ingenia

DECEMBER 2024 ISSUE 101

ENGINEERING A DINOSAUR

A MORE SUSTAINABLE SANTA

TREATING WASTEWATER NATURALLY

THE FUTURE OF ASSISTIVE ROBOTS

USING AI TO PREDICT THE WEATHER

Royal Academy of Engineering

Royal Academy of Engineering

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Front cover
Google DeepMind's award-winning GraphCast technology uses AI to forecast the weather © Benjamin Leon

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WELCOME

Engineering can be found in unexpected places. And often engineers take inspiration from the natural world around them to come up with innovative solutions.

No better is this demonstrated than on page 19, which details how engineers used expert understanding of dinosaur anatomy to create an unsupported bronze skeleton that now stands in the Natural History Museums gardens in London. Likewise, our How Does That Work? article in this issue looks at how the way in which fish swim in schools is influencing projects from energy-efficient wind farms to quieter underwater vehicles.

On page 14, we learn how Google DeepMind used decades worth of data about the weather to develop AI-enabled weather forecasting technology, which could help mitigate the impact of severe weather events and, ultimately, save lives.

People-focused solutions are also covered on page 29, in an article about how AI and robotics can support older people to live independently; while Michael Kenward looks at how engineered wetlands are taking a biodiverse approach to cleaning up our waterways on page 24.

For our Profile, we spoke to the new President of the Royal Academy of Engineering, Dr John Lazar CBE FREng, about his route into engineering – which included a doctorate in history and politics – and his leading roles in entrepreneurship and education.

And in the spirit of the festive season, *Ingenia* also investigates how Santa can make his gift-giving operation more sustainable. Do you have any ideas? If so, please do let us know at **ingenia@raeng.org.uk** or **@RAEngNews** on X using **#IngeniaMag**.

Faith Wainwright MBE FREng
Editor-in-Chief

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IN BRIEF

RADICAL NEW ARTWORK IS A FIRST FOR ENGINEERING

(Left) Manufacturing engineer Alice Kan, with the vibrant wooden artwork artist Kelly Anna designed to honour her technical contributions, tenacity, resilience, and commitment to making the world a more inclusive and better place for future generations. (Right) The digital artwork depicting (left to right) Navjot Sawhney, Dr Shini Somara, Meg Ginsberg, Laura Hoang, and Alice Kan © Kelly Anna

On National Engineering Day, on 13 November, the Royal Academy of Engineering unveiled a striking new artwork of a groundbreaking engineer at its headquarters in central London, as well as a digital artwork of five inspiring engineers selected by the public.

This year's theme of 'Engineering Role Models' aimed to inspire a new generation to see themselves reflected in engineering. In the lead up to the day, the Academy invited nominations for engineering role models from the public, with five ultimately chosen to be represented in physical and digital artworks. According to PSSA UK (Public Statues and Sculpture Association) only about 3% of statues in the UK are of non-royal women, and none celebrate modern engineers.

Macclesfield-born manufacturing engineer Alice Kan played a pivotal role in the manufacture of the COVID-19 vaccine and is now working on vaccines for Ebola. Her statue is not encased in traditional bronze or marble, but instead designed in a modern and vibrant style by visual artist and designer Kelly Anna, who is known for her work on the Paris Olympics and for the England Lionesses. The statue, displayed at Prince Philip House between 13 and 20 November, will later tour around the country to continue inspiring future engineers.

Kelly Anna's digital artwork depicted the four other engineering role models: Meg Ginsberg, a project manager in the wastewater industry who has launched 'Construct Ability', an initiative to help disabled people thrive in construction and engineering; Laura Hoang, a human factors engineer in the nuclear sector committed to inspiring young people, especially girls from minority ethnic backgrounds; Navjot Sawhney, Founder of UK-based social enterprise The Washing Machine Project; and Dr Shini Somara, a mechanical engineer, author and science communicator – and previous Ingenia guest editor – who is passionate about widening participation in engineering. The piece was on show at Network Rail stations including Charing Cross and Victoria.

This year's campaign came at a pivotal moment. New research commissioned for National Engineering Day shows the crucial role of representation in inspiring the next generation, with 80% of respondents aged 12 to 15 naming the importance of having a role model to look up to for personal and career goals. However, almost half (44%) struggled to remember an engineer featured in popular culture and more than half could not name a famous engineer. Furthermore, women still make up only 15.7% of the UK engineering workforce – down from 16.5% in 2023. The lack of visible role models is seen as a key factor in why fewer women are considering a career in engineering.

Alice Kan said about her statue: "Being honoured in statue form is a very unique experience and not something many people can say. I really hope my statue encourages people to understand more about engineering, what engineers do and why it is a great career for anyone who's got a curiosity for wanting to make things work better."

Scan the QR code to bring the statue to life through augmented reality, created by production company Atlantic Productions

FUNDING FOR STUDENTS UNDERREPRESENTED IN ENGINEERING

The Royal Academy of Engineering has recently announced funding support for more than 20 young people to help them pursue careers in engineering.

Working with Sir Lewis Hamilton's charitable foundation Mission 44, the Academy awarded Masters in Motorsport Scholarships to eight engineering graduates hoping to work in motorsport. The eight awardees are the second cohort of students to receive financial and careers support through the programme, which aims to help increase diversity in Formula 1 and the wider motorsport sector. The programme was launched to address a specific recommendation from The Hamilton Commission that Sir Lewis Hamilton MBE HonFREng set up to investigate the underrepresentation of Black people in UK motorsport and the STEM sector.

The MSc Motorsport Scholarship awardees

In partnership with Amazon, it has also awarded Amazon Future Engineer Scholarships to 15 women from low-income backgrounds studying engineering and computer science degrees in the UK. Each will receive up to £20,000 to pursue a degree in computer science or related engineering courses. Amazon and the Academy established the scholarship to help address the underrepresentation of women studying computer science and engineering at UK universities.

FIFTH OF UK WORKFORCE IN ENGINEERING AND TECHNOLOGY OCCUPATIONS

Recent research from EngineeringUK has revealed that about a fifth of the UK's workforce is employed in engineering or technology.

The UK workforce report also found that people working in engineering and technology occupations were significantly more likely to earn more compared to the average across all other occupations combined.

A further 10.2% were working in the industry but not in an engineering or technology focused role – for example, working in HR at an engineering or technology company.

The data pulled together the Office of National Statistics' latest 2023 Labour Force Survey and EngineeringUK's 'engineering footprint'. It also looks at the composition of the engineering workforce, including breakdown by characteristics including age, gender and ethnicity. Employment by region, industry and occupation are also analysed.


© BAE Systems

AWARD-WINNING STUDENTS INNOVATE IN MEDICINE AND SUSTAINABILITY

Olivia Humphreys with Athena, the portable scalp-cooling technology that was the medical winner of the international James Dyson Award

In November, the James Dyson Award announced its two global winners, awarding each £30,000 for solving significant problems of global importance in medicine and sustainability.

The medical winner was Athena, a portable, affordable device to prevent hair loss during chemotherapy, created by 24-year-old Olivia Humphreys from the University of Limerick. Scalp cooling involves applying ice-cold temperatures to the scalp before, during, and after chemotherapy, which can be very painful for patients. It mitigates hair loss by shrinking blood vessels and limiting blood flow to the scalp. Invented after Olivia witnessed her mother's painful battle with cancer, the battery-powered Athena weighs about 3 kg, and consists of a carry case and a cooling headpiece, which fits to different head shapes. It can be used outside hospital, reducing the time patients must spend on wards. It works by using low-cost thermoelectric semiconductors that cool a tank of water, which circulates the cold water around the head via the headpiece.

The sustainability winner was airXeed Radiosonde, a reusable, eco-friendly and nature-inspired weather sensor developed by Shane Kyi Hla Win and Danial Sufiyan Bin Shaiful from the Singapore University of Technology and Design. Unlike current weather balloons, it does not create plastic and electronics waste and descends like a maple seed to avoid aircraft collisions and land in designated collection zones. It also aims to increase the amount of atmospheric data these devices collect, improving quality of forecasting. Shane and Danial prioritised sustainability in their material choice, using balsa wood and foam for the lightweight wing and cowling. Modular components allow for easy replacement and recycling of worn parts.

Sir James Dyson FREng FRS, Founder and Chief Engineer at Dyson, praised the winners for addressing global issues with innovative solutions, reflecting the award's mission to inspire students to take action on pressing challenges. "We started the James Dyson Award nearly 20 years ago to encourage students at university to solve problems. And we've had thousands and thousands of entries since. It's wonderfully encouraging to see how many students have solutions to severe global problems. Instead of sitting back and talking about it, they're doing something about it – and that's what the James Dyson Award encourages. We've got two brilliant winners this year which we're thrilled to support, and I hope the Award will give them a springboard to future success."

Shane Kyi Hla Win and Danial Sufiyan Bin Shaiful work on airXeed Radiosonde, a reusable, nature-inspired sensor for weather forecasting that won the international James Dyson Award for Sustainability

GET INVOLVED IN ENGINEERING

BIG BANG COMPETITION

Nationwide

Know the next space explorer or climate change hero? Have your students got an idea that will transform people's lives? Students aged between 11 and 18 are encouraged to enter the Big Bang Competition. They can explore any topic in the field of STEM and enter their ideas in a range of ways, including drawings, 3D models and video submissions. They can choose from seven challenges and get inspired by themes such as robotics, sports engineering and many more! Entries close on 26 March. To find out more visit **www.thebigbang.org.uk/the-big-bang-competition**

TO BOLDLY GAME

National Space Centre, Leicester
25 to 26 January 2025

Head along to a weekend of tabletop games, role-player games, and immersive STEM and space-themed challenges. Explore the museum's galleries to meet developers, makers, creators and artists. Take a seat to play test games, and buy the best and latest games. To book tickets, visit **www.spacecentre.co.uk/whats-on/to-boldly-game**

DAVID ELDER LECTURE – DR CIARA MCGRATH

Glasgow Science Centre
20 March 2025

Join Dr Ciara McGrath, a lecturer in aerospace systems at the University of Manchester, for this talk on the problem of space debris titled *Can we win the sustainable space race?*. She will be exploring how new, sustainable approaches to space mission design – from lifecycle assessment supported eco-design, to the use of very low Earth orbit – could revolutionise the space industry and ensure that we can continue to provide vital data needed on Earth, while protecting the environment for generations to come. Book tickets at **www.glasgowsciencecentre.org**

VERSAILLES – SCIENCE AND SPLENDOUR

Science Museum, London
12 December 2024 to 21 April 2025

Discover how the Palace of Versailles used science as a tool of power in this new exhibition. From iconic royal residence of the past, to Olympic and Paralympic venue today, the Palace of Versailles is famous around the world for its opulent architecture and rich history. In the 17th and 18th centuries, it also became a major site of scientific thinking. *Versailles: Science and Splendour* will explore the important role science played at the Palace. For more information, visit **www.sciencemuseum.org.uk**

THE WORLD'S FIRST PLANETARY DEFENCE TEST

Royal Institution, London – in person and online
1 February 2025

Astronomers think that there are approximately 25,000 asteroids in near-Earth orbit – and most are yet to be found. Small enough to evade detection, they are capable of large-scale destruction and represent our greatest cosmic threat. Join volcanologist and science writer Robin George Andrews as he reveals how an international team of scientists and engineers are working to protect Earth by rearranging the night sky, using NASA's Double Asteroid Redirection Test (DART). To book tickets, visit **www.rigb.org/whats-on**

HOW I GOT HERE

Q&A

AURELIA BRZEZOWSKA
CYBERSECURITY EXPERT

Aurelia at Staffordshire University's Students' Union Awards, where she won both Department Representative of the Year and Staffs Women in STEM Student Group Member Recognition Award

An Amazon bursary has helped computer science student Aurelia Brzezowska to make the connections and find collaborators to launch a network for women working in tech.

WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE/ ENGINEERING/STEM?

From early on, I was always playing around with technology. I had a knack for taking things apart and breaking them in the process, which meant that I learned a lot about technology and how it works. That drive to get things working also helped me learn programming as I was always eager to solve those pesky errors. That passion sparked further in my GCSEs and carried on to university where I found a love for cybersecurity. Strangely, I'd say the lack of women in STEM motivated me more to succeed as I wanted to become a role model that little me didn't have.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I took a traditional route through my education following GCSEs: A levels and later an undergraduate degree with a placement year. While it was tricky having studied at nonselective state schools in which most of my computing classes had few supplies, I persevered. I continued studying, applying myself and helping other students in my area to get ahead. I wouldn't be who I am today without my hardships and this is just the beginning for me. For anyone reading this doubting themselves... you can do it!

In sixth form I also applied for and was awarded an Amazon Future Engineer bursary from the Royal Academy of Engineering. It is aimed at women studying computer science related degrees, who are from lower-income backgrounds to support them through their studies. It has provided me with an amazing and supportive community, mentorship from Amazon, yearly conferences, and access to opportunities I would not have had before. I'd recommend this scheme to every woman hoping to get into technology!

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

This would definitely be the creation of a UK-based women in tech network called Byte Queens. Some of the community I had met through the Amazon bursary worked together to create a greater network of women in tech around the UK. We've set up resource pages, a website, a dedicated community server and much more for our members. Our team works diligently to create content, share opportunities, highlight role models, create newsletters, and share the

Aurelia (bottom row, far right) at the Bright Network Women in TEC event

latest news in tech. It is open to any woman looking to get into technology and we have an exciting mentorship scheme coming up. My role is mainly community outreach based: I find role models, community members and work on projects such as our monthly newsletter. We're excited to see where this project goes and how many girls we can help achieve their dreams. This is just the beginning!

I love working with the team to inspire women to get into computing and highlighting amazing role models for them. The work everyone has put into it is truly amazing.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

Every day is different, especially where cybersecurity is concerned. Hackers are evolving their tactics on a daily basis and we have to keep up to stay ahead. You're always learning when it comes to tech and STEM and that's the best thing about it.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

Juggling societies, community networks, work and STEM ambassadorship leads to a busy schedule! I work from Monday to Friday 9 to 5, researching recent cyber incidents, catching up with regulations and helping conduct data protection impact assessments. From there on, I attend lots of meetings and catch ups later in the evening to plan events for students in tech. Some days I go to teach students STEM subjects. No day is the same for me, so I have my handy calendar to help with that.

I'm currently completing a placement year at IKEA where I've been getting hands on with a lot of projects and vendors in terms of information security and data privacy. The role varies depending on the day and what needs to be done departmentally. This could be assessing cyber risks, looking at past breaches globally or conducting OneTrust assessments.

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

Grab every opportunity that comes your way. You never know what may spark your love in that field. I had always thought that I wanted to become a software engineer until I found cloud computing and cybersecurity. If you're struggling in engineering, find a support system: the industry is tough and it's hard to make it alone. Sometimes you need someone who can push you towards your goals and motivate you to carry on doing what you love, even when it gets busy!

WHAT'S NEXT FOR YOU?

I will be looking to carry on my career in cloud computing, cybersecurity or information security and finish my degree in the meantime. It's hard to predict the future but I can definitely see the finish line for my undergraduate studies.

QUICK-FIRE FACTS

Age: **20**

Qualifications: **1. Computer science BSc with placement year (due to graduate with a first in 2026!)**
2. Carbon Literacy Certified
3. Linux Essentials Certified (LPI)

Biggest engineering inspiration: **Judith Love Cohen. Her story will amaze you**

Most-used technology: **Amazon Web Services for my next certification!**

Three words that describe you: **Driven, motivated, learner**

OPINION

HOW CAN WE ACCELERATE DECARBONISATION OF OUR ELECTRICITY SYSTEM?

Since taking office in July, the government has been developing its plans to accelerate the decarbonisation of our electricity system, a crucial step on the road to net zero. The scale of this challenge is immense and rapid action is needed to achieve it. Dr Nick Starkey, the Royal Academy of Engineering's Director of Policy and International, sets out the findings of a recent report from the National Engineering Policy Centre advising government on how to go about it.

The government came into office pledging to deliver on five missions. Making Britain a 'Clean Energy Superpower' was one of them, and rapid decarbonisation of the electricity system lies at the heart of it.

We need a more flexible, resilient, and fully decarbonised grid to power our future economy and lifestyle in a sustainable way, expanding over time to at least double its current size. The challenge is enormous. Renewing our electricity system is a major whole-system challenge touching every part of society, and an expanded system is the basis of many other changes: in how we travel, how we heat our homes and offices, and how we power industry – all complex systems in themselves.

It is far from 'business as usual', yet success here will not only support a lower carbon future but can also enhance the UK's global reputation as a nation capable of executing major engineering feats efficiently and effectively.

The National Engineering Policy Centre, led by the Academy, recently conducted a study on what it would take to radically accelerate grid decarbonisation. This work, co-chaired by Sir Patrick Vallance HonFREng (now Lord Vallance) and Dr Simon Harrison FREng, argued that accelerating the previous government's target of 2035 requires more than incremental changes. It demands a radical shift akin to the urgency and innovation seen in developing the COVID vaccine within a year, rather than the usual decade or more. What does that look like in this very different context?

The goal isn't just cleaner energy but skilled employment, cleaner transport, and ultimately, lower energy costs

Firstly, the effort needs a clear vision that resonates across all of society. The goal isn't just cleaner energy but skilled employment, cleaner transport, and ultimately, lower energy costs. These are tangible benefits that connect with the everyday needs we all have, not just abstract ideals.

Strong central leadership is also essential, not to stifle local decision-making but to establish an overarching framework that empowers good local choices and prevents the costs of uncoordinated, fragmented initiatives. Setting up government's 'Mission Control for Clean Power' was an important step in coordinating this national effort.

Decarbonising the electricity system isn't just a policy goal – it's a major infrastructure challenge. It encompasses wind, solar, nuclear and other forms of generation, modernised transmission and distribution, through to demand management and much else. Our study provided a high-level assessment of how to approach an engineering project on that scale, drawn from real-life engineering experience.

Next, the revolution must be digital. Digitalisation will be integral to transforming the system and must be at the heart of how that new system operates. If done right, it can provide consumers with greater flexibility and choice, making best use of the infrastructure we have. However, we must learn from the past: smart meter rollouts have had a difficult journey, and we must do better.

We also need a smart approach to managing costs. The UK has long set a high bar for new investment, often with the goal of keeping consumer costs low. But given the scale of change needed, the risk of stranded assets (those that have been subject to unanticipated devaluations) is now low, and investment ahead of demand is critical to meeting future needs at the pace required. We also need a more proactive supply chain strategy. The transition will place great strain on the supply chain, at a time when many other countries are making a similar change. And while market mechanisms such as auctions have their place, a more proactive supply chain policy that gives industry sight of a substantial long-term order book and clear investment pipeline will enable industry to invest and will reduce the risk of finding ourselves at the back of the queue, which could ultimately cost us more.

Finally, the decarbonisation challenge is another prompt for us to address the urgent need for a larger, more diverse and skilled technical workforce. The Academy is tackling this challenge with its Engineers 2030 project, but scaling up the workforce is not the work of a couple of years. Still, it's a task we must begin now, with better workforce planning to optimise use of the talent we already have.

More generation, upgraded transmission, modernised distribution, low carbon dispatchable power for when the sun isn't shining and the wind isn't blowing, plus a fresh approach to demand management, flexibility and grid stability – it's a lot to take on, and engineering expertise will be vital.

Engineers do more than design and deliver the technical solutions, they have an important role in advocating for this transformation, helping the public understand the scale and need of these changes and ensuring they benefit from them. Decarbonising the electricity system can make energy cleaner and more affordable, but it requires communities to support changes that may impact on them, such as by hosting new or expanded infrastructure nearby. A streamlined planning system, paired with a respectful and inclusive approach to communities, will be crucial here.

There is much that engineers can do. Engineering businesses, from energy companies to SMEs in the supply chain, can advocate for policies that support decarbonisation and follow that through in their own company strategies. Engineering leaders can act as thought leaders within their own profession, and pragmatic collaborators outside of it. And individual engineers have a role too – often the most trusted sources of information and opinion are those we know and respect, and few professionals are respected as much as engineers!

The challenge is immense, but so is the opportunity. Expanding, modernising and decarbonising the electricity system can improve quality of life for everyone – it's an opportunity we should take.

BIOGRAPHY

Nick is Director, Policy and International, at the Royal Academy of Engineering. He directs the Academy's leadership of the National Engineering Policy Centre, which brings engineering thinking to the heart of policymaking, creating positive impacts for society. Nick also leads the Academy's international work, including its Africa programmes, Engineering X missions, and bilateral and multinational relationships that enhance the UK's influence on global issues.

To read Rapid Decarbonisation of the GB Electricity System, *the report published by the National Engineering Policy Centre (NEPC), led by the Royal Academy of Engineering, please visit nepc.raeng.org.uk/enabling-a-decarbonised-electricity-system*

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HOW CAN SANTA BE MORE ENVIRONMENTALLY FRIENDLY?

Santa rides his sleigh with his reindeer around the world delivering gifts every Christmas Eve. Before Christmas, he rides steam trains. Chau-Jean Lin investigates the sustainability of his various modes of transport.

Every December, a small team of volunteers and six full-time staff run the Epping Ongar Railway Santa Special train. With six carriages carrying 250 people, the steam train runs on a line that Transport for London closed 30 years ago. It's part of a very particular British tradition.

This link between Christmas and steam trains is brought to life each year at many similar heritage railways around the UK. Each train plays host to its own Santa throughout late November and December – and burns tonnes of coal on its travels. Should Santa switch full-time to the hay-and-carrot-fuelled, reindeer-powered sleigh with which he travels the globe later in the season? From an emissions standpoint, what's naughty and what's nice?

POWERING A POLAR EXPRESS

At Epping Ongar, Bruce Harvey feeds coal into the engine. "The optimal coal size is a fist," says David Hall, one of Santa's trainees whose job is to sweep the engines. The light from the red-hot fire reflects onto the blackened, coal-covered floor. It's hot, despite the opening in the cab's roof.

Santa's traditional mode of transport is the reindeer-powered sleigh
© Shutterstock

The Epping Ongar steam train during a winter festival of lights © Epping Ongar Railway

Coal is what gets the steam train moving. It generates heat and boils water that is held in the engine, turning it into steam. The steam is then contained in a confined space, creating pressure that moves the pistons in the engine. As the pistons move, the wheels of the cab rotate, pulling along the rest of the carriages. The pressure that the steam creates in the engine is known as power, or work.

John Smith, the driver, says that the engine uses one tonne of coal each day. That's enough coal to drive the engine six miles six times a day. According to Harvey, who is currently stoking the fire, the coal comes to the railway by lorry. Is it sustainable? "Santa can probably get more miles out of a reindeer than we can get out of this engine," says Smith.

Assistant Professor Dana Rowangould of the Transport Research Center at the University of Vermont studies how to decarbonise rural transportation systems. She suggests that Santa should focus on greenhouse gas emissions and travelling more economically to be more sustainable.

The specifics of Santa's operations and the vehicles he uses – whether he makes one trip around the world or has his elves make similar trips – makes a difference to his carbon footprint.

Using a modern electric-powered locomotive over a steam engine would be an improvement for Santa, but Rowangould mentions that it might not be economically sustainable. Her research on electric vehicles in northern mountainous climates suggests that Santa would need a very large battery, a hybrid engine or lots of charging infrastructure

Adding freight like sacks of toys doesn't help, since the weight of toys adds to energy consumption and emissions. Rowengould suggests that if we're concerned about sustainability, we should think about asking for digital products to make his travels more efficient. (I doubt my five-year-old would like this idea.)

Using a modern electric-powered locomotive over a steam engine would be an improvement for Santa, but Rowangould mentions that it might not be economically sustainable. Her research on electric vehicles in northern mountainous climates suggests that Santa would need a very large battery, a hybrid engine or lots of charging infrastructure. "Investing in charging infrastructure for one night is probably not economically sustainable, not to mention the regulatory red tape that Santa would face," she points out. Perhaps reindeer would be better after all.

REINDEER GAMES

Ecologist and research professor Raija Laiho, at the Natural Resources Institute in Finland, studies peatlands, where reindeer graze, and explains that Santa's reindeer do not contribute much to greenhouse gas emissions in the way of methane. Using the national greenhouse gas inventory of Finland, she calculates that each of Santa's reindeer, which she assumes to be female (as she notes that only female reindeer have antlers in the winter), emits about 18.7 kg of methane per year. In comparison, a cow produces three times more methane, at 70 to 120 kg per year.

"If Santa wishes to reduce emissions, he should consider what he feeds his reindeer," she explains. Natural feed is better than processed feed, while seaweed has been shown to reduce methane emissions in cows. "Sending the helpers to collect seaweed might be a good option, if the reindeer could adjust to such an exotic dish."

With a herd of nine reindeer, Santa could capture the methane they produce and convert it to electricity to use in his shop. Assistant Professor Matthew Scarborough of Civil and Environmental Engineering at the University of Vermont works on anaerobic bioprocessing of waste and methane degradation on dairy farms. He suggests that Santa uses an anaerobic digestor.

"I imagine that Santa could feed, not just reindeer manure, but food scraps from the elves and any cookie leftovers that children might give him into an anaerobic digestor." Anaerobic digestors use bacteria to break down organic materials in conditions where there is no oxygen. The process creates a biogas, which is composed of a mixture of gases including methane.

"They can take the biogas and use it for heat and power generation. The electricity can be used to run Santa's shop, and they can generate heat to keep their shop warm in the North Pole. Santa could contribute to a circular economy," says Scarborough.

NAUGHTY OR NICE?

With such strong evidence that his reindeer are more sustainable, should Santa ditch his steam train? "A lot of children have never seen a steam train, and it's all part of their education," says Jeff Mesnard, operations manager of the Epping Ongar Railway. It appears that the tradition of Santa on the steam train will remain as long as people are interested. With some innovation, Santa could also power his trains with captured biogas.

Even so, the argument that Santa's reindeer are more sustainable than his steam train may be too simple. When it comes down to it, Rowangould notes that Santa's delivery of a toy to each child is special and that there is an intrinsic value it. "What we don't want to dismiss is to say his mode of transport should be more sustainable, and you need to decentralise Santa's operations," she says. "Though sustainability is important and there are trade-offs, Santa is also bringing a lot of value. We need to be thoughtful about how far we want to push Santa to be sustainable."

The next time we see Santa on a steam train or want to leave food for his reindeer this Christmas Eve, it's probably best to give him a few extra carrots. If they don't get eaten by his reindeer, at least they can go into an anaerobic digestor.

AI SHAKES UP THE WORLD OF WEATHER FORECASTING

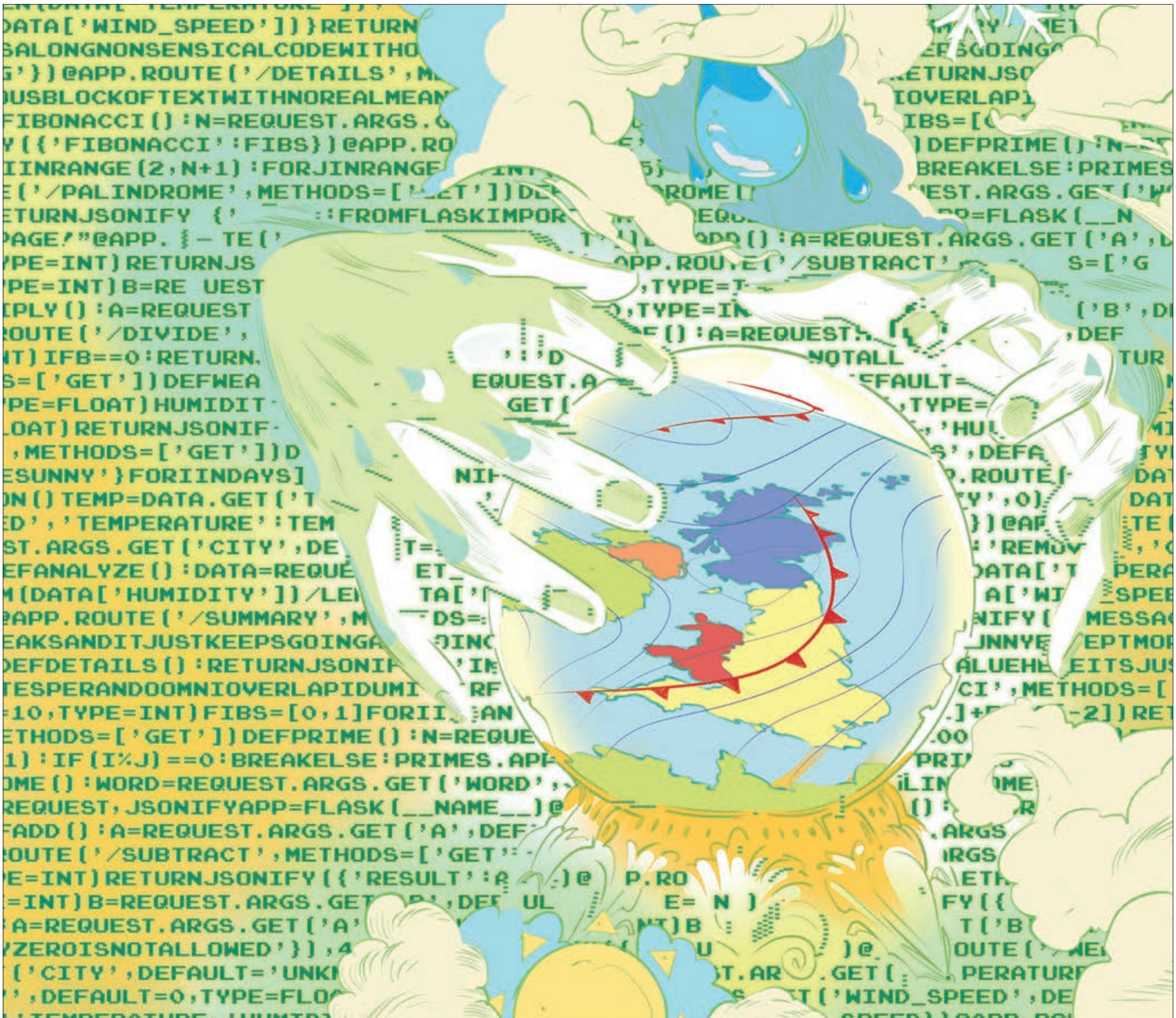


Illustration for *Ingenia* by Benjamin Leon

Did you know?

- Traditional weather forecasts take hours to generate on supercomputers that consume as much energy as thousands of homes
- Forecasts from weather agencies such as the UK's Met Office don't just go to weather apps – they're critical for the aviation and defence sectors
- Data from weather stations, balloons, buoys and satellites all over the world informs the models they use

It has been a banner year for the UK's AI powerhouse, Google DeepMind. Beverley D'Silva reports on how the company's award-winning weather forecasting technology is transforming meteorology and beyond.

The weather is governed by deeply complex physics. And yet, within seconds of swiping open a weather app, we can see a reasonably accurate forecast for the next couple of weeks. On a mundane level, forecasting might support a decision to wear a raincoat or pack an umbrella; in extreme cases, it warns residents in the path of a storm or hurricane to flee.

Forecasts are underpinned by precisely defined equations that attempt to describe the chaos of weather physics. Into these equations goes data continuously gathered from weather balloons, weather stations and satellites around the world. Processing all this data are supercomputers, each of which may consume as much energy as thousands of homes. For once, AI holds a surprisingly less computationally intensive – and less energy-intensive – answer. That's because once it's been trained, it consumes a fraction of the compute power of the massive models run in conventional weather forecasting.

Google DeepMind's AI weather forecasting model, GraphCast, drew widespread acclaim when it was published in late 2023 in the journal *Science*. While not the first of its kind, DeepMind's research showed the model outperformed the gold standard of medium-range weather prediction in 90% of measures. And where traditional weather forecasting methods take over an hour to generate – and require a supercomputer to do so – GraphCast can produce a 10-day forecast in 45 seconds on a laptop.

For this, GraphCast won the 2024 MacRobert Award, the UK's most prestigious prize for UK engineering innovation, presented by the Royal Academy of Engineering. "It's a massive technological leap forward in weather forecasting," said Dr Steve Allpress FREng, who was on the judging panel. "It really is very impressive."

SO FAST, SO GOOD

GraphCast is among a stable of AI technologies developed at Google DeepMind since its inception in 2010. The company has built a reputation for designing AI systems to solve challenges across the board in science and engineering. Most famously, in October 2024, DeepMind's CEO and Co-Founder, Sir Demis Hassabis FREng shared the Nobel Prize in Chemistry with Professors John Jumper and David Baker for their work demystifying and creating new proteins. Hassabis, Jumper and their team had decoded a decades-old biological problem, predicting how proteins fold up into 3D shapes. These structures give us vital insights into diseases and help us design better drugs. Google DeepMind's AI system AlphaFold, released in 2021, predicts protein structures from their amino acid sequences. Scientists worldwide now use AlphaFold to help them study malaria vaccines, and treatments for Parkinson's and Alzheimer's, with more medical challenges on the way.

But if there's one prediction problem people have been puzzling over a lot longer than protein folding, it's weather forecasting. Today, for the lab behind so many AI breakthroughs, GraphCast is one of its proudest projects, aligning with a core DeepMind tenet to build AI systems that benefit everyone.

"The weather affects everything," says Andrew El-Kadi, a research engineer at DeepMind who works on the team that developed GraphCast. "From deciding whether to take an umbrella with you, to potentially life-altering situations like cyclones and extreme temperatures."

"If we can improve the lead time [in which] we can issue warnings for individuals and get them out of harm's way when extreme weather is coming, that's going to save lives," said Dr Peter Battaglia, head of the GraphCast team and weather group, at the Royal Academy of Engineering's *Innovation Incoming* event in October. "We're only going to see an increase in the importance of this as climate changes become more extreme." Events unfolding a matter of days later underscored the significance of these words, as according to Reuters, early warnings of the catastrophic floods in Valencia went ignored by the regional government, leading to hundreds of deaths.

FLUID BEGINNINGS

GraphCast came into being as one step in a longer evolutionary process for DeepMind. Ever the champions of AI in fundamental science, the company was exploring how it could simulate complex physical systems, such as fluids, molecules, astrophysical systems, and power grids. "DeepMind has always had an eye on trying to use machine learning to do physical simulations," says El-Kadi.

Six years ago, Battaglia was leading a team applying AI systems called graph neural networks (GNNs) to modelling the movement of fluids. GNNs learn relationships between data points in both time and space, after being trained on vast amounts of historical data. It was a natural next step to apply the same techniques used for modelling fluids to weather systems – or essentially, how fluids such as water and gases in the atmosphere move over time. "That's really where, two and half years ago, things started turning towards weather," says El-Kadi.

DeepMind's foray into the weather began with a local precipitation prediction system trained with radar data, called NowCasting, before the company branched out to weather on a global scale. To find training data for this, it turned to the European Centre for Medium-range Weather Forecasts (ECMWF), home to the world's largest archive of numerical weather prediction data. DeepMind trained its models with four decades of weather information from ECMWF's high-quality data set, ERA5.

Conventional weather forecasting, such as NWP (see 'Computing chaos'), involves expert meteorologists writing equations that capture the complex physics of weather, which are then solved by supercomputers. Using machine learning, GraphCast builds a time evolution of atmospheric data and learns statistical relationships between the dataset, and what will happen next.

Training costs a lot of energy, but once that's done, AI weather models such as GraphCast can be run very easily – a key benefit. "AI gets lots of criticism for the energy it's using across all the different large language models, but believe me, traditional weather forecasting uses vast amounts of compute and energy," said Professor Penelope Endersby CBE FREng, CEO of the Met Office, who was also on the *Innovation Incoming* event panel. "That is the big advantage, much more than any accuracy gain."

To unlock this potential, powerful hardware would be needed. "To train

COMPUTING CHAOS

By far the dominant approach to weather forecasting today is numerical weather prediction (NWP), where meteorologists create models on supercomputers that describe the way the atmosphere changes. The UK Met Office uses a Cray XC40, which is so powerful it can perform 14,000,000,000,000,000 (14 quadrillion) sums per second.

The Cray XC40 and supercomputers like it rely on data – and a lot of it. Each day, the Met Office receives about half a million data points, including temperature, humidity, and wind speed and direction. It is gathered by sensors in the atmosphere, on land and the ocean surface, and on satellites.

With this data as a starting point, the supercomputer then creates a model of the atmosphere. It fills in the gaps where no data is available, choosing the pattern that most closely matches the data. This is called data assimilation and is "the most complex and expensive part of forecasting", according to the Royal Meteorological Society. Then, the prediction is made: a mathematical model based on physics equations that factor in how air in the atmosphere behaves, as well as the Earth's rotation and the transitions of water into vapour, liquid and ice. Meteorologists attach a confidence level based on probability. They also continually check that the forecast is on track, adjusting it if it's not.

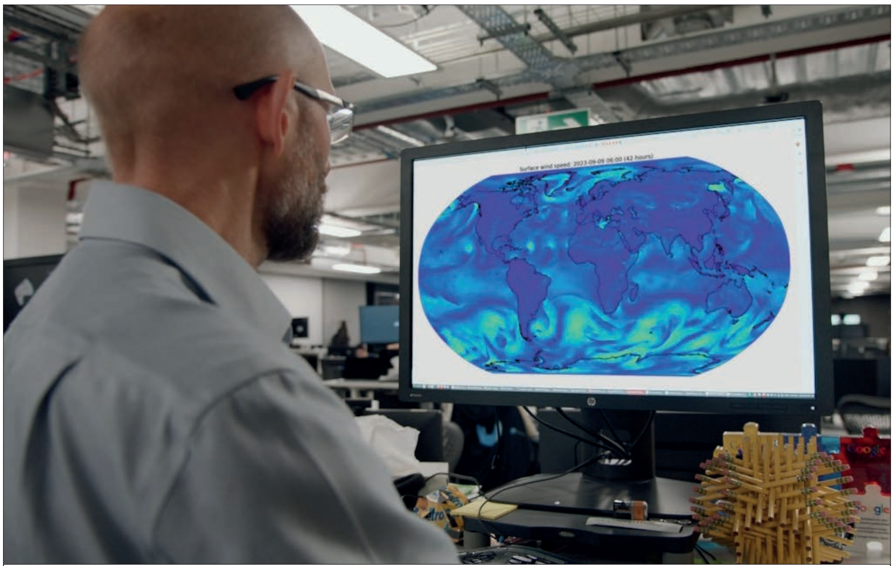
Conveying risks can be a matter of life or death in the case of extreme heat, flooding or a tornado – or even something as simple as needing to grit roads because of icy temperatures. In extreme scenarios, weather experts and other professionals pool their expertise to make decisions. So, despite supercomputers, advanced satellites and AI, we still need human weather forecasters. Their qualities are difficult to replicate: real-world experience and the ability to make observations and connections in a way that algorithms cannot.

these models, we need very specific hardware that is very good at doing the types of maths involved in machine learning," says El-Kadi. "In house at Google, we have our TPUs." The TPU, or tensor processing unit, is a Google-invented chip used for tasks such as machine learning.

In the last four years, these chips have advanced rapidly, making it possible for this hardware to handle monumental amounts of data. Each forecast is made over a million grid points representing the entire surface of the Earth. At each grid point, GraphCast predicts what different variables will be at the Earth's surface and across 37 levels of altitude in the atmosphere. It predicts all of these four times a day for a 10-day forecast, explains El-Kadi. "I think you can see how this adds up to a lot of data."

With so many possible scenarios on the cards, AI needs to be trained to learn how to forecast the weather. To do this, it's asked to predict the weather on two consecutive timesteps (each six hours apart) in the past. "Then we say, you were right here, wrong there. Try again," says El-Kadi. This process, called loss calculation and back propagation, tweaks the model's parameters so it can make better predictions of what the actual weather was in the second step, he says.

GraphCast then takes it a step further, looking at how different points in the atmosphere influence one another. "If you know a cold storm is happening on France's north coast, it's likely that in six to 12 hours' time that storm is going to affect the south coast of England," says El-Kadi. "Weather patterns are quite local, and the cold storm will probably move north." So, they tell the model that the weather on the Earth's surface affects the weather in other places. This is where the GNNs, which excel at learning from spatially structured data, come into their own, as GraphCast then spots connections between points on Earth, to learn how



GraphCast's forecasts cover over a million grid points representing the entire surface of Earth © Google DeepMind

they affect each other when it comes to forecasting the weather.

BLACK SWANS AND HURRICANES

GraphCast's acid test was in September 2023, when Hurricane Lee, a massive tropical cyclone, was heading to the east coast of the US and Canada. Nine days before it made landfall, GraphCast accurately forecast it would hit Nova Scotia. Official forecasts had been hedging on it landing on major northeast cities or missing them altogether.

More accurate hurricane-path forecasting would be a huge advantage for disaster relief. Weather data, coupled with information about where people live, is vital for rescue, explained catastrophe risk modelling expert Dr Joshua Macabuag FREng, also speaking on the *Innovation Incoming* panel. Macabuag was deployed to the Caribbean in 2017 when Hurricanes Harvey, Irma and Maria passed through within three weeks of one another. He and his colleagues didn't know where the area with greatest need would be at first. "If you end up on the wrong island, it could take three or four days to get to the correct one," he said.

Saving lives isn't the only benefit of GraphCast's accuracy. Macabuag is now Co-Founder of Renew Risk, which applies risk modelling to renewable energy. Extreme weather, such as tropical storms and major hurricanes, pose a significant risk to offshore wind farms. Macabuag explained that having greater certainty that potential damages are on the way gives operators time to check control systems, make sure they're protected or stop operations, if necessary.

You might ask, if it's trained on historic data, how can GraphCast forecast extreme weather events unlike anything we've seen before – so-called 'black swan' events? And can GraphCast adjust for climate change causing more unpredictable weather patterns than ever? "I don't know whether we can predict more intense winds than have ever been recorded in the ERA5 dataset," said Battaglia. But, he added, when this does happen in real life, it's important to ensure the learning methods are incredibly efficient, so they can predict them well.

El-Kadi explains that, as it continues to learn from recent weather events, GraphCast can predict the weather more accurately than any other model. This means it can better predict extreme weather, too. "We are constantly updating it as new data comes in," says El-Kadi. "So, it is learning from the impacts of climate change

Satellite images of Hurricanes Lee and Maria above the Atlantic Ocean in 2023
© Shutterstock

and severe weather and is better able to spot patterns and apply that going into the future."

METEOROLOGISTS IN THE LOOP

GraphCast has already had an outsized impact. "I was blown away by how quickly it had been brought to being extraordinarily effective. It's an astonishing example of what engineering can do," said Professor Sir Richard Friend FREng FRS, who chaired the MacRobert Award Committee that chose GraphCast as the 2024 winner.

Because it Is open-source technology, other scientists around the world can use it and tailor it to their needs. Weather agencies are making 10-day forecasts with GraphCast, and it is being run live as an experiment by ECMWF. "You can actually go and see the output on their website," El-Kadi enthuses. Currently, ECMWF is also using GraphCast to inform internal decisions on which warnings to output and send to local governments. The GraphCast team constantly liaises with weather agencies such as the Met Office, which receives GraphCast's outputs; and almost all countries in Europe are members of ECMWF.

So, scientists aiming to understand and predict the Earth's atmospheric phenomena will very much remain in the loop, says El-Kadi. "It's important we're still liaising with expert meteorologists, and that the model is being used to inform policymakers, rather than bypassing their decisions."

At *Innovation Incoming*, Endersby was animated about the opportunities that AI presents for weather forecasting but reckoned we're "nowhere near" a model that can do everything numerical models can. She cautioned that, before weather agencies can rely on them for everything, we need to be certain that they're as trustworthy as traditional NWP. "The level of trust you'd need for the app in your pocket that tells you whether you're going to have a picnic or hang out your washing is somewhat different to the level of trust for when we're routing your plane across the Atlantic or telling you where a nuclear dispersion cloud might go," she said. Meteorologists will run AI models and experiment with them, but only alongside NWP. "Unfortunately, I think I'm going to be riding two horses for quite some time yet."

In a way, the meteorological community is not alone in this. DeepMind published work on a hybrid model in July, which is partly physics-based and partly AI-based. Unlike GraphCast, and like conventional weather models, the hybrid model presents a set of forecasts to capture the inherent uncertainty. It forecasts not only weather, but also longer-term climate metrics over decades.

It's another tool in our arsenal to help us monitor climate change, and reaffirms DeepMind's commitment to its north star. So, too, did the company's recognition from the MacRobert Award judges. "[It] helps serve as a compass for us in a very profound way," said Battaglia, in October. "It says, what you've done here in applying AI to weather was good for society … Keep going, do more of that, bring more people into this mission."

BIOGRAPHY

Andrew El-Kadi is a research engineer at Google DeepMind, working on the Weather effort. He completed his MEng in mathematics and computer science at Imperial College London in 2023. His current work focuses on scaling and operationalising machine learning weather models.

Quotes from Dr Peter Battaglia, Professor Penelope Endersby FREng, Sir Richard Friend FREng, and Dr Joshua Macabuag FREng were taken from the Royal Academy of Engineering's panel discussion Innovation Incoming – MacRobert Award special, 'Weather warnings from AI'. *You can watch it online at* ***raeng.org.uk/events***

Nominations for the 2025 MacRobert Award are open until 31 January 2025.

The bronze replica of Dippy, named Fern, stands in the Natural History Museum's recently transformed gardens © The Trustees of the Natural History Museum

BRINGING PREHISTORY TO LIFE

Creating a freestanding bronze replica of the Natural History Museum's iconic Dippy presented unique engineering challenges, some of which would be solved by looking to nature itself. Leonie Mercedes speaks to the teams involved to find out how they did it.

Did you know?

- Sauropod dinosaurs had very long necks and tails, anchored by their hips, which are effectively cantilevers
- In a living dinosaur, the neck and tail would have been supported by strong ligaments running all the way along the spine
- Engineers looked to this feature of dinosaur anatomy when creating the freestanding dinosaur Fern

As museum exhibits go, it doesn't get more iconic than Dippy. One of the most famous dinosaurs in the world, the 25-metre-long plaster cast of *Diplodocus carnegii* stood in London's Natural History Museum for over a century.

When the museum sought a stunning centrepiece for its new gardens, a bronze replica of Dippy must have been a natural choice, although creating it would take some ingenuity.

The dinosaur would need to remain faithful to the beloved Dippy of old while being scientifically accurate, resist the elements and London air, and – the greatest challenge of all – stand with no visible supports. It's something that's never been done before.

Over the course of three years, a team of engineers, art conservators and palaeontologists collaborated to make it happen, and in July 2024, Fern was unveiled to the public. How did they do it?

A MARRIAGE OF ART AND SCIENCE

"The Natural History Museum was very clear and insistent that Dippy was the thing they wanted to recreate, not the original skeletons," says Adam Lowe, Founder of art conservation studio Factum Arte, which the museum selected to take on the project. "The fact that the Diplodocus was a plaster cast was part of its history."

As a start, the Natural History Museum 3D scanned every last one of Dippy's 292 bones, which Factum Arte used as the raw material for building Fern. However, it wasn't simply a case of immediately casting those bones in bronze – there were many steps to take first.

The team aimed to achieve a pose for the dinosaur that was not only natural and dynamic but also anatomically precise. For the latter, Factum Arte worked closely with the museum's Professor Paul Barrett, an expert on sauropods (large four-legged dinosaurs with long necks and tails).

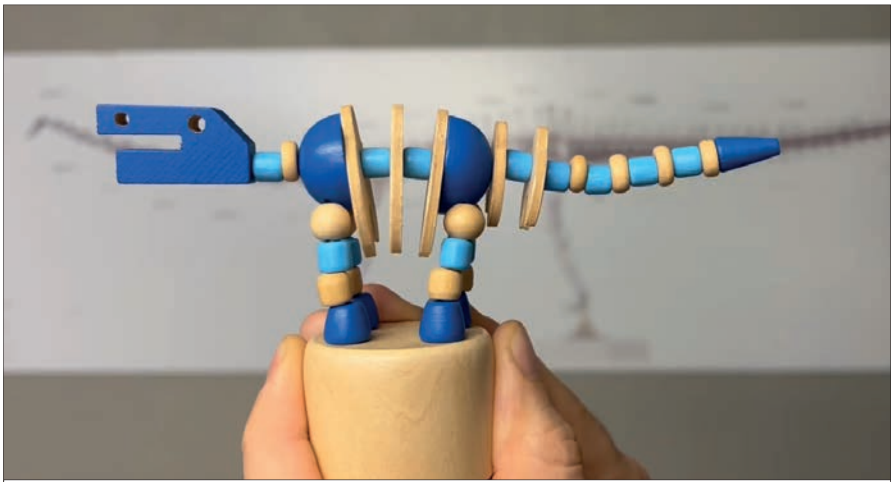
Dippy was first unveiled in London in 1905. Although it had been updated a few times in line with new knowledge about dinosaur anatomy and evolution – once in the 1960s to raise its neck to a horizontal position, and again in 1993 to give its tail that dramatic curve over visitors' heads – there were further adjustments to be made.

Barrett checked each of the bone scans to ensure they aligned with current understanding. Under his guidance, the team flipped one neck vertebra, which had been upside down, adjusted the hips, corrected its slightly knocked knees, and arched the feet. "I like to think that Fern is more accurate than Dippy was," says Lowe.

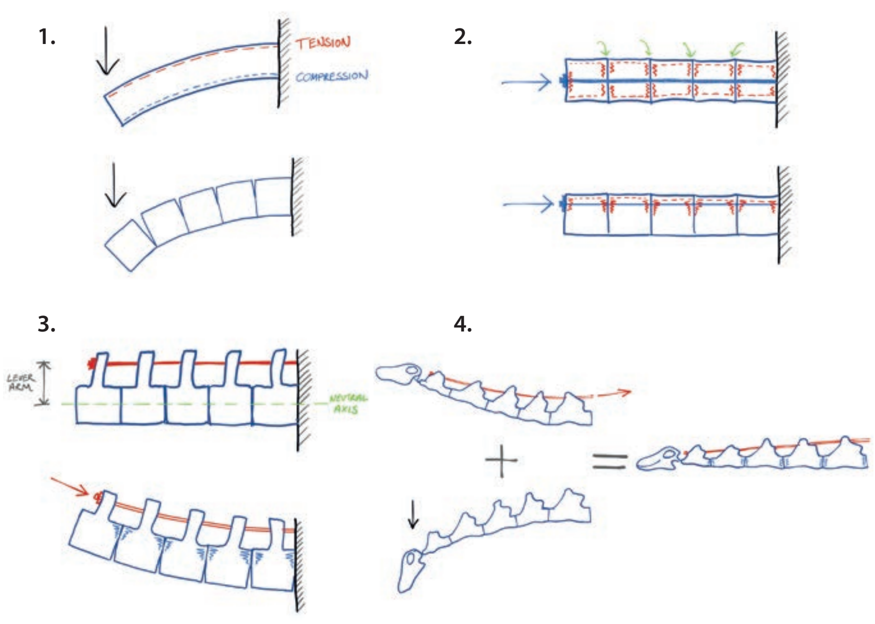
ENGINEERING FINDS A WAY

As well as ensuring the structure was anatomically sound, there was the tricky job of working out how to make a skeleton stand up on its own in the absence of restraining musculature. Factum Arte brought onboard Structure Workshop to oversee the structural engineering side.

Max Clayton, an associate at Structure Workshop, says that studying the anatomy of the dinosaur was key: "It's worth highlighting the amazing natural structure that is the real dinosaur you find after millions of years of natural selection," he says. "Nature



This wooden dinosaur toy is supported by cords that run through its wooden beads, just as Fern's body is supported by a steel bar running through its spine
© Structure Workshop



1. A continuous beam will go into tension and compression when it bends. A 'beam' made of separate elements cannot form tension and will simply fall apart. 2. A bar or cable under tension will pull the separate pieces together, compressing them. It is more effective if the bar is in the area at the top, where tension forms. 3. Moving the bar even higher increases its effectiveness – like a lever. It bends the beam upwards. 4. This upwards bending can be calibrated to cancel out the downwards bending due to gravity. Stresses and deflections are reduced © Structure Workshop

has come up with a lot of these solutions in a really elegant way."

To borrow from the language of structural engineering, both Dippy's long neck and tail are cantilevers – each is supported at only one end. In the living dinosaur, they would have been held aloft – seemingly impossibly – by strong ligaments that run all the way through the spine. These ligaments were anchored to the hip, letting the dinosaur hold its neck and tail horizontally without effort.

One of the most challenging parts of the process was thinking up a design concept to hold the structure together. Welding together the individual pieces was a no-no: "The complex biological form would have made the welding really difficult and it would be hard to actually inspect whether the welds had been done properly or not," Clayton says. A single weld failure could be disastrous, causing the entire structure to collapse. "As engineers, we want solutions that we're comfortable with, so we can sleep at night."

The team had thought long and deeply about how to get the prestressed tendon system to work. The winning approach – which came to Clayton as a flash of inspiration while he was sitting in a plane on a runway, about to go on holiday – built on an earlier idea, and might now sound familiar. "It was similar to that natural solution, where all the bones are individual pieces, and they're held aloft and held together with thin steel, we call them tendons."

There are two tendons running along the length of the spine, just like those ligaments in the living dinosaur. The lower tendon runs through the centre of the vertebrae, which joins them together, while the higher one provides structural support. The bones are threaded together "like beads on a string". (see diagram to the right.)

The main and dominant forces Fern undergoes are – unsurprisingly – because of its weight. However, there was another factor to consider: people. "It's outside in a public setting," Clayton says. "If someone were ever to climb up the legs and hang on the tail, you wouldn't want it to be a danger to the public and to collapse."

The tendons were prestressed to prepare the entire structure for the stresses it could expect throughout its lifespan (bridges undergo a similar process to prepare them for loads). In Fern, prestressing meant tensioning –

MAKING (PRE)HISTORY: THE CRYSTAL PALACE DINOSAURS

Just eight miles southeast from the Natural History Museum in Crystal Palace Park stand what are thought to be the world's first ever actual-size dinosaur replicas.

Although they're now perhaps best known for their anatomical inaccuracies, the 30 dinosaur sculptures at Crystal Palace Park, which include a squat Iguanodon and a hunchbacked Megalosaurus, were – just like Fern – based on the best palaeontological understanding of the time.

Sculptor Benjamin Waterhouse Hawkins worked closely with palaeontologists – including Richard Owen (who coined the term 'dinosaur', and was the driving force behind the founding of what is now the Natural History Museum) – to create the dinosaurs. He was meticulous in his work, following the literature, examining the fossils himself, and consulting with the experts when any judgements had to be made, such as about the texture of their skin or how long their toenails should be.

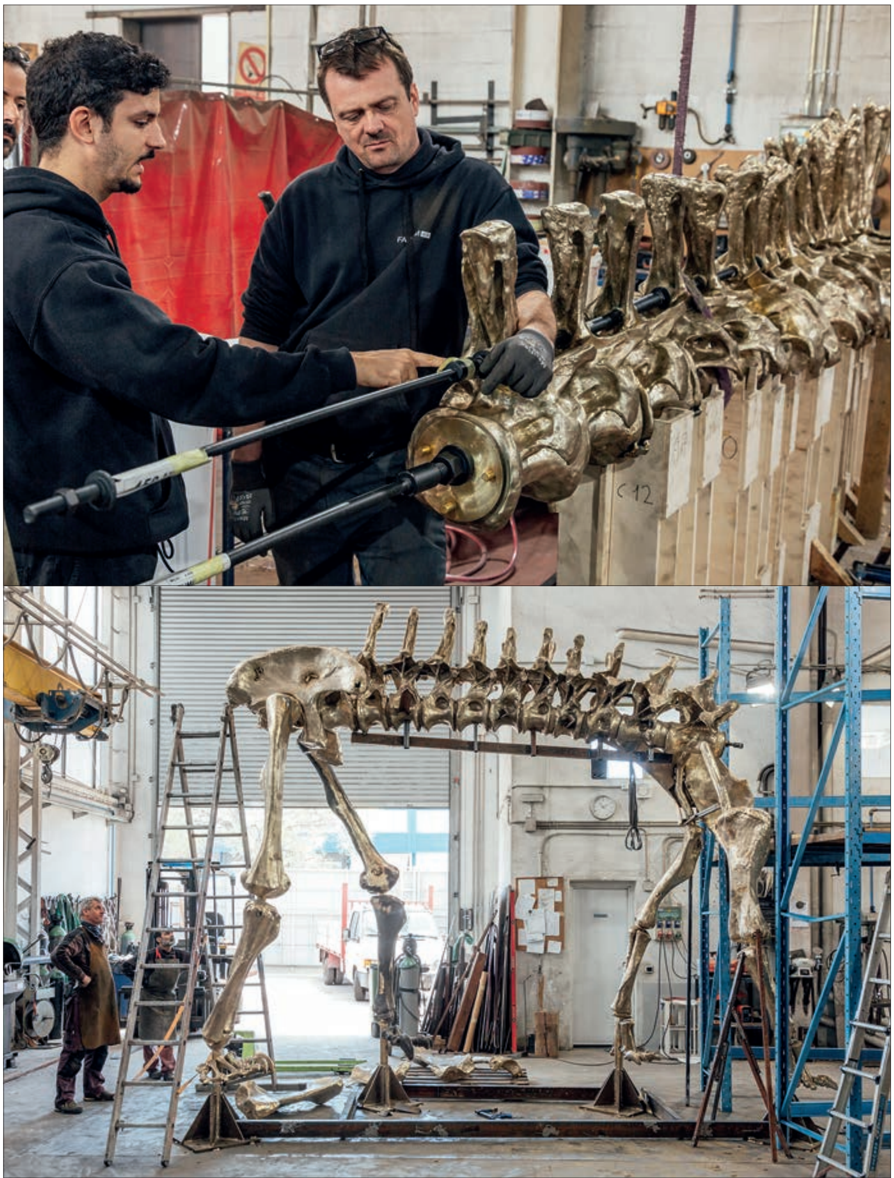
The form of many of the dinosaurs was extrapolated from a few bones, with familiar reptiles filling in the knowledge gaps, and so as more dinosaur skeletons emerged from the ground around the world (and crucially, more near-complete ones), the creatures of Crystal Palace, which opened to a delighted audience in 1854, fell rapidly out of date.

Now Grade I listed, the Crystal Palace dinosaurs remain largely as they were in the 1850s (though they've had a few facelifts over the years). Recent funding from the National Lottery to the tune of nearly £5 million will go towards the ongoing preservation of this loved relic and vivid look at the dawn of an exciting new science.

stretching – the tendons. As the tendon contracts again, it pushes the bones together, compressing the bronze, which closes up the gaps.

It's about striking a balance and optimising the level of prestress: "What we want is for the compression from our prestress to overcome any tension that would naturally form in our structure from just the bending due to external forces like gravity," Clayton explains.

The team used a computer method called finite element analysis to predict how the structure would behave under different stresses. It used computer models from the very start of the project to test ideas and work out what structural approaches to supporting the loads would work.



Assembling the dinosaur: (top) the team at Factum Arte check the vertebrae; (bottom) the dinosaur comes together in Madrid © Oak Taylor-Smith | Factum Arte

BONE BY BONE

While it's the steel tendons that hold the pieces together, the bronze bones – and especially the flat bearing faces between them – also play an important structural role. These bearings undergo huge compressive forces as the tendons squeeze them together, and must be able to take yet more stress given it takes pride of place in a public space. For this reason, the bones and their bearings had to meet exacting standards. "We had to make very, very complex moulds," Lowe says, adding that many of the casts were made at Factum.

The vertebrae had to be made in two halves, and again the team took inspiration from dinosaur anatomy. Their bones were filled with air sacs – similar to birds today – with a thin scaffolding of internal struts to prevent the bone from collapsing inwards. Fern's bronze vertebrae are hollow, with an 8-millimetre-thick wall and strengthening fins within. "We had to bring in the internal ribbing so that they could take the compressive strength," Lowe explains.

Successive castings, from the 3D prints on which the first moulds were based through to the ultimate bronze 'bones', introduced distortion. Therefore, before assembling the dinosaur Factum Arte had to compare the bronze casts to Structure Workshop's virtual model and make final tweaks so that they would perform as expected.

Fern's bones are cast in bronze, a material chosen for its durability, resistance to corrosion and the fact it's very, very long-lasting. The tendons are solid, high-strength, stainless steel bars made by Sheffield-based company Macalloy. The bars curve slightly with the dinosaur's spine, and step down in width from 20 millimetres at the base of the neck and tail, to 16 millimetres, and finally to 12 millimetres – about the width of a little finger – at the head and whip of the tail. "The only thing that would be strong enough to hold all those forces from the great weight of the bronze neck and tail would be a really, really high spec stainless steel… that's why we had to get specialists to make those elements," Clayton says. "They are the key to the entire structure."

It took about three months to assemble Fern in the Fademesa foundry in Spain. "The assembly of the dinosaur was quite awe inspiring," Lowe says. "You've got all these vast bits that are being fitted together, but with incredible tolerance, very low levels of tolerance." The pieces were tightened in place using a hydraulic jack.

After three years of collaborative effort, Fern stood for the first time.

Fern's skeleton is made of individual casts of the 292 bones that comprise Dippy, a plaster cast of several dinosaur fossils unearthed in the late 19th century © The Trustees of the Natural History Museum

Following some final tests, and inspections by Keith Jennings, the museum's Director of Estates, Projects and Masterplanning, and Eleanor Cornforth, a project manager involved in the gardens' transformation and Fern, it was time to pack for London.

FERN MEETS THE WORLD

One night in 2024, art handlers Mtec Fine Art installed Fern in its new home at the front of the Natural History Museum. "Fern is a masterpiece of engineering, and a true testament to the expert collaboration between the Natural History Museum, Factum Arte, Fademesa Foundry in Madrid, and Structure Workshop," says Jennings. "Watching as Fern was put into place in the gardens and assembled in the dead of night – another technical feat of ingenuity – was an incredible scene to witness. For many, visiting Dippy in the Museum's halls is a core memory. Now, Fern is a permanent homage that takes pride of place in our gardens, inspiring visitors to think about the world around us and its history before they even enter the galleries awaiting them inside."

In July 2024, Fern was presented to the public for the first time and finally received its name. Its dynamic pose, courtesy of the graceful curves of the neck, back and tail, the invisible supports, as well as its garden setting, give the overall impression – 150 million years after its heyday – of a creature that lived.

The bronze of its bones has been left untreated, allowing the now burnished vertebrae to mature and darken with time. "It's picking up its own character within the garden," says Lowe. And Fern is expected to stand in the museum's gardens for about 100 years.

Like Dippy before it, Fern could inspire generations to come. "I love the idea that something like 100 million children are going to pass by that dinosaur in the next decade," Lowe says. "Even if we get just 1% being awe-struck and awe-inspired, it would be a very meaningful project."

Clayton recalls the impression Dippy had on him as a child: "I used to go to the museum all the time as a child, and I remember being so inspired by Dippy," he says. "To be working on this is a real dream come true."

BIOGRAPHIES

Adam Lowe was trained in Fine Art at the Ruskin School of Drawing in Oxford and the Royal College of Art in London. He has been an adjunct professor of the MS in Historic Preservation at Columbia University, New York, since 2016. In 2019, Lowe became a Royal Designer for Industry, awarded by the Royal Society of Arts. He has written extensively about originality, authenticity, and preservation.

Max Clayton leads his own design team within Structure Workshop, with a focus on technical innovation, geometry and low-carbon design. In 2024 he won the Nethercot Prize for his paper on the engineering behind Fern, and his recent retrofit project, Yorkton Workshops, won *Architects' Journal*'s Retrofit of the Year Award 2021.

WATER TREATMENT TURNS TO NATURE

The UK's water industry recently began to introduce surface flow wetlands as a natural way to treat wastewater. An early flagship project was on the River Ingold in Norfolk. Implemented by Anglian Water jointly with the Norfolk Rivers Trust and launched in 2019, the Ingoldisthorpe wetland is a part of the local wastewater treatment system © Joseph Gray WWF-UK

Releasing treated wastewater into rivers and lakes is usually a bad idea. However, if done in the right way, nature can clean up after us. New regulations on river pollution and biodiversity, along with a need to move towards net zero, have prompted water treatment engineers to build wetlands where plants and microorganisms filter out pollutants, leaving water clean enough to flow into rivers without doing any damage. Michael Kenward OBE looks into how they are being deployed across the UK.

Did you know?

- Wetlands can be engineered to store and clean up surface and road runoff before it gets into treatment plants or rivers
- Wetlands can also be designed to clean agricultural and industrial wastewater
- Phosphorus is just one of a raft of pollutants that wetlands can be designed to trap, as when excessive amounts end up in waterways, it can cause algal blooms that drain the water of oxygen, killing wildlife in the process

Hardly a day goes by without a reminder that water management is a sensitive subject. A particularly contentious issue is river and sea pollution from wastewater treatment facilities. The National Engineering Policy Centre's recent report, *Testing the waters: priorities for mitigating health risks from wastewater pollution*, investigated the role of engineering in tackling wastewater pollution to reduce exposure to human faecal pathogens. As the report says: "Our wastewater system is, at its core, an asset for the protection of public health, and it has been remarkably successful, including interrupting the transmission of major epidemics and protecting the environment by treating wastewater before it is returned to our rivers and seas." The challenge now is to adapt how we treat wastewater to meet growing demands and changing aspirations.

An increasingly popular tool that water engineers are employing comes under the general umbrella of treatment wetlands. In essence, these engineered wetlands enlist nature to clean up after us. At its simplest, a wetland is a stretch of shallow water and plants where natural processes capture pollutants and keep them out of rivers and drinking water supplies. Engineers have created numerous artificial wetlands in the UK over the past 20 years or more, which have been cleaning up rivers and road water runoff, for example. In 2000, the Constructed Wetland Association was established to spread the word about the concept. And in recent years water companies have investigated engineered wetlands for processing wastewater after we have flushed it into the network of 'sewage farms' around the country.

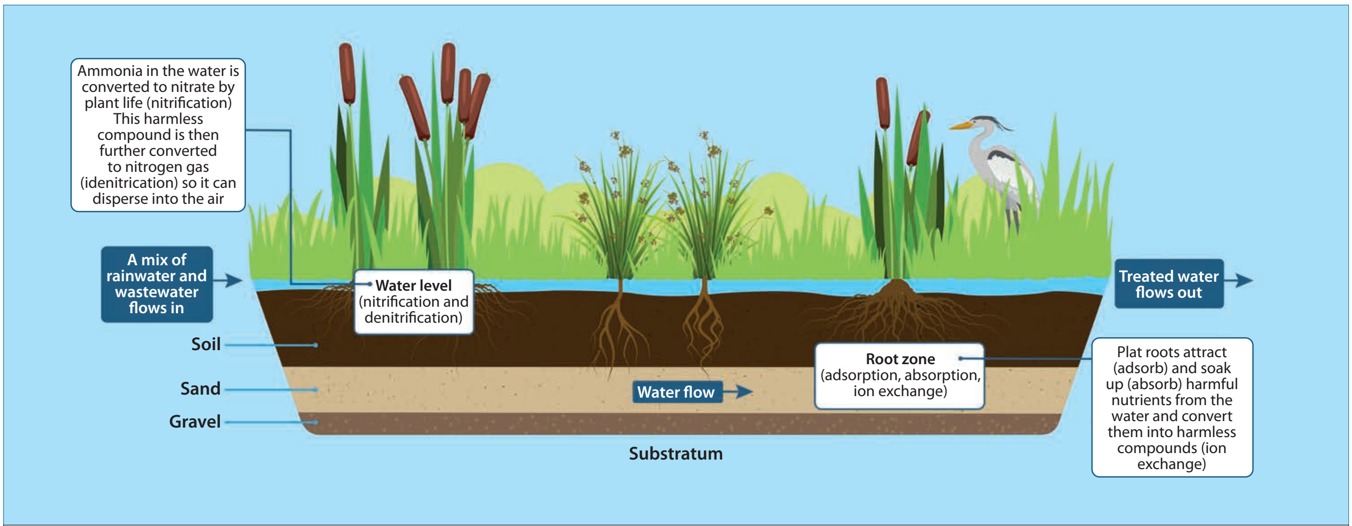
The Environment Agency (EA) sees engineered wetlands as an emerging approach for wastewater treatment. The agency's view is that "understanding the effectiveness of wetlands for nutrient removal is a rapidly evolving field of research where there are still evidence gaps which need to be understood". The EA currently permits water companies to implement treatment wetlands for storm and nutrient removal on a trial or pilot basis.

POLLUTION ON THE AGENDA

The growing interest in engineered wetlands for wastewater treatment is a response to new standards that the industry must meet to deal with pollutants from sewage processing plants. Phosphorus in particular has floated to the top of the wastewater treatment agenda. Phosphates pass into wastewater in human waste and detergents. Some estimates suggest that nearly 98% of the phosphorus consumed by humans in urban areas ends up in sewage sludge. Approaches used in conventional wastewater treatment, such as chemical dosing, remove much of this pollutant. In 2010 the government passed legislation that aimed to reduce the level of phosphates in detergents sold in the UK, but unacceptable amounts of phosphorus still get into waterways. This flush of nutrients into rivers and lakes encourages eutrophication – a rapid growth of microorganisms that drains the water of dissolved oxygen, killing fish and other wildlife. In effect phosphorus fertilises the growth of algae, leading to the 'algal blooms' that turn rivers green, a process bolstered by increasing water temperatures.

In a move to reduce how much phosphorus enters rivers from water treatment plants, in 2022 the Department for Environment, Food and Rural Affairs (DEFRA) released new standards specifying that by the end of 2024 water companies must reduce phosphorus levels in wastewater to 0.5 mg/l (milligrams per litre). Since 2020, the EA has had the ability to impose limits down to 0.25 mg/l on water company discharges. To reach this lower limit, water companies are investing in new ways of treating wastewater.

One chemical dosing approach to remove phosphates involves treating water by adding iron. This reacts with phosphorus, forming a solid precipitate that can then be filtered out. However, chemical dosing has several drawbacks. One is the unpredictable cost of the dosing chemicals. There are also questions about the availability of these chemicals. According to Mott MacDonald, which manages the development of water treatment facilities, "the global production of ferric sulphate and ferric chloride is not sufficient to provide for demands and there is significant concern from all water companies surrounding the supply of these chemicals". Dosing also creates additional solid waste that must be taken away by road, adding to local traffic. And it gets progressively harder for chemical processing to remove phosphorus as concentrations decline. Finally, extra chemical processing uses more energy, another unpredictable cost.



Engineered wetlands can act as nature's water cleaners. Plant roots take up some phosphorus while naturally occurring bacteria absorb more phosphates in the form of adenosine triphosphate. Water emerges from the wetland with a reduced load of unwanted chemicals © Southern Water

A NEW APPROACH TO WATER TREATMENT

The drawbacks of traditional treatment and other factors have prompted moves to use 'nature-based solutions' to meet social challenges. In its 'strategic priorities' for Ofwat, DEFRA has specified: "We want Ofwat to enable and encourage the increasing use of these nature-based solutions." Water companies see wetlands as an increasingly attractive way of achieving this. In wetlands, plants and microbial activity take over from chemical processing to remove phosphorus. Plant roots take up some of the phosphates while bacteria that are naturally present in the wetland absorb phosphates in the form of adenosine triphosphate (ATP), a molecule that all living cells use for energy.

The most obvious sign of a wetland is its plant life. But Dr Gabriela Dotro, Principal Research Fellow in Ecological Engineering at Cranfield University's Centre for Water, Environment and Development, says that while plants do filter out solids and provide shade to prevent algal blooms, they play a minor role in the direct uptake of pollutants. Plants are there mostly so that microorganisms can attach to their roots. "Most of the pollutant processing is performed by microorganisms and soils, sediments and substrates." She has described constructed wetlands as "engineered systems designed to optimise processes found in natural wetlands, producing treated water and a multitude of additional co-benefits including biodiversity, amenity and aesthetic value".

Dotro leads an industry-funded project at Cranfield gathering evidence to improve the design tools available for wetlands, to achieve predictable effluent concentrations of phosphorus. The first stage of the project involved analysing data from around the world on the use of surface flow wetlands for phosphorus removal. For example, Ireland has pioneered the use of so-called integrated constructed wetlands (ICW) for water treatment plants. "What the Irish have done," says Dotro, "is create a flowsheet [flowchart] with a primary settling tank that is followed by a number of surface flow wetland cells or units. The wetlands are designed with the principles of integration into the surrounding landscape and using local materials wherever possible. They look like natural wetlands and provide habitat for a range of wildlife."

Since 2004, Ireland has seen a steady increase in the use of ICWs. These constructed wetlands were originally developed for farms and then expanded to sewage applications. Irish constructed wetlands have also featured in cleaning water from urban runoff and industrial wastewater. For example, the Irish consultancy VESI Environmental has created about 200 ICWs across Ireland and Europe. It was behind the development of a wetland system to treat wastewater from a potato processing plant at Palmerstown, Oldtown, in North Dublin. VESI has even adapted the concept for homes that are not connected to a municipal wastewater network. Adding constructed wetlands to traditional septic tanks can even create a 'water feature' while cleaning up domestic wastewater. ICWs are now finding their way into the UK's water treatment systems. Yorkshire Water installed an ICW at its Clifton Wastewater Treatment Works, near Doncaster in South Yorkshire, which came into operation in 2022.

Wetlands for water treatment come in various guises. For example, in West Sussex, Southern Water is building a wetland close to the wastewater treatment plant in Bosham near Chichester to cope with heavy rainfalls. As Joff Edevane, Pathfinder Delivery Lead – Wetlands & Harbours with Southern Water, says: "We're also looking at wetlands to treat storm overflows." In winter months, rainwater can overload Southern Water's local network of pipes. After periods of heavy rain, groundwater seeps into local sewers, overwhelming the wastewater treatment plant's capacity. When this happens, a mixture of rainwater and sewage can end up in local waterways. As a part of the government's storm overflow reduction plan, the Bosham wetland is designed to keep rainwater out of the treatment plant. "These overflows can continue for days or months after it rains," says Edevane. Using a wetland to keep rainwater out of the sewage can stop this from happening.

For its first engineered wetland alongside a water treatment plant, Southern Water is creating a series of four ponds, or cells, in a 3.2-acre field in the village of Staplefield. The field's clay undersoil stops polluted water from seeping into the groundwater and eliminates the need for liners.

The existing treatment works feeds water into the wetland. It then flows under gravity through weirs between the ponds. Water tolerant plants and naturally occurring microbes capture contaminants.

Cécile Stanford, Southern Water's Project Manager, describes this as "a really important project that will have clear benefits in improving biodiversity and is a natural way of treating wastewater. This project will also help educate future generations about the benefit of wetlands."

Wetlands can also process discharges from smaller wastewater treatment facilities even when there is less risk of added rainwater. The UK is dotted with hundreds of small processing plants that handle wastewater from a few hundred houses. In one experimental project, Southern Water recently started work on its first ICW to 'polish' the outflow into a local river from wastewater treatment. The new project is near the small West Sussex village of Staplefield. Southern Water already operates a wastewater treatment plant just outside the village of about 200 residents. The idea is that water will flow into a new ICW created in a field alongside the existing works. The main contractor for the project, Mott MacDonald, describes the Staplefield ICW as "one of the first projects of its kind in England". It says that the wetland will reduce total phosphorus discharge concentrations from 2 mg/l to 0.5 mg/l.

CLEANER WATER, NATURALLY

There are two main variants of wastewater treatment wetlands built alongside smaller treatment plants. Where there is limited space, the answer can be to install an aerated wetland. This entails growing reeds in a concrete box with an aeration grid beneath them. "They're quite an intensive process," says Edevane. Aeration grids have a smaller footprint in terms of land use, but they use more energy. "We don't want to use those," says Edevane, "But if that's the land you've got available, you cut your cloth accordingly."

Where there is enough land, as in Staplefield, the alternative is to create a variant of the ICW in what the water industry calls surface flow wetlands. These wetlands are outwardly low tech. You could say, you're just digging a hole to act as a water store, which will then do some treatment, says Edevane. But there is more to it than that, he adds. "We look at the local geology, the local plant community and say, 'If there was a wetland here naturally, what kind of plants would it have?' Then we create that." As Dotro explains: "You need to provide planting media, plants, design it for the right residence time for the pollutant you are targeting, and so on." The idea, says Edevane, is that "if you walk past them with your dog, you wouldn't know that they were anything to do with sewage treatment, apart from the fact there's a sewage treatment works next to it."

When Southern Water assessed the site for its Staplefield wetland, it found that it sat on clay. This makes it possible to create a natural liner simply by moving clay around to create the wetland. The clay's impermeability prevents treated water from leaking into groundwater. For its first free-surface ICW, Southern Water called on VESI for design advice. It came up with a series of four ponds, or 'cells'. Over time, treated sewage flows through the sequence of cells. Operators manage the wetland by controlling the water flow through the cells. In this case, there is no need to put water through a chemical processing plant or aeration grids as gravity does the work. The details depend on the layout of the wetland. If there is a series of cells, weirs will automatically control the water flow between cells. These weirs can also be lifted or lowered manually for maintenance or when operators want to keep some water in the cells to avoid them drying out for too long, in a hot summer for example.

After the treated water has travelled through the ponds, it is pumped back into the effluent chamber in the existing waterworks before discharge through its outfall into the local river.

ENHANCING THE NATURAL ENVIRONMENT

The rise of wetlands is also linked to new government regulations that require new construction projects to increase biodiversity (see 'Engineering biodiversity', *Ingenia* 91). Mott MacDonald points out that: "Wetlands support about 10% of all wildlife species in the UK, including birds and plants, so creating a wetland habitat will enhance biodiversity." In the case of the Staplefield wetland, it will be on farmland that was prone to becoming waterlogged, thanks partly to the clay that makes it easier to create a wetland. According to Mott MacDonald, replacing farm crops with a wetland is a "significant improvement in biodiversity".

It isn't just water pollution and biodiversity that water industry has to consider, there is also increasing awareness of its carbon footprint. Edevane points out that digging a wetlands means no need for concrete. "If we don't have to pour concrete, it's a lot less carbon." In its Whole Life Carbon assessment of the Staplefield wetland, Mott MacDonald compared the wetland with two conventional alternatives. This showed that "carbon emissions are significantly lower for the ICW than for the other two conventional solutions".

The wetland approach to wastewater treatment isn't just good for biodiversity, a wetland can remove pollutants that are beyond the reach of chemical dosing with iron to remove phosphorus. Let nature have its way and a properly engineered wetland can reduce nitrates, for example. "You might get rid of some metals," says Edevane. "You might get rid of some ammonia. It's a whole range of things that it does. So for just one piece of technology, you're getting five or six hits." This is one role for the pioneering wetland at the Ingoldisthorpe Water Recycling Centre, which Edevane installed for Anglian Water with Norfolk Rivers Trust and Rivers Ecology.

One Irish project investigated the ability of ICWs to remove antimicrobial resistant organisms from farm wastewater. Agricultural use of antibiotics is implicated in the spread of antimicrobial resistant to humans. In Denmark, another group has carried out lab experiments to show that wetlands might be able to remove micro- and nanoplastics from water.

In another project, which has received funding from the Royal Academy of Engineering, Cranfield University has helped two Jordanian pharmaceutical factories to build pilot-scale wetland systems for their wastewater treatment. The final effluent from the systems complied with Jordanian industrial wastewater reuse standards. The team is now seeking to implement the technology to help protect water resources in this water scarce country.

These may be early days for constructed wetlands for wastewater treatment in the UK, but if the concept catches on, we may get used to walking our dogs around the local water treatment facility. For that to happen, the trials now underway must prove their value. The EA says that wetland trials will operate for at least three years: "We continue to assess results from these trials and use this information to inform and improve our regulatory approach to wetlands. The use of these wetland trials allows the Environment Agency to obtain data on the efficacy of wetlands for nutrient removal and to understand performance, using a safe and controlled approach."

BIOGRAPHIES

Dr Gabriela Dotro has worked with treatment wetlands for over 20 years across four countries. She is the current Chair of the Constructed Wetland Association and has served for over 10 years at the International Water Association's specialist group on wetland systems for water pollution control. She is passionate about nature-based solutions for water management and combines her knowledge of traditional engineered technologies with engineered wetlands to create synergies for the benefit of people and the environment. She is always happy to talk nature-based solutions and you can easily find her on LinkedIn.

Joff Edevane has an MSc in inland fisheries and water quality from the University of Hull. He has followed a career in environmental regulation and planning in the water industry. At Anglian Water Services he was responsible for the Ingoldisthorpe wetland project in Norfolk. As Pathfinder Delivery Lead Wetlands & Harbours at Southern Water he now manages an extensive network of wetlands projects in the south east of England.

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THE FUTURE OF ASSISTIVE ROBOTS

Robots have made their mark for 'dull, dirty and dangerous' tasks, as the saying goes. But when it comes to working closely with people, there's still a way to go. Dr Gerard Canal explores the future for assistive robots designed to help older people live independently for longer.

Maintaining fusion reactors. Scaling wind turbines in the North Sea. Packing online shopping orders. Welding parts onto cars in factories. Scouring the surface of Mars for signs of ancient life. So far, robots have passed all of these tests with flying colours, whether they're wheeled, flying, walking, or just an arm bolted to the floor.

In these cases, the robots in question are either working well away from humans, or at least at arm's length. But for as long as the field has existed, robotics researchers have been keenly exploring how robots can interact safely (and usefully) with people. The holy grail, although it may still seem like the stuff of sci-fi films, is developing robots that assist people at home.

With an ageing population and far fewer care workers than we need, the UK government and others are exploring robots in social care, also known as assistive robotics. Researchers maintain that they could play an important role in supporting people to thrive as they age, while alleviating pressure on the care sector. But first, there are technical challenges that must be addressed before robots can be used safely in settings such as homes, residential homes and

Did you know?

- Roboticists are exploring different types of assistive robots that could help people live independently for longer, such as by helping with household tasks
- Large language models such as GPT-4 (the AI model behind one of the latest iterations of ChatGPT) are increasingly guiding robots' behaviour, to help them interact with people more intuitively
- Lightweight robotic clothing might be able to help people climb stairs, stand for longer, and sit and stand from chairs more easily

hospitals. Ethics are equally important – especially how we ensure that assistive robotics are never seen as a substitute or replacement for human care.

IN SAFE HANDS

Robots designed to carry shopping or physically assist with household tasks could become the equivalent of household appliances that will help older people continue to live independently. While we are still far from seeing them in our homes, with more engineering and robotics research, they may become a reality in the future.

One of the most important challenges to address first is safety. Assistive robots must be safe by design, as they will be working very close to people, often touching them. At the extreme end, they may potentially be handling sharp objects – a fork, if they are helping someone to eat a meal, or a razor, for shaving assistance. These scenarios underline the fact that robots must be designed so that they are unable to make any mistake that may harm someone. Even with a less seemingly 'risky' example such as helping someone put on a jacket, a robot accidentally forcing their arm could injure them.

Improving safety may be achieved in different ways. On one side, it will mean the robot will have to be able to monitor the person and understand the situation, to react quickly to any potential harms. For instance, the robot may stop, slow down or back away to avoid a collision. Another route is through the controller, the hardware that guides robots' movement. Ordinarily, robots compute and then follow set movements. A 'compliant' robotic controller would allow the robot to follow a set movement trajectory, but crucially, give way to being pushed or pulled, similar to a human. Currently, this means solving a delicate trade-off, as stiffer control modes are more precise, whereas compliant controllers are less precise.

Unsurprisingly, progress on all of this might come down to learning from the expertise of caregivers. In March 2024, a team at the University of York's Institute for Safe Autonomy developed a dressing robot that uses AI to learn from a demonstration performed by a human. One learning was the fact that two hands were better than one (which was previously the norm for dressing robots). Jihong Zhu, the lead researcher, explained that using just one robotic arm could force the person to move or bend their own arm in an awkward or uncomfortable way. After opting to design a two-handed robot, they then also built in algorithms that would allow the gentle touch of a human to stop its actions.

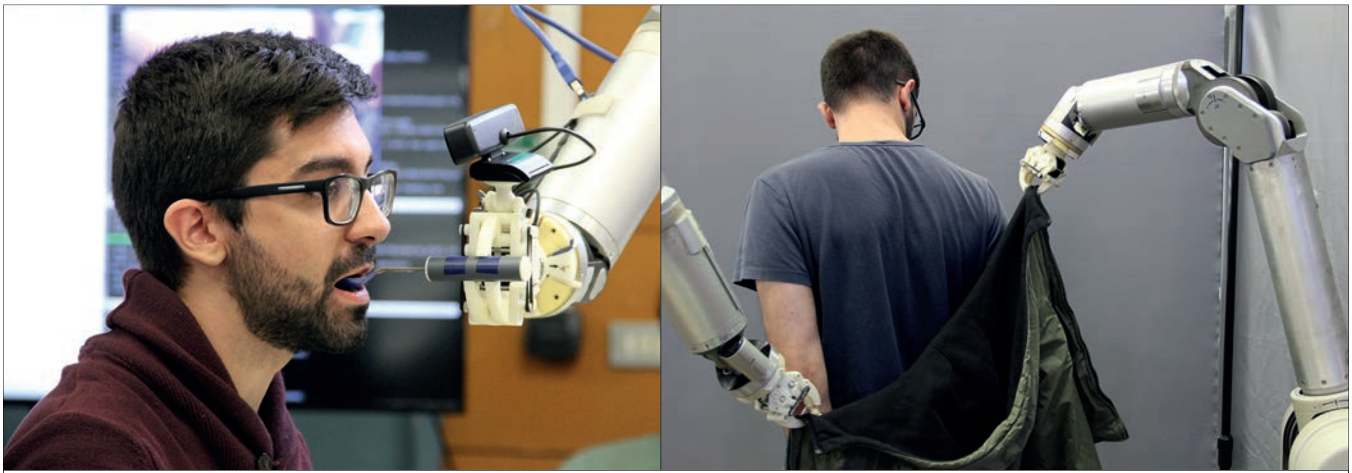
Safety is also tied to perception. Assistive tasks often involve dynamic and deformable objects, such as clothes or food. These kinds of objects are particularly hard for robots to perceive and model, not to mention to manipulate – whether picking up an orange or a T-shirt. Perception is impacted by the surroundings, too. Operating in someone's real-life living room – perhaps with several chairs, a coffee table and a cat to navigate – is very different to operating in a specially designed robotics lab. Hoping to address this, a team of roboticists, architecture researchers and healthcare specialists from several

WHAT ARE ASSISTIVE TECHNOLOGIES?

Assistive technologies are designed to help people whose needs are not otherwise met by the existing built or social environment, such as disabled people, older adults or people with long-term health conditions. They can positively impact many different areas of people's lives, from school and work, to getting around, cooking and leisure activities.

Whether we realise it or not, most of us use assistive technologies regularly. Voice-to-text and voice recognition technology are among the many everyday technologies that help show why making reasonable adjustments for disabled people benefits everyone. Other examples include devices such as hearing aids, objects such as a wheelchairs, and digital technologies such as screen readers.

Assistive technologies don't have to be as 'high tech' as these examples. After visiting Google's Accessibility Discovery Centre in London, Stephen Morris, a campaigns officer at Sense who is deafblind, wrote about a self-balancing spoon for people with hand tremors. He emphasised the need to always involve disabled people when designing and developing technology. (And indeed, many disabled people take a DIY approach, developing their own assistive technologies or adapt existing devices or objects to better meet their needs.)



Eating (left) and putting a jacket on (right) with help from robots © Dr Gerard Canal, Institut de Robòtica i Informàtica Industrial

universities, including UCL and Cardiff, are analysing the layouts of 'typical' residential homes to create practical guidelines for robot developers.

A promising route under development at a research hub based at the University of Bristol is robotic clothing – which combines elements of robotic exoskeletons with everyday clothing. "Smart robotic clothing has the potential to act as an enabler of movement, activity and independence for people with disability and frailty," explained Professor Jonathan Rossiter, a project lead, in a press release. Launched in October 2024, one of the project's aims is to develop robotic clothing that will help people climb up stairs, walk further and more easily stand up from a chair. This could easily make for a cumbersome, bulky device. How might engineers go about designing something people actually want to wear?

Clues could lie in a prototype from the same researchers shown at the British Science Festival in 2018, called 'The Right Trousers'. These lightweight trousers apply small electrical pulses to stimulate muscle groups in the wearer's legs, and included a stiffening knee brace based on thermally sensitive graphene, to help people stand up for longer.

HUMAN, BUT NOT TOO HUMAN

Perhaps the most important challenge of all is how robots and humans communicate. We're used to communicating with other people, but not so much with robots. In any assistive tasks, effective, natural, and quick communication will be crucial to provide smooth assistance. While robots that are too like humans are often considered creepy, this doesn't mean that robots shouldn't be social. Some people may find it easier to communicate their needs by speaking to a robotic assistant, and having it talk back to them. Making communication simpler in turn helps the robot to complete their task more easily.

In January 2024, engineers from a research consortium including Heriot-Watt University's National Robotarium took socially assistive robots to a hospital in Paris for a trial to help staff with routine tasks. Thanks to large language models (also known as LLMs, which are the type of AI behind ChatGPT) embedded in the robots, they could smoothly greet patients, answer questions, and provide directions – even following a conversation with several people. However, the consortium noted challenges relating to their 'ease of use and conversational complexity', so there's more to be done for them to be a seamless fit in real-world healthcare settings.

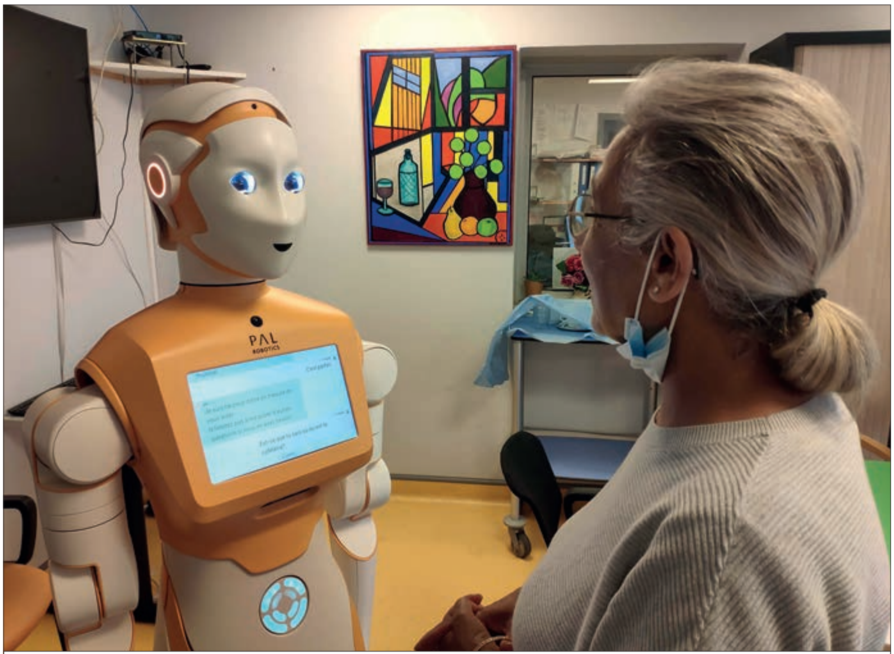
On top of this, if they're to be truly helpful to people, assistive robots must be able to understand the context of the task. For example, if a robot is helping someone eat, it needs to 'know' to hold off when the person is speaking or chewing. Engineers could inform their research in this area by talking to carers, who take in many different cues, from visual and verbal to tactile when assisting a person.

Recent advances in AI such as LLMs and vision language models (which are similar to LLMs, but also take image data into account) look very promising to tackle these issues too. However, it is still unclear how to model and understand social situations so that robots can act according to human expectations. Unlike humans, robots (and even our most advanced AI models) still lack common sense. My group at King's College London has recently published work exploring whether LLMs can align to people's social intuitions – our preferences and values. More advanced models, such as GPT-4, have improved on their predecessors, so it stands to reason

HOW DO ROBOTS NAVIGATE THEIR ENVIRONMENTS?

Usually, robots detect their surroundings to move around obstacles with 2D laser sensors in their base, rather than cameras. However, camera-based navigation methods also exist, such as those used by some robotic vacuum cleaners. Other kinds of sensors, such as sonar and distance sensors, may also be combined with vision and other types of sensor through what is known as sensor fusion. This all depends a lot on the kind of robot and its hardware.

To detect objects and people, 3D cameras such as the Microsoft Kinect are often used. These cameras provide both 2D colour images and depth maps (where every pixel in the image describes the distance from an object to the camera). Both images can be combined to create 3D point clouds, which are useful to visualise the data and represent the real-world objects and surfaces.



The SPRING project's ARI robot in conversation © The National Robotarium

that LLMs will continue to improve in this way, although we are still far from achieving human-level performance.

Because of this, they also lack the much-needed ability to adapt to a person's needs. This means adapting to and understanding their needs, but also their preferences – which is important for comfort. Such an adaptation must also be consistent throughout a person's lifetime: the robot should 'remember' if a person likes to dress in a certain way. At the same time, people naturally change over time and so will their needs and preferences. The robot should change accordingly. Personalising behaviour to specific people is what carers do when assisting someone and helps make robotic assistants both more effective and more socially acceptable.

Adapting assistive robotic behaviour to people's preferences was the subject of my PhD thesis at the Institut de Robòtica i Informàtica Industrial (CSIC-UPC). I looked at the types of preference that were relevant to certain assistive tasks, such as helping people eat, or put on shoes or a jacket, then used these to guide the robot's decision-making when carrying out the task. After implementing these changes to the robot's behaviour, surveying people showed greater satisfaction in their interactions with the robot. We are likely to see work in this area continue: so-called 'person-centred' autonomous robots are also the focus of a recently announced research centre at the University of Edinburgh. This will investigate frameworks for autonomous decision-making, as well as researching people's reactions and behaviours.

In terms of maturity, social robots – designed for companionship – are ahead of the curve. Several research labs are studying social robots in residential homes. One of the leading contenders here is PARO, a commercially available fluffy white baby harp seal robot. Like a therapy pet, but easier to care for and less unpredictable, it's designed to soothe and improve mental wellbeing for older people with dementia. Yet opinions in the field are split. Many researchers studying ageing believe social robots could hamper opportunities for genuine human contact and raise the potential for privacy and personal data risks.

PRICING IT UP

Cost may be the ultimate barrier to the adoption of assistive robots. Currently, robots are still highly specialised equipment and their cost reflects this. PARO is marketed at £6,000, for example. While some specific-purpose robots exist for some tasks (such as assisted eating, or vacuuming), their cost is still high and a person might need different devices to assist them with different tasks, while a general-purpose assistive robot might be able to help them with different tasks.

Importantly, assistive robots should only form a small part of the care environment, as human interaction in care settings is vital to people's emotional wellbeing. Co-creation and co-design should consider feedback from older people, the potential future recipients of assistance from robots, as well as carers, who will be working alongside them. Maybe, for example, people don't mind a robot dispensing medication, but prefer a human carer to help them eat. And perhaps carers would welcome manual support from robotic equipment designed to lift and transfer people – if they are reassured that it is safe for people in care.

Assistive robots therefore have a huge potential to change and improve the lives of many people, but lots of work and research in engineering are still needed to make them a realistic option to support people in the future.

BIOGRAPHY

Dr Gerard Canal is a lecturer in autonomous systems at the Department of Informatics, King's College London. He researches how robots in home environments can be made more autonomous, to be able to further assist people in living independently for longer. His research interests involve robot explainability (to make robots explain their behaviours to humans), goal reasoning, and planning applied to robotics. Before joining King's, he did a PhD in robotics at the Institut de Robòtica i Informàtica Industrial, IRI (CSIC-UPC) in Barcelona, with research on adapting assistive robot behaviours to user preferences.

A NETWORK FOR CHANGE

Dr John Lazar CBE FREng still likes to get his hands on technology, as Chair of the Raspberry Pi Foundation, a mentor and investor in startup businesses, and the new President of the Royal Academy of Engineering. He talks to Michael Kenward OBE about his role in changing the shape of network engineering and his passion for technology businesses that meet social needs.

When it came to that vital nudge that pushed John Lazar towards a life in engineering, he cites his father who was a GP in South Africa but also "very practical and good with his hands". His father liked making and fixing things and insisted on having the right tools for the right job, which helped develop Lazar's respect for people who make and build things.

His father's interest in technology influenced his own medical work. He switched from being a GP to specialising in radiology and pioneered the use of new medical technology in South Africa. Lazar senior was one of the first radiologists to introduce medical NMR (nuclear magnetic resonance) and CT (computed tomography) scanners into the country. He also sowed the seeds of interdisciplinary thinking in his son, who recalls the time when an eminent palaeoanthropologist asked to use his father's medical kit to X-ray fossil skulls.

Beyond parental influence, Lazar first encountered his ultimate professional engineering domain, computing, at an early age. At 10 years old, he started a computer course where he learned to program with punched cards and a mainframe computer. He recalls: "I thought it was complete magic. I took to it like a duck to water and it just made sense to me." Lazar's technically inclined dad supported his son's interest in computing, buying him one of the first Sinclair programmable calculators. "That's where it started."

Choosing a degree course wasn't difficult – he studied computer science at the University of Witwatersrand in Johannesburg. Unlike the system in the UK, degree courses in South Africa took four years and were broader in their remit. So, Lazar also opted to study political history, an interest that proved invaluable later on.

After graduating, Lazar lectured in computer science in Johannesburg for a year. In 1983 he won a Rhodes Scholarship to Balliol College, University of Oxford, where he enrolled on a master's degree in computer science and embarked on a project on natural language processing for his master's thesis. "Even at that stage I was interested in AI," he explains. He wanted to carry on studying the topic at doctorate level but at the time Oxford's PhD programme was highly mathematical and full of formal logic. Lazar looked into the possibility of joining Donald Michie, an eminent AI pioneer, but the scholarship didn't allow a move to Edinburgh, where Michie was based. So, he stayed in Oxford and changed subject, revisiting another longstanding interest and completed a DPhil in history and politics. Lazar didn't see this as a setback. "I always knew that my future would be back in technology," he explains. As he saw it studying history would help him "as a rounded person".

The return to technology came at the end of Lazar's time at Oxford. In 1987 he started "an entry level job" as a software engineer at Data Connection Limited (DCL), a supplier to the major telecoms businesses. Lazar's "junior job" turned into 28 years of what he calls "a wonderful, wonderful ride".

The 1990s were interesting times in computer engineering, especially network technology. Old-style telephone systems, with their large exchanges and networks, were feeling the heat from the rapidly rising use of the internet. Computing and telephones were coming together, and DCL played an important part in enabling that change. It evolved from supplying subsystems to major telecommunications operators into a driving force that helped to change the shape of the industry. At the end of the 1980s, telecoms revolved around a handful of global suppliers delivering massive, purpose-built network systems. DCL had few direct dealings with network operators. The notion then was that operators needed resilient, fault-tolerant, heavy duty, bespoke hardware with highly embedded software. Lazar says: "The original business [of DCL] was designing communication components that got embedded into the products of large equipment providers and OEMs [original equipment manufacturers]. I grew up through that as an engineer. It was fun."

BUILDING A BUSINESS

In the late 1990s, Lazar was part of a small team of software engineers at DCL that set out to change the major supplier model. "We took some of our componentry and built new technologies to start a new business," he explains. That business, Metaswitch, set out to bypass the telecoms giants. "We were selling directly to service providers and carriers." It started small. "We built products where the hardware team was never more than 10 people. We were using mainly industry standard hardware with some developments around that to improve it, supporting highly fault-tolerant and scalable software. It was pretty groundbreaking in the way that they designed that." Lazar likens this change to what became cloud computing.

The start of Metaswitch also laid the grounds for Lazar's growing business role as he moved from engineering and product management into leading a new division within the company. He set up an office for the new division in the US and jokes that in his time there he "did a lot of travelling around to the small carriers. I visited 42 states." By 2009 about 80% of Metaswitch's business was in the US. As Lazar explained at the time: "We had a UK heart and our R&D was primarily based here, but we were beyond thinking of ourselves as a UK company. The original market was always going to be in the US." The US, unlike the UK and much of Europe, had plenty of small telecoms operators. The US government's breakup up of the 'Bell System' (a group of telecoms companies owned by Bell and later AT&T that dominated the US's telephone systems) in the 1990s unleashed a wave of competition and innovation as new operators entered the market. Metaswitch was able to help the newer decentralised and regional operators. The strategy worked: Metaswitch's business took off and global growth followed. The brand also caught on to the extent that the whole company became Metaswitch.

Lazar's time at DCL took him through numerous engineering and customer-facing roles, ending up as CEO and then chair of a business in an area of technology that had changed beyond all recognition. In 2016, after 28 years with the company, Lazar stepped down as chair. Along the way the company had helped to change the shape of telecommunications engineering.

In one of his very first actions as President of the Royal Academy of Engineering, John Lazar presented the Sir Frank Whittle Medal to Tristram Carfrae RDI FREng at the Academy's AGM in September 2024 – at which he was also elected President

After leaving Metaswitch, Lazar combined his enthusiasm for engineering with his understanding of what it takes to create a successful technology business. In particular, he wanted to address the challenges of financing technology, especially startups. He also wanted to help these to develop the skills needed to run a new business.

Lazar was also keen to build on another lesson from his GP father and to meet social needs. He describes his post-Metaswitch move and hopes of combining these ambitions as being like a Venn diagram. "Engineers like Venn diagrams," he jokes. "My number one interest was in engineering and technology. Number two, I was very interested in education and entrepreneurship." The third circle in Lazar's Venn diagram is being involved in engineering that meets social needs and does good in the world.

SHARING EXPERTISE AND KNOWLEDGE

At Metaswitch he had devoted time to working on tech-related non-profit initiatives in Africa. And while part of the Academy's International Committee, he chaired the steering group that organised the Global Grand Challenges Summit held in London in 2019, which focused on engineering in an unpredictable world.

More recently he has acted as a mentor in the Academy's Enterprise Hub, helping to guide technology startups in turning engineers' ideas into successful businesses. In 2022, he became chair of the Academy's Enterprise Committee, which oversees the Hub's work.

Since its launch in 2013, the Enterprise Hub has supported nearly 400 researchers, graduates and SME leaders who have gone on to start up and scale up businesses. Awardees have created nearly 6,000 jobs and have raised over £1.3 billion in extra funding. The Hub is now recognised as a leader in fostering startups. In 2024, it was rated ninth out of 125 startup hubs in Europe in FT-Statista's first ever rankings of such organisations.

As Lazar said of this achievement: "The Enterprise Hub has helped them to transform breakthrough engineering innovations into disruptive spinouts, startups and scaleups that seek to solve the pressing problems of our time. We hope this ranking helps us to attract even more engineers from all backgrounds to apply for our schemes and get the support they need."

Another of Lazar's activities with the Academy parallels the work of the Hub. Since 2016 he has been a judge and mentor for the Africa Prize for Engineering Innovation. Launched in 2014, the prize sets out to stimulate, celebrate and reward innovation and entrepreneurship across sub-Saharan Africa. Over the past decade, the prize has backed over 140 African innovators, who have created over 28,000 jobs, and introduced more than 470 products and services to the market in more than 40 countries.

One activity that falls into the third circle in Lazar's Venn diagram of what makes him tick, engineering that does good for society, is his role as Chair of the Raspberry Pi Foundation since 2020. The foundation exists so that future generations can experience the enthusiasm for IT that set Lazar into a career in computer engineering. "It was something that I was very keen to do." It's an area that he had already started work on in another Academy

QUICK Q&A

What is your favourite project you worked on?
Metaswitch – proving that we could disrupt an industry with a highly reliable and scalable software product running on industry standard hardware. We didn't need a large hardware development team or manufacturing facility to succeed.

What's your advice to budding engineers?
Remember that engineering is a collaborative team-based exercise. Always be open to feedback.

Which record/book would you take to a desert island
Nobel laureate Richard Feynman's *Lectures on Physics* from Caltech in the early 1960s. And a recording of Maria Callas singing Bellini's *Norma* – one of my wife's favourite pieces of music.

Who is your most admired historical engineer?
Claude Shannon. His 1948 article *A Mathematical Theory of Communication* is absolutely groundbreaking: modern digital communication and information theory would not exist without it. And he did so much else!

Do you have a favourite tool/tech gadget?
Two 3D printers. Various Raspberry Pis. Love my Pi400.

Most impressive engineering to look at?
Sagrada Familia. I was so excited to recently present the Sir Frank Whittle Medal to Tristam Carfrae. A great example of engineering remaining true to a vision while embracing modern methods.

What do you do in your spare time?
Run, walk, looking at art (my wife is an artist), read, sometimes find time to mess around (incompetently) with my Pis and printers!

role. While a member of its Education and Skills Committee he was very involved in the joint work the Academy did with BCS, The Chartered Institute for IT, on developing the programme of study for the new computer science curriculum.

The foundation is the charitable arm of Raspberry Pi. It owns a large chunk of the company that makes and sells these credit-card-sized computers (see 'Chips that changed the classroom', *Ingenia* 72). The commercial operation floated on the London Stock Exchange earlier in 2024, with the foundation receiving £150 million for its global mission, while still retaining the largest share of the business.

The foundation, with its aim of making digital skills and programming accessible to young people and to support people worldwide, especially from socioeconomically disadvantaged communities, is another activity that ties in with Lazar's interest in encouraging engineering in Africa. Kenya and South Africa are two of the foundation's largest targets for its global programme. "There are programmes in both countries where we work with partners and with governments to try to improve access to computer science education and also AI education for young people."

INVESTING IN INNOVATION

Lazar's work with the Academy's Africa Prize and the Raspberry Pi Foundation runs alongside another African engagement. For many years, Lazar has been an 'angel' investor, funding early stages of tech startups. Then, along with two colleagues, David Cohen and Mike Mompi, he set up Enza Capital in 2019, a venture investor that supports startups and nurtures them through the earliest stages until larger investors enter the picture.

The fund's mission is to invest in "teams using technology to solve large and meaningful problems across Africa". Many engineers and business founders in those startups use IT in domains "from health and logistics, to fintech and human capital management". Enza's portfolio also takes in startups in education and energy and climate change. Lazar points to examples in healthcare, remote

IN AND OUT OF AFRICA

John Lazar (far left) with fellow Africa Prize for Engineering Innovation judges in 2023

As a Fellow of the Royal Academy of Engineering since 2011, it was natural for Lazar to become part of an activity that involved his home country and the wider African continent. The Academy has placed a particular emphasis on supporting entrepreneurial engineers in Africa. It launched the Africa Prize for Engineering Innovation in 2014, which Lazar became a judge and mentor for in 2016.

Winners of the Africa Prize have tackled an array of challenges. In 2021, Noel N'guessan from the Côte d'Ivoire, won for creating Kubeko, a set of low-cost biowaste processing equipment designed for smallholder farmers in West Africa to efficiently manage and generate income from biowaste.

In 2017, Godwin Benson from Nigeria won the prize for Tuteria "an online platform that connects people seeking to learn anything with verified local experts who can teach them what they want to learn, as well as ensuring safety, accountability and quality learning delivery".

On the medical front, Norah Magero, a mechanical engineer in Kenya, was the 2022 winner for VacciBox a small, mobile, solar-powered fridge that stores and transports temperature-sensitive medicines, such as vaccines, "for use in field vaccinations and in off-grid hospitals".

In 2024, Esther Kimani, also from Kenya, won for her device for early detection and identification of agricultural crop pests and diseases to swiftly detect pests and diseases. Her innovation has helped smallholder farmers to reduce crop loss by up to 30%, increasing yields by as much as 40%.

Alongside his work on the Africa Prize, Enza Capital, which Lazar co-founded, has invested in 33 companies that want to solve "meaningful problems" in Africa, in fields that range from health and logistics, to fintech and human capital management. It also has investments in education and energy and climate change. These are in 10 African countries from Egypt to South Africa.

One business in the portfolio that straddles both financial technology and human resources is SeamlessHR. Based in Nigeria, the company has set up a cloud-based suite that "helps medium to large-sized companies automate and optimise their entire HR process from recruitment to retirement".

Another Enza investment is Cloudline, a South African business set up by Spencer Horne to bring solar-powered autonomous flight to the world. Helium-filled blimps, fitted with solar panels and backup batteries to power their engines, have a flight time of up to 12 hours and a range of up to 400 kilometres.

health monitoring and "hospital at home" services, to illustrate Enza's interests.

One reason for Lazar's interest in, and enthusiasm for, African engineering is simple demographics. "It is a young continent." The population is younger than in most of the rest of the world. Africa has a lot of bright young people with great ideas, he explains. As backers, Enza Capital can help the founders and teams running new tech businesses to tackle the usual challenges of management, marketing and manufacturing. The fund has invested in more than 30 African ventures so far.

This support mirrors Lazar's work with the Enterprise Hub. As he points out, wherever they are, startups face the same key question, "How do you scale?" – demonstrating another parallel between Enza and the Hub. It can help startups to find the critical infrastructure that they need to get somewhere. For example, Lazar mentions the lab space that innovators may need to work on their ideas.

Lazar brings other lessons from his experience with the Hub. One is the complexity of what should be the simple bureaucracy involved in doing deals. "Every university has a technology transfer office," he explains. "They all operate in different ways which throws up barriers. Something like reaching an agreement on intellectual property and licensing can take ages. Adopting a standard approach would be a great help." This is an approach that Lazar is keen to also bring to his role as the Academy's President: "I want our new strategy to provide us with the clarity and simplicity to continue to make a difference to our profession, the UK and the world."

Just as Lazar uses an engineer's approach and a Venn diagram to explain his interests, another diagram could encapsulate how his various past and present roles fit in with becoming the Academy's President. One circle would be his continued interest in keeping up with technology and engineering that can benefit society. Another circle would include his role in starting businesses, beginning with when a handful of DCL engineers created an internal 'startup', Metaswitch, and went on to change the shape of networking and to build a global tech business. Then there would be a circle for Lazar's work as an investor and mentor for startup tech businesses. All this overlaps to encompass many of the key roles that he will encounter as President of the Academy.

John Lazar speaks at the Enterprise Hub Showcase event in 2023

CAREER TIMELINE AND DISTINCTIONS

Studied computer science, maths and politics, University of Witwatersrand, **1979–1983**. Master's in computing then a doctorate in history and politics, University of Oxford, **1983–1987**. Joined Data Connection Ltd as a software engineer, **1987**. CEO, Metaswitch, **2009–2010** and **2012–2015**. Chair, Metaswitch, **2010–2012** and **2015–2016**. Fellow of the Royal Academy of Engineering, **2011**. Awarded a CBE for services to engineering, **2016**. Non-Executive Director and Board Member, what3words, **2016–2023**. Co-Founder and General Partner, Enza Capital, **2019–present day**. Chair, Raspberry Pi Foundation, **2020–present day**. Elected President of the Royal Academy of Engineering, **2024**.

HOW PUNCHING HOLES IN PAVEMENTS COULD PREVENT FLASH FLOODING

Climate change is raising the risk of flash flooding in cities around the world. Could rethinking our impervious roads and pavements stop sewers from becoming overwhelmed?

Surface flooding near Tower Bridge, London © Shutterstock

Not just one, but two days in July 2021 saw over 2,000 homes and properties in London flooded with stormwater and sewage after biblical rainstorms. Newham Hospital and Whipps Cross Hospital were forced to evacuate wards, while Chalk Farm and Pudding Mill Lane were among the 30 stations deluged with floodwater.

As the climate warms, rainstorms with effects as extreme as this will only become more likely. Upgrading our Victorian-era sewers is one solution, although it's a long-term and costly one. In the meantime, engineers are exploring other ways to drain waterlogged streets – such as punctuating pavements with holes.

"At the moment, our cities are covered in impermeable surfaces," says Dr Alalea Kia, an Advanced Research Fellow at Imperial College London in civil engineering and materials. This means rather than seeping into the ground, rainwater either pools on roads and pavements or flows directly into drains and overwhelms the often ageing sewers. The more intense the storm, the more likely that the sewers become backed up, causing flooding. "At the time [cities] were being planned, this effect of the climate emergency was not taken into account."

When she started her PhD in 2014, Kia knew she wanted to do something with her research to help deal with the increasing flooding around the world. At the same time, she was fascinated by the material properties of concrete and cement that make them so ubiquitous. Concrete is the second most used material in the world after water, contained in most structures somewhere because of its strength, durability and ability to be cast into almost any shape. She had come across permeable concretes, designed to allow water to drain through, but noticed they weren't widely used. So, she decided to develop her own.

TWISTY FLOW

The main problem with permeable concretes is that they are easily clogged, explains Kia. Composition is key to this. Standard concrete is made by binding together small stones

EYES ON THE INNOVATORS

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

Bioengineers from the **University of Tokyo** have cultivated solar-powered hamster cells – the first example of animal cells that can photosynthesise.

O2 has launched an AI granny chatbot called 'dAIsy' to frustrate phone scammers by talking at length about her passion for knitting.

Dr Alalea Kia with slabs of Kiacrete ready to be installed. The slabs can be cast in different colours – for instance, for cycle lanes – and all feature six millimetre diameter holes to allow water to pass through and ease surface flooding
© Dr Alalea Kia

and sand with cement. In permeable concretes, omitting the sand creates small voids. It's a little like filling a jar full of small pebbles: you would see gaps of varying sizes between the stones. If you were to add sand into the mix, it would fill much of the available space, making it harder for water to travel through.

In practice, when rain falls on permeable concrete, rainwater seeps down through the gaps in the material, flowing in a twisting, convoluted path. Relatively quickly, in as little as a few months, sediment washed from the surface can block these tiny voids. And once blocked, there's no unblocking them: pressure washing, vacuuming and sweeping can only clean the top couple of centimetres, says Kia. That's not the only problem with these types of permeable concretes. Once inside, water can't easily escape, so if it gets cold enough to freeze, it can expand and crack the concrete.

Kia's idea, called Kiacrete, was to cast regular concrete around a grid of vertical recycled plastic tubes to create drainage holes. More recently, Kia and her research group have developed a version without the plastic tubes. These six millimetre-wide holes channel water away from the surface, allowing it to be quickly captured and then diverted to the sewer system or even reused. Importantly, any clogs are easily cleaned by a pressure washer, says Kia, noting that enough rain will also do the trick.

The exact way that rainwater is then reused depends on the soil underneath. If it is permeable, collected rain will flow into the groundwater (which is helpful for drought-prone regions). If the soil is already saturated, or impermeable – which might be the case if it's heavily compacted, or rich in clay – the water will sit in a gravelly underlayer until the flooding has subsided. On new sites, a storage tank can be installed underneath, so that the rainwater can be funnelled elsewhere to flush toilets or irrigate gardens.

The design benefits other types of extreme weather event, too. Thanks to the improved airflow through the channels, the concrete is less likely to crack in a heatwave.

You might think that filling a block of concrete with holes would make it weaker. And technically, you'd be right. However, Kia and her team have carefully tested different diameters and densities of holes to achieve a puddle-free pavement surface with high strength. This means it's strong enough to turn it into footpaths, cycleways, roads and even the paving for airport taxiways. Any type of concrete can be used to form Kiacrete, with recent trials using low carbon and zero cement mixes, as well as pigmented concretes.

PIECE BY PIECE

Thankfully, digging up and replacing all of London's roads and pavements – and the associated carbon footprint – is not on the cards. The idea is a more targeted approach, replacing sections such as the surface flooding hotspots that are typically lower in the landscape of a road or pedestrian footpath. In a recent trial at Imperial's White City campus, Kia explains that a 10-square-metre section of Kiacrete created drainage for the whole front entrance of the site.

However, since roads require maintenance and resurfacing every seven years, there will be plenty of opportunities to install Kiacrete. In the long term, Kia says we should see a change in the pattern of where water flows, and fewer accidents relating to heavy rainfall and flooding, such as when cars hydroplane. Eventually, the plan is to take it to beyond the UK to other countries that regularly experience flooding.

So, watch this space. Aside from the successful White City campus trial, the team is working with engineering consultancies, contractors and local authorities in the UK and internationally who are interested in testing Kiacrete. (But it's a little too early to name them, says Kia. "Obviously it's not concrete yet.")

A gene-editing treatment based on CRISPR-Cas9, **Casgevy**, is being given to patients with sickle-cell disease for the first time.

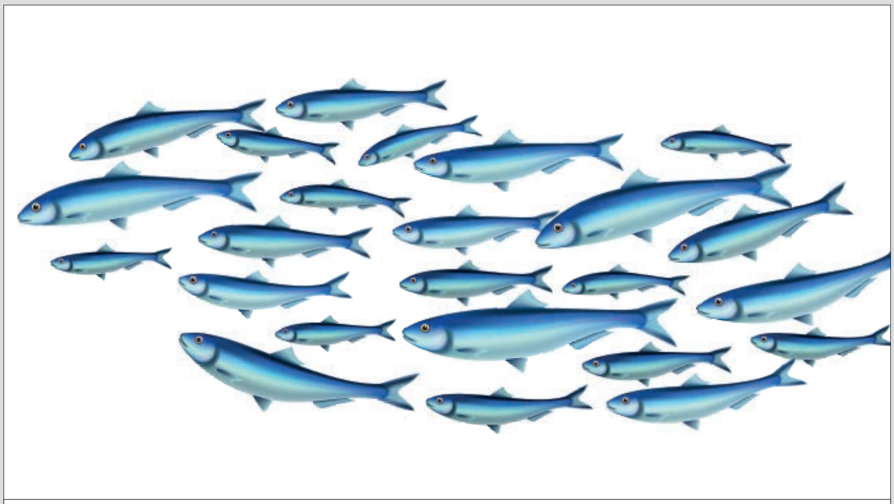
Engineers at the **University of Southampton** have analysed Team GB windsurfer, Sam Sills' kit to give him a competitive edge.

Researchers from the **University of Cambridge** have developed an 'artificial pancreas' that algorithmically determines insulin delivery.

HOW DOES THAT WORK?

FISH SWIMMING IN SCHOOLS

For fish, swimming as a school has a host of benefits. This feat of nature is now inspiring engineers and impacting their innovations.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If you've watched *Blue Planet* – or even seen *Finding Nemo* – you'll have seen fish swimming together as a group, with every single fish heading in the same direction at the same time.

Not to be confused with a shoal, which is where fish of the same species swim together but in different directions forming a social group, a school is where fish of the same species work and swim together as one group. Schools of fish vary in number, ranging from just four to hundreds and even thousands in the wild.

Research suggests that many species of fish have evolved to swim in schools for several reasons: to protect themselves from predators (it's much harder to attack a group of fish together than one on its own), to increase their chances of finding food, and to swim more efficiently. Researchers believe that the close proximities between the fish in the school mean that it's much easier to swim, similar to the way that cyclists make use of slipstreams in a peloton to conserve energy.

This efficiency has captured the imagination of engineers. Most commonly robots are programmed to operate together in a school-like formation to problem solve or complete a task more quickly (see 'Engineering swarm robotics', *Ingenia* 97).

The influence of schooling fish has also made it to surprising places. In 2010 engineers at the California Institute of Technology (Caltech) took inspiration from the flow behaviour of water left in schools' wake to design the layout for a wind farm. The design proposed using vertical axis turbines, which look like giant, upright, spinning egg whisks, that turbulent winds bear down on from different directions. Engineers had studied the whirling masses of water, called vortices, left behind by fish swimming in a school. They noticed that some rotated clockwise, while others rotated counterclockwise. The design planned to arrange the wind turbines based upon the vortices shed by schooling fish to maximise energy generation. These principles continue to underpin work carried out by the Caltech Field Laboratory for Optimized Wind Energy (FLOWE), which demonstrates innovative approaches to wind energy that have the potential to concurrently reduce the cost, size, and environmental impacts of wind farms.

More recently, in April this year, engineers at Johns Hopkins University discovered that a school of fish make less sound than a solitary swimming fish. Their findings could inspire the design and operation of much quieter submarines and autonomous undersea vehicles. To simulate different numbers of fish swimming, the researchers created a 3D model showing variations of between one and nine fish being propelled forward by their tail fins. They changed formations, the closeness between the fish as they swam, and the synchronisation of their movements.

They discovered the synchronisation of the group's tail flapping – or lack of – was a vital component in reducing the sound of the school as it swam. If fish moved their tail fins at the same time, the sound added up and there was no reduction in overall sound. But alternating tail flaps cancelled out each other's sound. The team also noted that these same sound-reducing tail fin movements are key to lessening friction between the fish, allowing them to swim faster while using less energy.

From more efficient wind farms to quieter underwater vehicles, the influence of nature – in the case the behaviour of schools of fish – on technological advances is clear to see.