands of people to safely return to their homes and livelihoods.

What are you are most proud of?
I'm most proud of the outstanding team at Renew Risk and all we have accomplished together, truly making a remarkable impact in our sector.

What is the best part of your job now?
Finding and bringing together the best people in the world at what they do. At both Renew Risk and SARAID, we've created teams that are both unique and highly impactful, representing the very best in their respective fields.

Who influenced your engineering career?
Paul Jowett CBE FREng FRSE, a Past President of the Institution of Civil Engineers, who I was President's Apprentice to in 2010. He taught me how engineering requires a holistic view to problem-solving and that's been a central tenet of everything that I've done ever since.

What's your advice to budding engineers?
Do what you care about. When we are learning to be engineers it's important to remember to care about something and care about the impact that engineering has on people, their lives, their livelihoods. Find that passion and then you can never really go wrong.

In the immediate aftermath of disasters, structural engineers play an essential role within urban search and rescue teams, which aim to find and extricate people from collapsed buildings. Within that, engineers advise on and devise the least dangerous way to access those victims, as well as assessing damaged buildings, identifying viable access routes for rescue teams and monitoring live structural risks

and using computers to simulate how structures will be influenced by factors such as bad weather.

Macabuag was "the first in my family to go beyond O levels". He applied to the University of Oxford, choosing a general engineering science course to give him a broader understanding of other disciplines. "I had a strong feeling I wanted to work in civil engineering, but I didn't know much about it then."

LEARNING ON THE JOB

Before starting at university, he wanted to try working: "I was very lucky to be offered a year's work experience at Arup, one of the top, if not *the* top, civil structural engineering companies in the world. It has worked on the sort of structures you look at and wonder: 'how did they do that?'." These include Sydney Opera House, HSBC HQ in Hong Kong and Apple Park in the US, and rail projects such as the Elizabeth Line and High Speed 2.

He was tasked at Arup with "building in-house software for the thermodynamics of buildings, heating and cooling, that sort of thing"; and building "the front end, the user interface" he says. "That was my first exposure to programming. As I now run a company that creates software for catastrophe modelling, my gap year was definitely seminal." And so were lunchtime talks he attended there – "I went mainly for the free sandwiches, and as I'd eaten them I had to stay till the end," he jokes.

One talk was by an engineer associated with the learning and development NGO RedR (which then stood for Register of Engineers for Disaster Relief), which was a game-changer. "The speaker was talking about international development and working overseas – I recall Africa and elephants being mentioned. It made me sit up and think: ah, so you can do *that* [humanitarian work] with engineering. That really stuck with me."

Macabuag recalls watching the news about the devastating tsunami in the Indian Ocean in December 2004, triggered by a massive undersea earthquake off the coast of Sumatra, Indonesia. It was one of the worst natural disasters ever, resulting in about one-quarter of a million lives lost and many thousands injured. "I was in Jamaica with my dad, who's from there. I was watching the reports, thinking this is really bad. I had not long started at university, and I remember feeling very helpless, just thinking what can I do about this?" That disaster would later strengthen his resolve to work in a field he now describes as "disaster resilience or any disaster happening around the world, and what we can do about it".

His time at Oxford meanwhile developed "a very strong work ethic" in him that would be "very beneficial" when he began his engineering career. He also made invaluable

In the UK, he started his career as a design engineer. In parallel he led the London professional network of EWB and set up projects on earthquake retrofitting for low-income housing in Nepal and Peru, organising the funding himself from sources including the Institution of Structural Engineers

Working in a structured framework, urban search and rescue engineers often have to make rapid and life-critical decisions with confidence and consistency. As such, clear-thinking under pressure is essential in such emergency situations says Macabuag

professional relationships and contacts while there. Some originated from the day he was offered a summer job, working on Japan Railways' Shinkansen (bullet trains), the country's high-speed rail network renowned for its punctuality, comfort and safety.

"I was super chuffed about the job offer and I was on my way to hand in some course work when I bumped into one of my professors, Suby [Professor Subhamoy Bhattacharya]. I told him about the offer, and by chance – everything's by chance, right? – he said he knew earthquake risk researchers in Japan and he could introduce me to them." He did and Macabuag went to meet them, "in fact we're all still in touch 20 years later."

His close affiliation with Bhattacharya continued too. Professor Bhattacharya and Macabuag would later become co-founders, along with two others, of Renew Risk.

INTO THE FIELD

His first humanitarian mission abroad came in 2008, when he went to work in rural KwaZulu-Natal, South Africa, with Engineers Without Borders (EWB), a charity supporting engineers in international development work. "[As a team of engineers] we were supporting the community with facilities like water reticulation, low-cost housing … people facing very difficult living conditions and problems." He sometimes felt "the gravity and scale of issues" were "insurmountable" but it was also a "fantastic and very formative" year.

Back in the UK, he started his career as a design engineer. In parallel he led the London professional network of EWB and set up projects on earthquake retrofitting for low-income housing in Nepal and Peru, organising the funding himself from sources including the Institution of Structural Engineers. His paper in 2009, investigating the use of polypropylene straps to earthquake-proof buildings in Nepal, won first prize in a competition by the Institution of Civil Engineers (ICE). The win was "a great confidence boost" for him to carry on in that field, and he used the prize money to make further investigations in Peru.

Macabuag made two more inspiring contacts around then: Professor Paul Jowitt CBE FREng FRSE (then President of ICE), who he was apprenticed to, and with whose backing, he helped create an engineer's handbook on the delivery of the Millennium Development Goals; and Jean Venables CBE FREng, ICE President before Jowitt, and the first woman to be elected in the role. Venables had reviewed his pitch for funding to do research in Nepal and Peru. "I was looking holistically at the problem of international development and engineering, and it was a great year of speaking to some of the best minds in that field," he says: "Paul and Jean have been incredibly seminal people in my career and life, and continue to be so."

When Japan was hit by a devastating tsunami in 2011, generated by a 9.0 magnitude earthquake off the country's northeastern coast, Macabuag was deployed there a fortnight later on a reconnaissance mission. He went with the Earthquake Engineering Field Investigation Team (EEFIT, which is affiliated with the Institution of Structural Engineers). "EEFIT's remit is to learn from disasters, bring back key lessons and disseminate them among built environment professionals. I felt honoured to be part of it." He became Chair of EEFIT several years later.

FROM DESIGN TO DISASTERS

The Japan mission would be influential for him too: when he returned, he made two life-changing decisions. One was to leave design engineering after five years, to study catastrophe modelling, which he describes as what can go wrong, how often and how bad, and what can be done about it.

"My technical passion lies in risk modelling and catastrophe modelling," he explains. "Essentially, it's about quantifying risks to enable people to make informed decisions in managing those risks, ultimately making lives,

Macabuag at the Royal Academy of Engineering's Awards Dinner 2024, where he announced the winners of the Young Engineer of the Year Awards and the Sir George Macfarlane Medal

livelihoods, and infrastructure safer." His PhD, at University College London, was sponsored by an insurance company. That makes sense, as the science uses computer-assisted calculations and data to estimate costs where there is physical loss, such as damage to buildings, or indeed loss of life, and mostly originated in the insurance industry. It has broader applications too, he says, "anywhere you can imagine risk happening. Governments also need that kind of information." He was to be employed by the World Bank, working with the Global Program for Disaster Risk Analytics, under Rashmin Gunasekera. He modelled the impacts of disasters for governments in low- and middle-income countries to advise them on their disaster risk, "supporting ministries of finance in making decisions about their earthquake and hurricane risk, their civil protection teams, and so on."

His second big decision was to join SARAID as a volunteer engineer. He'd long wished to but wanted to be chartered first (which he was in 2012). SARAID is the first and only UK voluntary team to be officially classified by the UN International Search and Rescue Advisory Group as a light urban search and rescue (USAR) team.

His first mission with SARAID was to Nepal, in the aftermath of the earthquake in April 2015. Known as the Gorkha earthquake, it had a magnitude of 7.8 and was the worst earthquake in 80 years to hit the country. The earthquake resulted in the loss of almost 9,000 lives and widespread destruction to homes and hospitals.

When the SARAID team, usually 15 to 20 members, is called out, "the idea is to go immediately, but if you're going internationally (as SARAID does) you're generally going quite far and to places where the transport and aviation structures are often damaged. If you're in front of a damaged building within 48 hours of an earthquake, say, you've done well."

Search and rescue "isn't just about running around collapsed buildings, pulling people out of rubble. That's kind of the last bit," he says. "It's everything up until then, from when there's been a disaster, to deciding to go, getting to the country, coordinating with others in the field, understanding where you need to go, getting there, enacting those rescues. A lot happens in every one of those phases. You navigate all those to get to that last one: going into the building and supporting the people."

The SARAID team train together one weekend a month: "We come from all around the country, we know each other very well, we are friends." He stresses they are all unpaid volunteers and the organisation relies on donations to continue its valuable work. Deployment to a disaster zone is usually two or three weeks: "The rest of the time we get on with our day jobs."

For Macabuag that now means leading Renew Risk and focusing on its vision to accelerate the transition to a sustainable world, "calculating the analytics, which means informed quantitative decision-making and analysis around disasters for renewable energy, such as wind farms, solar farms, battery storage. And not just disaster risk, but all forms of risk." For renewable energy to be sustainable, "it has to be resilient" and making informed decisions on resilience requires "good data and a good understanding of that. So my passion now is leading a growing company that provides end-to-end software and consulting solutions to answer those questions."

Renew Risk is based at Lloyds of London. The team of 20 has already achieved a lot in the four years since it was founded; and last year it raised £4.7 million to forge a bridge between the renewable energy sector and financial markets – funds that will enhance its proprietary risk models, grow its team of risk modellers and climate experts, and extend its market reach globally.

He is keen that his work has a positive impact on people's lives, whether that's through search and rescue, humanitarian work such as damage assessment, or renewable energy.

"I'm proud that we've founded a company that takes our expertise in risk management and applies it to renewable energy, helping to accelerate the transition to a sustainable future."

"I remember being at the Science Museum with my daughter, showing off my engineering knowledge, and she asked, 'What do you do about climate change?' I didn't really have a good answer at the time. That moment wasn't the reason I started the company, but it certainly made me reflect. Now, I'm proud that we've founded a company that takes our expertise in risk management and applies it to renewable energy, helping to accelerate the transition to a sustainable future."

TEAMWORK BEHIND THE MISSIONS

If his USAR role has a downside, it's the impact it has on his family. "The imposition I know I'm having on [them], when I'm training and I'm leaving my wife to look after our kids," he says, referring to his daughter, ten, and son, six. "When I went to the Albanian earthquakes, in 2019, my son was only three weeks old. So, the weight I'm putting on my wife, is immense. That's the worst part. But that is countered by the love and care [they] give me."

Which takes us back to the OBE. It took him by such surprise he didn't at first believe it was real. "I genuinely thought it was a hoax, but it was on expensive looking paper, headed Cabinet Office, so it looked like it could be an elaborate hoax." Once he was convinced it was true, he still had mixed feelings: "Why would I be picking up an OBE when SARAID, for example, is made up of many people, all who put in amazing work and effort, many of them far greater than my own and for longer. I'm very proud to be picking up an OBE but [the award] is entirely about the team." Still, he admits it was fun to have gone to pick it up at St James's Palace with his family.

He wants any credit for his achievements to be shared with "all the people I've been working with." That includes many at SARAID such as fellow engineer Mark Scorer, the teams at the World Bank and Renew Risk, Paul Jowitt, Jean Venables, and Dr Hayaatun Sillem CBE (former CEO of the Royal Academy of Engineering), "who played a significant role in promoting engineering excellence and diversity during her tenure".

He pays it back to those coming up behind him via his involvement in the Academy's *This is Engineering* campaign, which encourages young people to follow their passions into an engineering career. It is a "real honour to be involved with," Macabuag says. If the young people seeing the campaign share his perspective on engineering as "seeing a problem as a challenge and taking an analytical approach to break that challenge down and solve each of the steps of that problem to have an impact on the world," he feels they will be on the right track.

"Engineering is the lifeblood of society, of making everything we have and we do. It not just the Donatellos, the guys using the spanners, who are changing and doing things. It's everything around it. Engineering has so many useful applications for positive societal change."

And if anyone should ask him, as they have, whether working in disaster response is "depressing and morbid," he has a positive answer for them: "I can honestly say no, not at all. Now, if I see a disaster on TV, I think, OK, that is terrible – let's do something about it."

CAREER TIMELINE AND DISTINCTIONS

Studied engineering at the University of Oxford, **2003–2007**. Pre-university trainee, Arup, **2002–2005**. Intern, Central Japan Railways Company, **2006**. Assistant engineer, Jozini Local Municipality, South Africa, **2007–2008**. Graduate structural engineer, Edge Structures, **2008–2010**. Institution of Structural Engineers Future Leader and President's Apprentice, **2009–2010**. Structural engineer, Building Design Partnership and Buro Happold, **2010–2012**. Research structural engineer, Earthquake and People Interaction Centre, University College London, **2013–2017**. NatCat R&D Analyst, SCOR, **2017– 2019**. Chair, Management Committee, Earthquake Engineering Field Investigation Team, **2011–2023**. Disaster risk consultant, **2019–2023**. Catastrophe modelling consultant, The World Bank, Amlin, Argo, **2019–2023**. Elected a Fellow of the Royal Academy of Engineering, **2023**. OBE for services to disaster search and rescue engineering, **2025**. Urban search and rescue engineer, SARAID, **2012–present day**. Co-founded Renew Risk, **2021.** Became CEO of Renew Risk, **2026**.

COULD BRAIN IMAGING BECOME AS ROUTINE AS ULTRASOUND SCANS?

UK neurotech spinout Sonalis is developing a first-of-its-kind ultrasound brain imaging technology that will be more portable and affordable than MRI.

Where MRI and CT scanners take up entire rooms and are expensive, ultrasound is a much cheaper and smaller alternative. But doctors don't typically image the brain with ultrasound, as it can't easily penetrate the skull and cannot provide accurate images.

That could be about to change. An Imperial College London spinout, Sonalis, is repurposing algorithms originally invented for oil and gas exploration, along with sensors from nondestructive testing, to boost medical ultrasound far beyond what it's currently capable of. The hope is to make brain imaging much more accessible to hospitals with smaller budgets, for example in low-income countries.

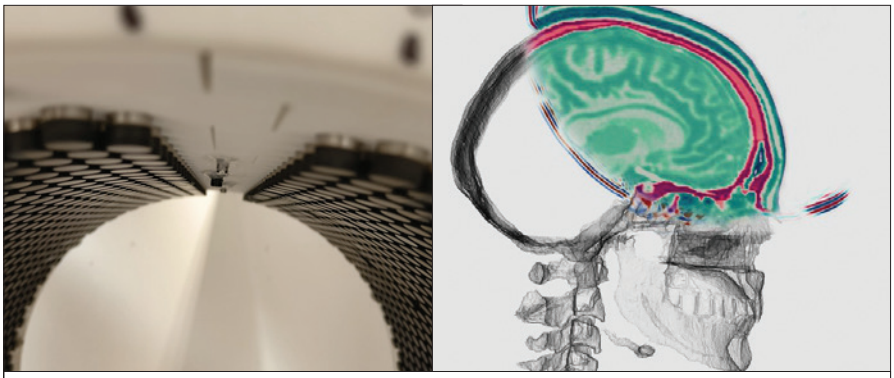
Oscar Calderon Agudo and two other seismologists at Imperial founded the company in 2017 after seeing parallels between visualising oil and gas reserves and visualising the brain.

Between hardware development, attracting investment and gaining acceptance as outsiders among the neurotech research community, the journey was at first an uphill struggle. "It's taken a long time to make these theoretical predictions and simulations a reality," says Agudo. Nearly eight years later, the company has proven its imaging technology in human testing.

GOING UNDERGROUND

Identifying underground reserves of oil and gas is a tricky problem to crack. Oil and gas companies have pumped "millions and millions" into developing seismic imaging that reveals complex underground geology, says Agudo.

By sending low-frequency sound waves into the ground, capturing reflected energy and analysing the



The first sensor-packed helmet prototype that Sonalis has developed (left) can generate high-resolution images of the brain (right, in simulations) © Sonalis

EYES ON THE INNOVATORS

***Ingenia* is keeping a close eye on the engineering breakthroughs making a difference around the world.**

Cerca Magnetics, a University of Nottingham spinout, has developed a 'quantum bike helmet' that will be able to show epileptic bursts in real time

Imperial College London spinout **Polaron** has closed an $8 million seed round to develop its AI-driven materials design software for batteries, metals and ceramics

signals with specialised algorithms, geophysicists can discern the presence of oil and gas reserves from underneath salt bodies, for example. As it turns out, the skull's capacity to reflect waves is not unlike that of underground salt bodies.

In a typical medical ultrasound scan, a handheld scanner sends ultrasound waves into the tissue. Weak reflections from boundaries between different tissues are used to produce the resulting image, but with the head, most of the signal is reflected from the skull surface.

Agudo and his co-founders wondered what would happen if they surrounded the head with sensors and analysed both the reflected and transmitted energy. By coupling this data with the algorithms applied in subsurface exploration, they could model the way the waves propagate through bone and tissue.

The prototype device resembles a helmet packed with hundreds of sensors. This first helmet cost a fraction of the cost of a commercial MRI machine, and with optimisation, the company expects the cost will fall further.

At first, the images were "very noisy", says Agudo, comparing them to CT scans from 30 years ago.

But one day in 2025, the cortical folds – the characteristic ridges and grooves on the surface of the brain – and central cavities, known as ventricles, came into view. These areas of the brain are where clinicians look when a patient is suspected to have had a stroke or brain haemorrhage.

It was a thrilling moment. "We were like, oh wow, that's amazing. Nobody in the world had seen this before."

DRIVEN BY THE AI BOOM

Sonalis' brain imaging technology has come to fruition partially thanks to the exponential rise in computing power driven by the AI boom. "Now, it's feasible in a very short amount of time [to produce] reconstructions of the brain. That was not possible two decades ago," says Agudo.

New sensors have been essential, too. Existing medical ultrasound usually operate at high frequencies, which are highly absorbed by the skull. Instead, Sonalis employs lower frequencies, which are safer and penetrate deeper into the brain. The team sourced sensors from nondestructive testing of pipes, where the sensors can pick up ultrasound frequencies a thousand times lower.

You might expect with lower frequencies, and thus lower energy, that the images would be lower resolution. However, thanks to the algorithms, they are approaching millimetre-scale resolution.

This precision is limited by current sensors and has not yet peaked, the company believes. "As the technology evolves, this resolution will get better and better. It's just a matter of time," says Agudo.

A PATH TO TREATMENT

Imaging the brain with ultrasound is just one of Sonalis' goals. The spinout also aims to treat neurological conditions such as epilepsy with its technology.

The idea is to focus the ultrasound at a precise point in the brain, concentrating the ions, and combine it with an electric field in this small region to stimulate the neurons.

Currently, stimulating neurons can only be done by very invasive methods, such as inserting electrodes in the brain after removing parts of the skull – so the prospect of doing this with no surgery required is exciting. But it's still early days, stresses Agudo. Further investigation is needed to explore suitability for epilepsy and other conditions, such as Parkinson's and drug-resistant depression.

MOONSHOT RESEARCH

The journey has not been without challenges. With the founding team's home territory in geophysics and seismology, publishers and funders were initially reticent. "There was a bit of scepticism at the beginning and we kind of persevered until we got published," says Agudo.

Another difficulty thrown up by operating in speculative, uncharted territory: off-the-shelf hardware wasn't an option. "We were a moonshot project," says Agudo. "We had to build our own labs to build this hardware."

And as many startups find, there was a slow grind to accumulating enough funding. But over time, the team amassed enough grants to build their proof-of-concept device, and since 2023, things have taken off.

Investment from the UK's Advanced Research + Invention Agency (ARIA), has accelerated Sonalis' trajectory, explains Agudo. As well as ARIA's funding and support in navigating regulatory bodies, Sonalis could tap into a unique network of engineers that helped them design parts of the current device.

At the current rate of development, Agudo estimates the device will be in clinical use in the next five or six years. But with enough of a boost from an ongoing fundraising round, this could be cut down to two and a half years, and as planned, the technology deployed in low-income countries.

"Where people have struggled to access to this high-resolution technology, [it will] benefit as many people as possible," says Agudo. "That's the goal."

UK self-driving company **Wayve** is planning robotaxi trials in 2026 and supervised autonomy in consumer vehicles from 2027

The **University of Bristol** and deep-tech ecosystem **Science Creates** are opening a new deep-tech incubator to help spinouts continue to scale in the city

The UK government is investing £36 million to increase the power of Cambridge's **DAWN**, one of the UK's leading supercomputing centres, by six times

HOW DOES THAT WORK?

CRISPR GENE EDITING

Often likened to 'genetic scissors', CRISPR is a gene-editing tool that allows researchers to change the DNA of living organisms with extremely high precision.

Modifying genes in cells used to be time-consuming, difficult and sometimes impossible work for researchers. However, since the development of the CRISPR gene-editing tool, it can be done in a few weeks.

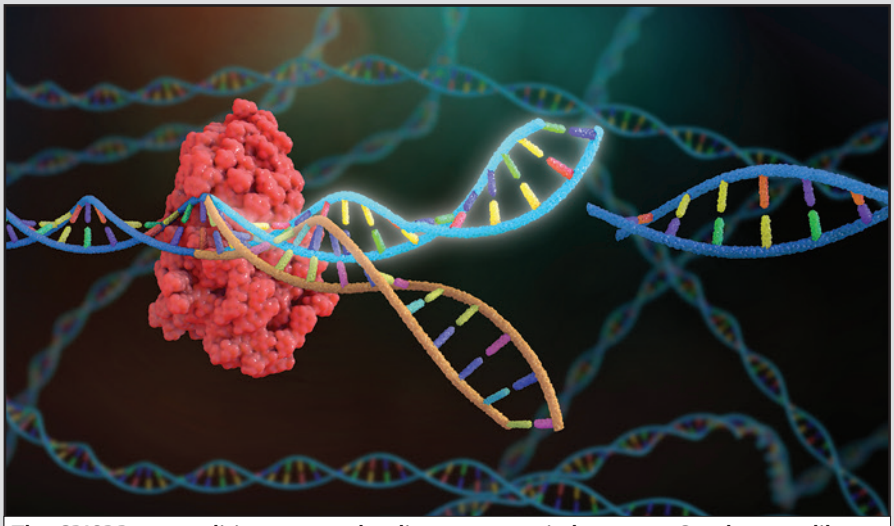
CRISPR is based on an ancient bacterial immune system mechanism. The mechanism, CRISPR-Cas, was first discovered by scientists working for a Danish food manufacturer. They were engineering yoghurt and cheese-making bacteria to be more durable when they happened upon a defence system in the bacteria. This monitors the cell for viruses and if it recognises one, slashes its DNA in specific places to render it inert.

The system relies on bacteria keeping a genetic record of any invading viruses. If a virus invades, the cell inserts a section of the viral DNA in a specific location in its own genome as a memento. (That region of the genome contains characteristic short snippets of DNA, called clustered regularly interspaced short palindromic repeats – CRISPRs for short, hence the name.)

The action happens when a Cas, or 'CRISPR-associated', protein takes a piece of RNA, the mirror image of DNA, to use as a guide as it patrols the cell. If it finds matching DNA, signalling the virus's presence, Cas's molecular scissors destroy it.

In 2012, researchers realised this defence system was programmable. If we know the DNA sequence of a specific gene we want to edit, we can give the Cas protein a so-called guide RNA that matches that gene. Cas will cut the DNA, like it would for a virus, which can inactivate or remove a gene.

Unlike viruses, cells have DNA repair mechanisms designed to rebuild a gene if it is damaged. But the repair machinery can be tricked into replacing that gene with another or correcting a defective gene. This is done by flooding the cell with the desired DNA sequence while the Cas protein is cutting the DNA. While there are several types of the Cas protein, Cas9 is the most widely used in gene editing.



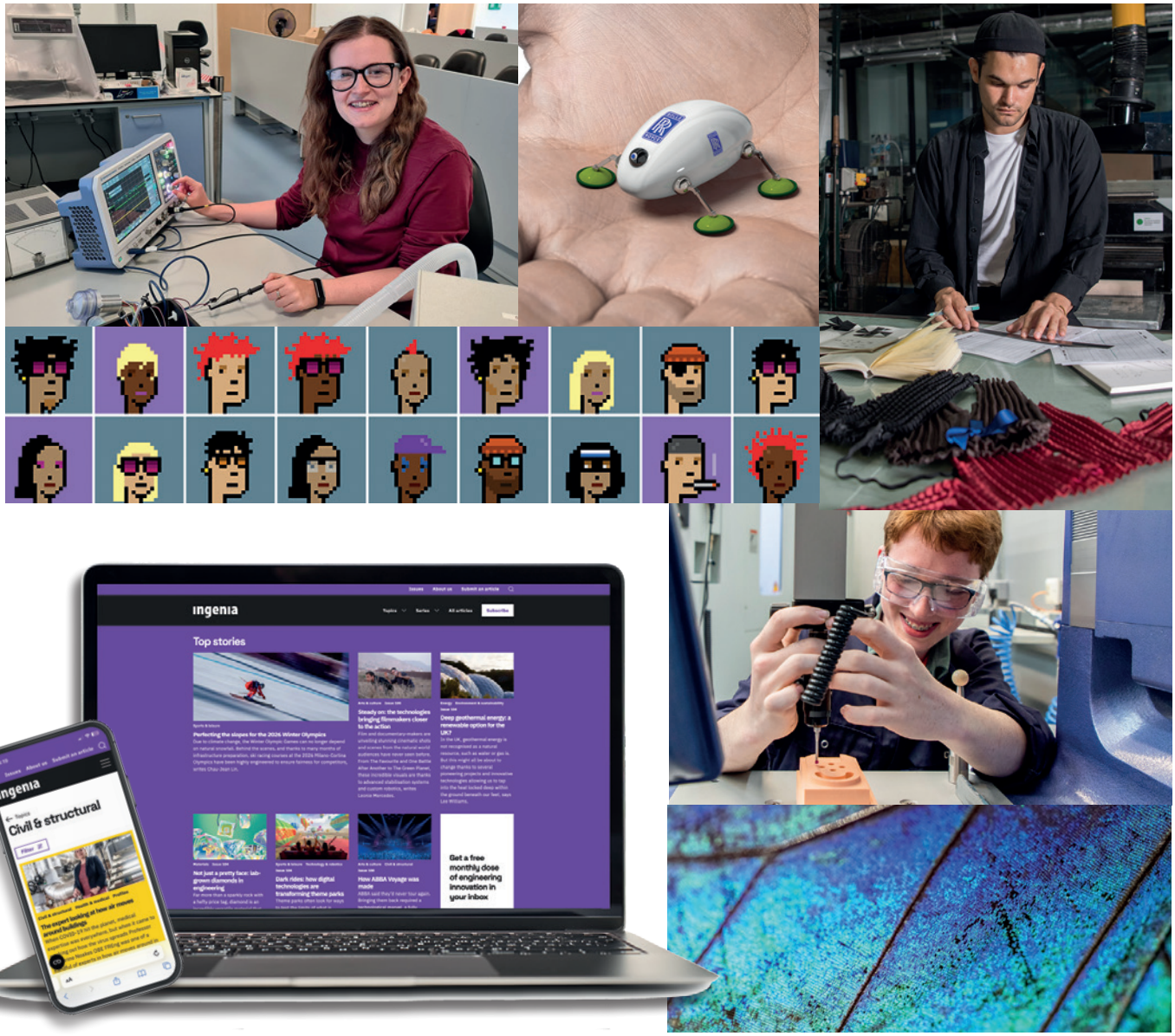
The CRISPR gene editing approach relies on a protein known as Cas that acts like molecular scissors, cutting DNA and allowing genes to be modified or replaced

After it was first published, the technique was hailed as the most powerful and efficient way to modify genes yet. But it is not perfect. The active Cas protein can linger in cells and break DNA elsewhere, potentially damaging unintended genes. In 2019, He Jiankui, a Chinese scientist, gene-edited the embryos of two twins to make them resistant to inheriting HIV from their father. The twins were born healthy, but the downstream effects of gene editing embryos are not yet known. The act provoked huge controversy among the international scientific community and resulted in He being sentenced to three years in prison.

As a result, synthetic biologists are working to make CRISPR gene therapies safer, without these so-called off-target effects. One active area of research is exploring anti-CRISPR proteins, which bind to and inhibit Cas9 after its intended work is done. These proteins are normally difficult to get into the cell because they are large and negatively charged. So, in 2025, researchers from MIT fused the anti-CRISPR protein to a nontoxic component derived from anthrax that could help transport it into the cell. While they showed it increases Cas9's specificity in human cell culture, the approach has not yet been tested in living organisms.

Nevertheless, the NHS approved the first ever gene-editing treatment in the UK in 2024. Based on CRISPR, Casgevy was designed to tackle sickle cell disease and beta-thalassaemia, genetic disorders that deform red blood cells. Clinical trials showed no off-target effects, but patients are being monitored until 15 years after they received the treatment. Johnny Lubin, a US teenager, had been unable to lead a normal life because of frequent bouts of severe pain until he received Casgevy. Two years after the treatment, he told CNN he remained pain-free.

WANT TO FIND OUT ABOUT MORE INNOVATION IN ENGINEERING?



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