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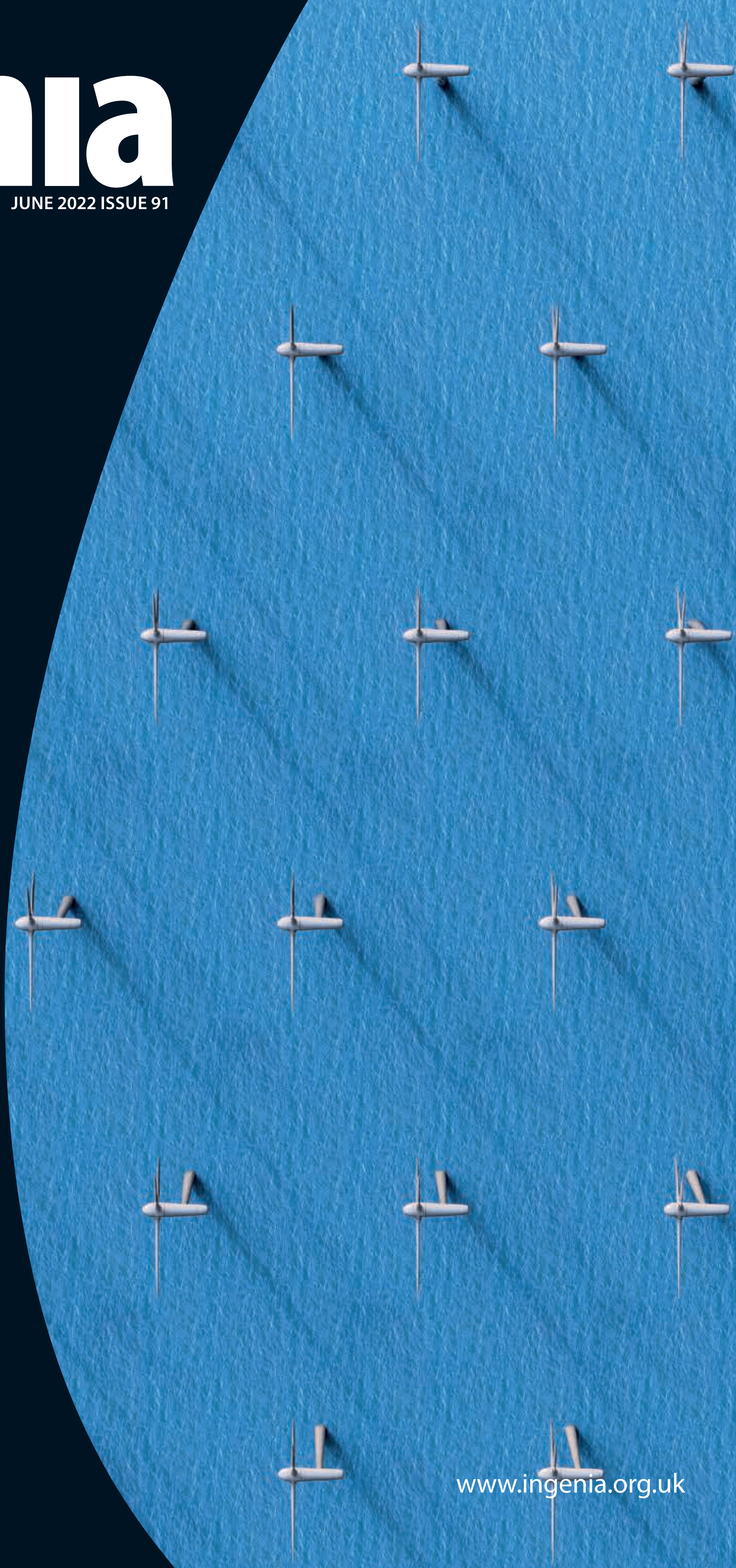
JUNE 2022 ISSUE 91

PREVENTIVE MAINTENANCE

KEEPING BIODIVERSITY INTACT

THIN LENSES FOR GREATER FOCUS

NEW USES FOR TURBINE BLADES



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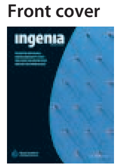

Aerial view of wind turbines in the ocean. Innovative techniques are providing new lives for wind turbine blades, including a recyclable blade.
© Adobe Stock

ISSN 1472-9768

WELCOME

To live within our planet's finite resources, we need engineers to turn science into practical ideas that make a difference. Frequently, solutions can be found in novel ways of working with materials – whether this is designing them differently, repurposing them, or using advanced technology to extend the life of products.

Toddlers might be where this starts – not how they think, but what they wear. Read about aeronautical engineer Ryan Mario Yasin, who was inspired by folded structures used in deploying satellites to invent clothes that grow (page 38).

At the other end of the spectrum, major engineering industries are tackling the enormous costs of maintenance by using remote sensing, artificial intelligence and robotics to accurately predict exactly where and when maintenance is needed, to maximise efficient use of every component (page 22).

And when it comes to recycling, complex composite materials are particularly challenging. Wind turbine blades are a good example, with about 4,000 retired annually in Europe. Learn about a new recyclable blade breathing new life into wind turbine blades (page 12).

Advocates for right-to-repair argue that it is a critical part of extending the lifetime of all kinds of electronics. Paul Hide of AMDEA (page 10) discusses this hot topic from another angle, including important considerations such as consumer safety and the potentially improved environmental credentials of new domestic appliances.

Our natural capital is also nurtured by engineers. We need to reverse the decline of natural habitats and every infrastructure project is a potential opportunity. 'Engineering biodiversity' (page 27) will inspire engineers to explore ecology and closer collaborations with ecologists.

Stay up to date on engineers' work across a wide range of industries: sign up for more regular *Ingenia* digital content at www.ingenia.org.uk/subscribe.

Faith Wainwright

Faith Wainwright MBE FREng
Editor-in-Chief

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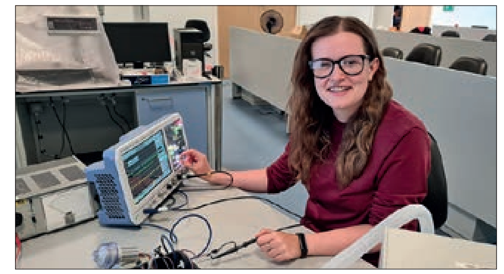

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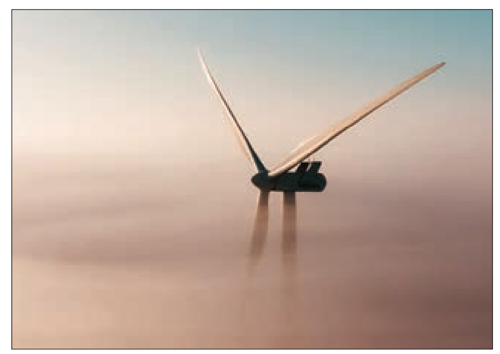
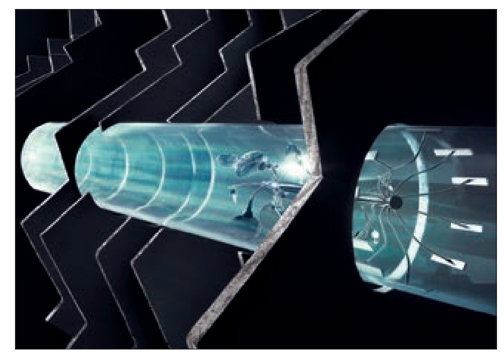
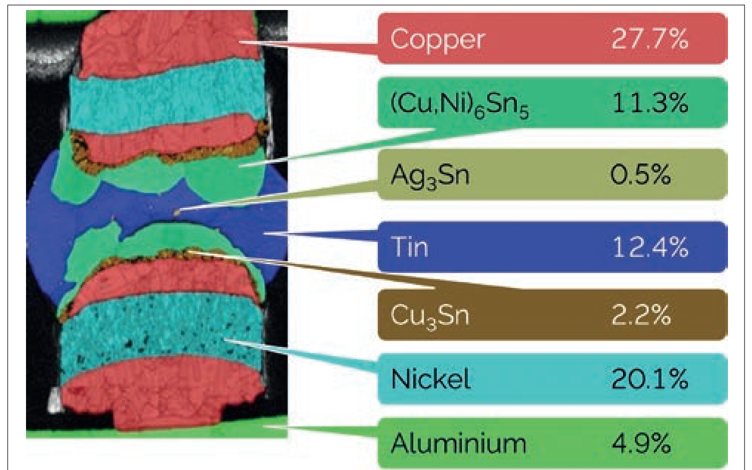




IN BRIEF

FINALISTS ANNOUNCED FOR 2022 MACROBERT AWARD


Intelligent Growth Solutions' vertical farm technology in use



Materials analysis using Oxford Instruments NanoAnalysis' Symmetry detector

A compact dialysis machine that can treat kidney patients in the home, a vertical farming technology driving cost-effective precision agriculture, and a new camera that is transforming scanning electron microscopy and its applications have been announced as finalists for the 2022 MacRobert Award, the UK's most prestigious prize for engineering innovation.

The three finalists – Quanta Dialysis Technologies, Intelligent Growth Solutions and Oxford Instruments NanoAnalysis – cover strikingly different aspects of engineering and are recognised not just for technical innovation but also for the commercial and societal impact they have demonstrated.

Quanta Dialysis Technologies is committed to making dialysis accessible to every patient in every setting with its SC+ haemodialysis system. As a compact device with performance comparable to larger, traditional machines, SC+ is a modular and powerful solution that provides the clinical versatility needed to deliver dialysis care across multiple settings.

Intelligent Growth Solutions is addressing key challenges in the food industry through precision indoor agriculture that blends engineering, crop science and agronomy in a modular and scalable vertical farming system.

Oxford Instruments NanoAnalysis' Symmetry detector integrates with scanning electron microscopes to enable a deeper understanding of a material's structure at the nanoscale. It makes possible the analysis of crystal structures at high speed and with high resolution and sensitivity via a single camera, making it suitable for a wide range of applications.

The winner of this year's MacRobert Award will be announced in July. The winning team will receive the signature MacRobert Award gold medal and a £50,000 cash prize.

The MacRobert Award is run by the Royal Academy of Engineering with support from the Worshipful Company of Engineers. Since 1969, it has recognised engineering achievements that demonstrate outstanding innovation, tangible societal benefit and proven commercial success. Over the last 52 years, MacRobert Award winning innovations have changed the world, by delivering enormous societal benefit and contributing to the UK economy.


Quanta Dialysis' compact, lightweight dialysis machine

IN BRIEF

TFL'S ELIZABETH LINE OPENS

On 24 May, Transport for London's (TfL) Elizabeth line opened to the public for the first time. The engineering marvel, 15 years and £18.9 billion in the making, required 42 kilometres of new rail tunnels to be bored into the ground below the city. The platforms are longer than Winchester Cathedral – the longest intact medieval cathedral in the world – and burrow as deep as 40 metres (over 10 storeys) below the ground.


Tottenham Court Road Elizabeth line station © TfL

To construct the tunnels, eight giant boring machines dodged sewers, foundations and other underground tunnels in a process that displaced over seven million tonnes of earth and took over three years. The majority (75%) of the displaced earth has been used to form a new nature reserve at Wallasea Island in Essex.

The project also became the largest archaeological dig in Britain, with more than 100 archaeologists finding tens of thousands of items across the different sites. At Canary Wharf, team members found a piece of 55-million-year-old amber; while a rare bronze Roman medallion was found at Liverpool Street – not to mention the many plague skeletons that were dug up.

Meanwhile, the project supported 55,000 jobs, plus more than 1,000 apprenticeships and a supply chain that stretched from the Isle of Wight to Inverness. The new line stretches over 100 kilometres from end-to-end, from Reading and Heathrow in the west, to Shenfield and Abbey Wood in the east.

The Elizabeth line is expected to increase London's public transport capacity by 10% once fully up and running, while parties involved hope that it will provide a post-pandemic economic boost to London.

INNOVATIVE PORTABLE INCUBATORS SENT TO UKRAINE

Fifty-one portable incubators, designed for more flexible neonatal care, especially in challenging environments, are being sent to Ukraine as part of a shipment of essential medical supplies. The mOm Essential Incubators will provide life-saving medical intervention for up to 100 babies per week.

The incubator weighs just 20kg and has been designed to be assembled anywhere so it can be set up and used by doctors immediately. It does not require lengthy training for use and can be moved around hospitals. It can also run off inconsistent voltage supplies, is energy efficient and equipped with a backup battery. Because it can compact to half its size, it is highly portable.

The incubator saw its first clinical use in the UK in November, and has recently been awarded its CE mark, meaning it has regulatory approval to be sold commercially.

Reports state that high levels of stress during pregnancy can increase the chances of having a premature baby (born before 37 weeks of pregnancy) or a low-birthweight baby. Following the Russian invasion, the stress and trauma occurring on a daily basis has led to a sharp rise of premature births in Ukraine within a fractured hospital system.


The mOm Essential Incubator, compacted to half its size (left) and fully set up (right) © mOm Incubators

To send the shipment, mOm partnered with an international development not-for-profit, Crown Agents, to design and implement practical solutions to the crisis. Crown Agents has remained in contact with the Ukrainian Ministry of Health and confirmed the need for infant incubators.

INGENIOUS PROJECTS FOR THE NEXT GENERATION OF ENGINEERS

HandBuild/HandAssess will run a workshop for pupils focused on prosthetics. It will explore routes into a career in medical engineering, and recognise how engineers work alongside healthcare professionals and patients © University of Salford

In May, the Royal Academy of Engineering announced 23 new *Ingenious* public engagement awards for projects across the UK designed by engineers to engage the public with engineering and inspire the next generation.

Taking place in locations from Peckham to Dundee, the projects cover everything from ocean health and prosthetics, to air pollution, sport and sustainable future food. In all of these areas, engineers are coming up with creative solutions to problems and bringing new technologies to life. These projects aim to spark the imagination of local communities about these diverse themes and the impact being made by engineers.

In Portsmouth, bioengineers will host co-design puppetry workshops together with local makers and secondary school students, on the theme of 'Puppets as Enzyme Engineers of the Imagination'. Top of the agenda in Belfast will be the importance of shipbuilding for Northern Ireland, plus the shipping industry's sustainability challenge – a project that will culminate in the 'Ingenious Cardboard Regatta'.

In Peckham, an eight-week programme will connect ambitious students with engineers to develop engineering solutions to air pollution – a severely concerning local issue in Southwark. Meanwhile, there will be two escape rooms, a climate emergency-focused one in Lewisham and a space engineering-themed one in Kent, plus a STEM-themed 'Theatre in a Box' in Yorkshire and immersive drama engineering workshops in Birmingham.

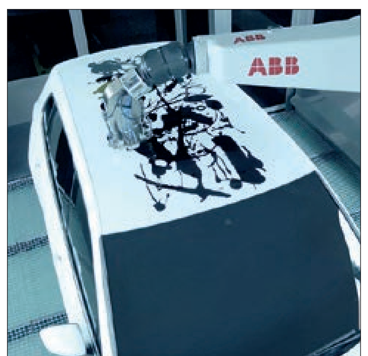
These are just a few of the projects on offer for the 2022/2023 *Ingenious* programme; for more, please visit the Royal Academy of Engineering website.

ROBOT PAINTS CAR WITH DESIGN BY EIGHT-YEAR-OLD BOY

A robot has painted detailed artwork on a car for the first time, in collaboration with two artists, including an Indian child prodigy. ABB Robotics's PixelPaint robot was used to replicate the artists' designs onto a refurbished Volkswagen SUV that was damaged in the flooding in Germany during the summer of 2021.

Ordinarily, intricate paint jobs such as these are laborious, requiring multiple stages of masking and unmasking. However, the robot painted the artworks in a single application, sometimes even using two colours at once. Thanks to its inkjet head, comprised of 1,000 nozzles, it completed the painting in less than half an hour. Furthermore, software enabled the paint head to track close to the body of the car, ensuring no paint was wasted, to make the process more cost effective and sustainable.

One of the artworks recreated on to a car, a black-and-white Jackson Pollock-esque piece called *Zebra Utopia*, was originally painted by eight-year-old Advait Kolarkar. An abstract artist who has sold his work for upwards of £100,000, Advait had his first exhibition in Pune, India, in July 2021. The other artwork was produced by Dubai-based digital design collective, ILLUSORR and was inspired by the airflows around the car.



Closeup of the design by Advait Kolarkar being painted onto the car by the robot © ABB

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And of course, it would be remiss not to mention our monthly round-up of the best in engineering and STEM events, exhibitions and podcasts. Sign up using the form at **www.ingenia.org.uk/Subscribe**

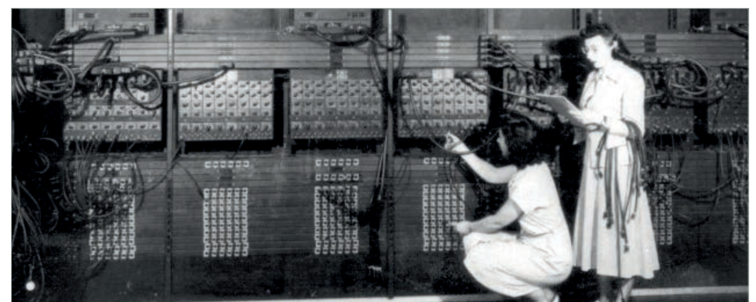
GET INVOLVED IN ENGINEERING

DOCTOR WHO: WORLDS OF WONDER

27 May to 20 October 2022
World Museum, Liverpool
Doctor Who fans awaiting the 2023 arrival of the new timelord on the small screen can visit a new interactive exhibition in the meantime. It explores some of the Doctor's many adventures in space and time – a must-see for science enthusiasts.
www.liverpoolmuseums.org.uk/whatson/world-museum/exhibition/doctor-who-worlds-of-wonder

WIFI WARS 7.0

17 June, 7.00pm
Royal Institution, London
Join the audience for this latest rendition of the live comedy game show that promises to combine laughs with computer science and gaming technology.
www.rigb.org/whats-on/wifi-wars-70



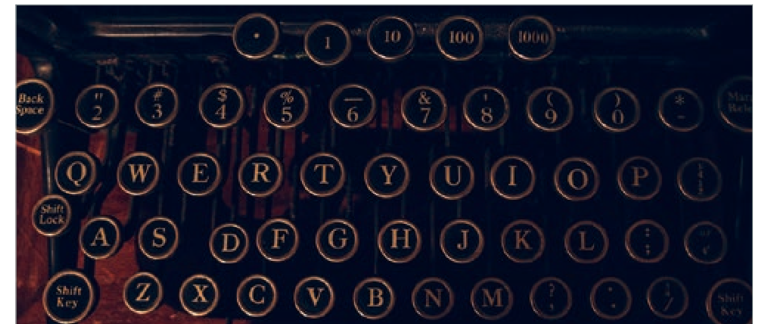
The ENIAC computer worked on by Klára Dán von Neumann © thekirbster

LOST WOMEN OF SCIENCE PODCAST: SERIES 2

ALL PODCAST PROVIDERS
While you may have heard of mathematician John von Neumann, have you heard of Klára Dán von Neumann? The second series of this podcast series delves into the story of the self-taught woman who wrote the first modern-style code every executed on a computer.
www.lostwomenofscience.org/season-2

THE SEE MONSTER

Summer 2022
Marine Parade, Weston-super-Mare
Unboxed Festival's 'See Monster' opens this summer. The decommissioned North Sea oil rig has been reimagined as a giant art installation with its own garden, waterfall and renewable energy-generating technologies, and will be open to the public for two months.
www.unboxed2022.uk/see-monster-weston-super-mare



THE TYPEWRITER REVOLUTION

24 July to 11 September 2022
National Museum of Scotland
If you've ever wondered where the QWERTY keyboard came from, this is the exhibition for you. Not only does it explore how typewriters revolutionised the world of work – it also looks at how the humble typewriter became key ammunition in the fight for women's suffrage.
www.nms.ac.uk/exhibitions-events/exhibitions/national-museum-of-scotland/typewriter-revolution/

© Peter Hudson's Charon, by Mitzi Peirone

GREENWICH+DOCKLANDS INTERNATIONAL FESTIVAL: CHARON

1 to 10 September
Canning Town, London
An exciting new installation originates from the legendary Nevada festival, Burning Man. Expect shades of Arcadia with this 32-feet-high rotating skeletal zoetrope, inspired by the titular mythological ferryman and powered by festival visitors.
www.festival.org/gdif/whats-on/charon/

IN BRIEF

IN BRIEF EXTRA

AWARD-WINNING APPRENTICESHIPS

For more than two decades the West Midlands-based Warwickshire College Group (WCG) has helped develop some of the UK's most successful engineers, working in partnership with leading employers such as Jaguar Land Rover (JLR) to provide specialist training for apprentices, ensuring they are ready from day one on the job.

Towards the end of 2021, WCG was awarded the Queen's Anniversary Prize, which is awarded to UK further and higher education institutions to celebrate their excellence, innovation and benefits to the public.

The group received the prize in recognition of its training and apprenticeships programme, and its overall contribution to, and ensuring the long-term future of, the scheme across the UK. Apprenticeships provide a productive and effective route to nurturing home-grown talent and developing a workforce that remains engaged, motivated, highly skilled, and qualified. More than 85% of employers say apprenticeships have helped them develop skills relevant to their businesses; 78% said apprenticeships helped improve workplace productivity; and 74% said apprenticeships had directly helped improve the quality of their products or services.

More than 20 years ago, the college overhauled its engineering apprenticeships, becoming one of the UK's first institutions to invite partner employers to help set the agenda, and working directly with them to ensure its training met their needs. The collaboration resulted in the shaping of the college's training programmes, ensuring the students' education met the exact skills required. The group is now one of the UK's largest apprenticeship providers, with success rates at 11% above the national average, and offers more than 100 engineering apprenticeship roles across 35 job families, benefiting advanced manufacturing companies such as Rolls-Royce and Aston Martin nationally.

Here, two of its current apprentices share their apprenticeship journey.

AMELIA WESTBURY

Amelia embarked on an apprenticeship at WCG almost immediately after studying A levels, as she wanted to earn while she learned. The 23-year-old from Warwick is nearing the end of a six-year Applied Engineering Programme Degree Apprenticeship, delivered in partnership with JLR, WCG and the University of Warwick.

The first two years of her apprenticeship were at WCG studying for a foundation degree, while the remaining four were at university. The foundation degree combined specialist employment and academic skills by allowing Amelia to apply what she had learned through study in work placements.

Amelia achieved a distinction in her foundation degree at Warwick Trident College and is now completing an engineering degree through the university. She is a battery engineer degree apprentice working on creation and development of JLR's battery cell model and creating associated data analysis. Her ambition is to join the ranks of senior management at JLR so she can mentor new recruits.

From a young age she wanted to be a barrister, focusing on corporate law where she could use her favourite subject – maths. But after a careers fair at school, where she listened to a group of apprentices relaying their experiences, Amelia realised she might be more suited to an apprenticeship. She also learned more about engineering and the opportunities it offered to put her maths and further maths skills to good use.

Although Amelia won a place at University of Warwick after gaining her A levels, by then she had set her heart on an apprenticeship. Her choice in part was due to her spending her childhood in care – an experience she says taught her to be self-reliant from a young age.

She says: "Since the apprenticeship I have not looked back. I could have gone to university and paid for it, but thanks to the apprenticeship I am still there: it's all paid for and I've gained a lot of invaluable, on-the-job experience along the way."

She continues: "The apprenticeship opened so many doors for me, coming from foster care with no parental support. It allowed me to support myself without worrying about things like fees and accommodation."

Shortly after completing her foundation degree, Amelia won Apprentice of the Year in the large employer category at the City of Coventry Freemen's Guild awards. She has since made the shortlist for a further eight awards.

DILLON HAGAN

Dillon is in the second year of a three-year apprenticeship, delivered by WCG in partnership with manufacturing company Alstom.

The 21-year-old from Liverpool is studying Advanced Level 3 Fitter/Wireperson, covering electrical and mechanical maintenance. He combines full-time work at Alstom with a block placement of two to three weeks at Warwickshire College every couple of months.

Dillon, who is dyslexic, said design technology and hands-on science sessions were among his key strengths at school. He went on to complete an NVQ, Levels 2 and 3, in electrical installation at his local college. The college has supported Dillon with his dyslexia, including extra time for assignments, all of which have earned him distinction marks.

Dillon's relationship with Alstom started when he worked as a part-time industrial cleaner at the company's site in Chester while completing the NVQ. He had applied to several companies for an apprenticeship and was waiting to hear back but was then approached by a senior member of staff at Alstom who offered an apprenticeship at the company's new site in Widnes.

He is now an apprentice fitter/wireperson. After completing his apprenticeship, he wants to study for a Higher National Certificate (HNC) in electrical engineering with Alstom and become a team leader.

Dillon says: "I knew I wanted to pursue a career as a rail technician/fitter wireperson. Apprenticeships are a great option and if you enjoy being hands on then why not work on the rail? There is massive expansion with the new HS2 line meaning more jobs in the future.

"This is just the start of my journey – I will continue to ride this train to my destination!"

Dillon's achievements earned him an invitation to accompany the group to St James's Palace to collect its prestigious Queen's Anniversary Prize for Higher and Further Education. He was also invited back to his old school to talk about the benefits of an apprenticeship and his opportunities with Alstom.

Dillon adds: "One thing my apprenticeship has taught me is that the only limitation you have in life is yourself. I really believe that if you believe in yourself you can achieve anything you want to. It is a lot of work but I have a healthy social life and can still balance all this with my assignments.

"I remember telling people I would be seen as an apprentice of the year back in 2020 and I believe I have done just that."

HOW I GOT HERE

Q&A

JEAN MORRIS
RESEARCH ENGINEER

Jean and a team of engineers from the National Physical Laboratory took a central role in building and testing prototype ventilators against a developing MHRA specification © thisisjude.uk 2020

A passion for physics led Jean Morris to her role as a research engineer at the National Physical Laboratory, where she recently won an award for pandemic service.

WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE/ ENGINEERING?

When I was younger, we had a big book called How Things Work and it absolutely fascinated me. I would spend hours with my twin brother taking apart different things around the house to see how they operated, and our parents hated us! The intrigue behind how everyday things (and more exotic machines like satellites) work has kept me enthralled with engineering.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I studied physics, maths, chemistry, and English at A level and did a master's in physics at Lancaster University (which I got into through clearing!). After university, I joined a graduate scheme at Airbus where I was a space systems engineer specialising in radio frequency analysis of telecommunications satellites (one of the satellites I worked on is now in orbit). I also did a placement in Munich where I worked on machine learning algorithms. After this I became a research engineer at the National Physical Laboratory (NPL) and have worked on a multitude of projects, from atomic clocks and a satellite calibration instrument, to the Kibble balance, which redefined the kilogram in 2019.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

In 2020, I helped set up the new ventilator testing facility and led a team that created a low-cost ventilator prototype, for which the Royal Academy of Engineering awarded me the President's Special Award for Pandemic Service.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

I have a passion for physics, and engineering is essentially realising physics in the everyday world. It's amazing going from an equation or a model to something that moves and works right in front of you!

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

Every day is completely different depending on the project I'm working on. Currently, I do lots of electronics design and test, so I'm often picking up a soldering iron and then doing some design or analysis work on a computer. I also help design the enclosures these electronics boards sit in so I do lots of 3D printing.

Jean tests a prototype ventilator using an oscilloscope © National Physical Laboratory

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

Don't think that just because you're not top of your class that you can't be an engineer. There are so many different qualities that make a good engineer, from working with others to problem-solving to aesthetic design skills. Enthusiasm and a willing to learn are the main attributes of a good engineer.

WHAT'S NEXT FOR YOU?

I hope to be able to publish some papers and work on something related to climate change as that is one the most pressing topics at the moment. Hopefully in a few more years' time, I'll be leading a project of national importance at NPL.

QUICK-FIRE FACTS

Age: **26**

Qualifications: **MPhys**

Biggest engineering inspiration: **Margaret Hamilton (who was responsible for the new code written for the Apollo mission)**

Most-used technology: **3D printing**

Three words that describe you: **sporty, enthusiastic and Welsh!**

OPINION

REPAIR OR REPLACE – WHAT DRIVES A CIRCULAR ECONOMY?

Right to repair legislation is being enacted around the world, designed to help governments achieve their net zero targets and meet obligations to reduce the environmental impact of waste. But is repair always the most efficient solution? Paul Hide, CEO of AMDEA, sets out why sometimes the alternative might be a more sustainable approach.

When the 'right to repair' regulations came into force in July 2021 some commentators heralded it as a major shift in the dynamics of the circular economy, predicting that this would open the gates to a new era of repair rather than replace, driving a step-change in extending the average lifespan of consumer electrical goods.

But is that likely to be the case? To consider the impact of this change, we should reflect on what drives repair versus replacement and what motivates us when faced with appliances that no longer operate as intended.

Domestic appliances are ubiquitous in terms of household penetration. There are an estimated 170 million large and over 300 million small appliances in the UK's 29 million homes. Of the 15 million new appliances sold in the UK last year, most replace an existing product, so what drives this replacement purchase?

We take for granted that appliances usually run reliably for years with no requirement for maintenance or servicing, providing a consistent level of performance at the touch of a button. We keep appliances for longer than many of us realise. In 2020, *Which?* reported that in the UK, on average, large appliances are kept for between 16 and 23 years, depending on the type of appliance. So, based on this length of ownership is it realistic to expect householders to extend the life of their appliances even longer through repair to, say, 25 or 30 years?

Appliances represent relatively high levels of value for what they deliver. From just a few hundred pounds for an appliance that will perform reliably for a decade or more, will the owner want to pay to extend the life further when they can purchase a replacement at, in real terms, no higher a cost than they paid over 10 years ago? Many consumers choose to replace an appliance not because a repair is impossible, but because the appliance has served them very well and they wish to upgrade to an appliance with greater energy efficiency, performance and features.

Manufacturers do not actively aim to prevent repair options. All reputable brands work to maximise customer satisfaction, as happy customers return to buy the same brand again and again. In reality, demand for repair is driven by cost factors. Maintaining an inventory of spare parts incurs cost that needs to be reflected in the price of spares. Repair engineers must be trained and paid a competitive wage: they have vehicles to run and service centre overheads to meet.

Many manufacturers keep commonly requested spare parts for up to 20 years from when a model is placed upon the market. Holding spare parts that are never required is costly and has a huge negative environmental impact: if there has been no demand for them, they must be destroyed or recycled at end of life. The regulations only enforce requirements for washing machines, washer-dryers, dishwashers, refrigerators, and TVs (so electrical goods such as smartphones and laptops are not covered). However, responsible manufacturers are working hard to ensure that they offer a consistent level of support across all the categories that they sell.

There has been much talk about encouraging consumers to conduct their own repairs and maintenance. This has the potential to be a serious safety issue where repairs are undertaken on appliances that use high voltage, have high speed moving parts or generate heat as part of their operating cycle. There is a reason that it takes several years to fully train a repair engineer. Appliances can be complex to fault diagnose and repair and much of the training focuses on safe disassembly, repair and reassembly. We would not want to encourage untrained personnel to attempt more than very simple repairs, such as replacing door seals, shelving or fixing cosmetic parts, to do otherwise would be irresponsible for us as an industry and could lead to an increase in appliance-related fires or personal injury.

A key factor is how modern appliances are designed from an engineering perspective; and the balance of design when considering the factors of performance, durability, and ease of component level service and repair. As an example, many washing machines are now designed with a fully sealed drum and motor assembly. Some repair agents have complained that this makes the appliance impossible to repair down to component level, pushing up the cost of repair should the drum assembly fail. However, there are clear design and R&D factors behind this approach. A sealed drum is proven to perform at a higher level, spinning faster, which helps clothes dry more quickly and reduces the demand for tumble drying, a major use of energy. Sealed drums also have a longer operating life and are quieter when running, factors that are important to the user. They can also be more cost effective to volume manufacture, so when you add all these things together the benefits of modular design and assembly far outweigh the negatives.

The other factor when considering repair or replace is the relative efficiency of older versus newer appliances. For example, fridge freezers now use 40% less energy than those sold a decade ago and washing machines 35% less water. 15% of an average home's energy consumption is used to run appliances and therefore we need to maintain the replacement cycle of older versus newer appliances to reach the target of net zero homes as once built an appliance does not become more energy efficient.

Understandably, there is concern over the environmental impact of end-of-life appliances. We must ensure that they are captured, sent to regulated recycling centres and fully recycled, ensuring zero waste to landfill and the recovery of all reusable materials and precious metals. Manufacturers ensure that appliances that are collected when new models are delivered are recycled through authorised and regulated treatment centres. Models are also routinely stripped for commonly requested spare parts to extend the life of older appliances. This provides a cost-effective route to source spare parts that are no longer in production and can help third-party repair agents access hard to obtain parts.

It is reasonable to expect that appliance purchasers will increasingly consider the environmental impact of appliance ownership and therefore, where a repair is seen as a suitable alternative to replacement, the demand for extended life will increase. Markets respond to demand, so if the customer requests it, my belief is that the manufacture and repair networks will respond to these demands.

AMDEA research shows that sustainability considerations are moving up the agenda for most customers. However, interest appears to more driven by improved energy and water efficiency and end-of-life recyclability, rather than a demand for greater repairability.

There are many steps we can take to support better choices being made. From ensuring the right appliances are chosen, to encouraging greater use of the eco settings manufacturers have designed – especially on washing machines and dishwashers as this can reduce energy and water consumption by over 50%. Manufacturers have a responsibility to ensure that repair information is easy to find and that serviceable parts are easy to access and replace. And we all need to separate all our end-of-life electricals to ensure they reach designated recycling points.

BIOGRAPHY
Paul Hide is the CEO for AMDEA (the Association of Manufacturers of Domestic Appliances). AMDEA is the UK trade association for manufacturers of domestic appliances, large and small. Its members represent over 80% of the UK domestic appliance market, rising to 95% for large white goods. Paul's experience spans 30 years in the consumer technology sector. He is also a Trustee of the Electrical Safety Board, a tech startup adviser, and a Road Racing Commissaire for British Cycling.

BREATHING NEW LIFE INTO WIND TURBINE BLADES

Did you know?

- Some of the longest wind turbine blades are longer than Big Ben lying on its side
- Thousands of blades are retired annually – all made from composite materials, which are currently difficult to recycle
- While chemical engineering may have the key to recyclable future blades, many sectors (including wind) are working on approaches to recycle current blades

Significant progress is, at last, being made in finding ways to make wind turbine blades recyclable. For years, the world's blade-makers have been looking to save composite decommissioned blades from landfill. Writer Dominic Joyeux looks at what is being done with retired blades and spoke to Siemens Gamesa's Jonas Pagh-Jensen about the breakthrough development of RecyclableBlades.

In the 1990s, when the first wave of wind turbines was being installed, was there a plan of action as to what to do with them 25 years later, when they finished their working lives? Landfill would have been seen as one solution, and for the US that option is being used on a large scale. Around 8,000 wind turbine blades are retired in the US annually, with thousands being buried across the country each year. In the last few years, this problem has become more high-profile: one 'wind turbine graveyard' in Wyoming that plays host to 1,000 blades sparked a frenzy of media interest in alternative solutions to landfill.

There is a reluctance to go down the burial route in Europe, where 4,000 are being taken down annually. In June 2021, WindEurope, representing 400 wind energy organisations, called for a Europe-wide ban on landfilling decommissioned wind turbine blades by 2025. Such a ban is already in place in Austria, Germany, Finland, and the Netherlands, with other countries due to follow suit.

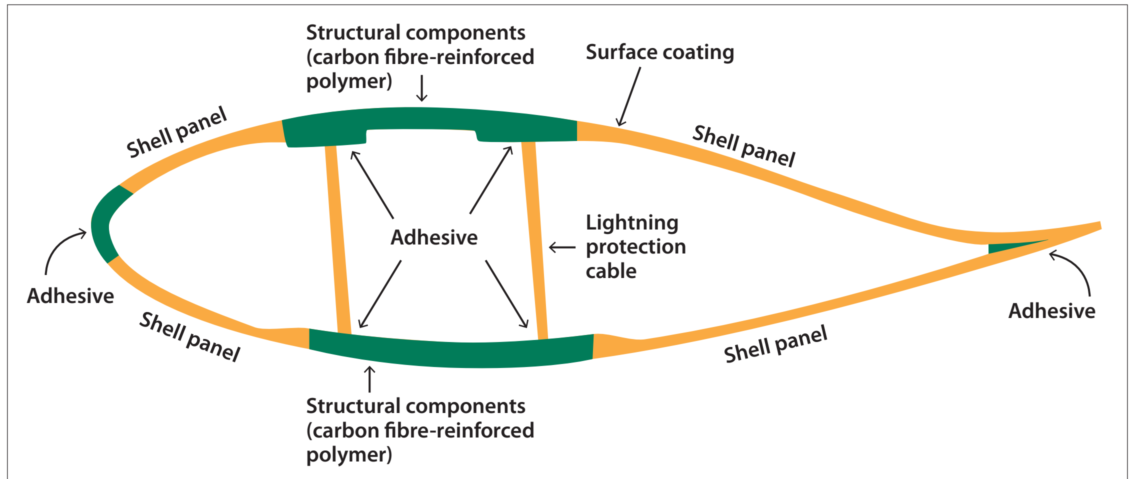
WindEurope's aim is that a landfill ban will accelerate the development of recycling technologies for composite materials. The innovation endgame is to create a circular economy within the wind industry whereby all the resources that go into making the wind turbines can be reused, recycled, or recovered. For decades, that vision seemed a long way off, but in the last couple of years a few significant technological developments have been made.

THE PROBLEM WITH COMPOSITES

Wind turbines are already 85 to 90% recyclable. Components contained within the tower and nacelle, including steel, copper, wire, and gearing, can all be recycled and reused. However, the wind turbine blades themselves are composites built to withstand hurricane-force winds. They are engineered to have high stiffness for optimum aerodynamics, low density to reduce gravitational forces and a long fatigue life, which make them difficult to compress or repurpose. Offshore blades are usually longer than onshore ones, with some stretching to over 115 metres – longer than a football pitch, or Big Ben lying on its side.

Most wind turbine blades are based on a laminate core material, usually balsa wood or high-density foam such as polyethylene terephthalate (PET). This is cast with a polymer resin matrix and reinforced with mostly glass and some carbon fibres. This creates a composite material – combining materials with different physical and chemical properties – that enable greater stiffness and reduced weight for the blades, as well as corrosion resistance. In addition, some electrical items are incorporated to prevent damage from lightning strikes (see schematic 'Generic cross-section of a rotor blade' on next page).

It is because the turbine blades are made with these composites based on thermoset polymers that



Generic cross-section of a wind turbine blade, showing its components. Materials vary depending on the manufacturer, but normally the shell panel (a 'sandwich'-like core material) is made from balsa wood or a foam like PET, reinforced by sheets of glass fibre and cast in a polymer resin. Structural parts of the blade are made from carbon-reinforced polymer. A lightning protection cable is included, as well as adhesives to bind the components together, and coatings that provide protection from corrosion

they are so difficult to break down or reuse at their end of life. During manufacture, thermoset polymers become cross-linked together within irreversible chemical bonds. This makes them resistant to high temperatures and remain in a permanent solid state once cooled.

WindEurope estimates that there is currently 2.5 million tonnes of composite material in use in the wind sector worldwide. And blade waste is only a fraction of the larger composite waste problem. By 2025, it is estimated that blade waste will make up 10% of all thermoset composite waste, with much of the rest coming from the automotive, aerospace and sports goods industries.

So, how are decommissioned blades (and other composite waste streams) being recycled today? And how will companies and countries tackle this avalanche of composite material waste if landfilling them is forbidden?

CEMENT, PLAYGROUNDS AND ENERGY

Most blades being taken down from their turbines today are bonded with glass fibre (carbon fibres have been a late addition to blade strengthening). Today, German blades form the bulk of European blade decommissions. It is also in Germany – where direct landfilling of blades is banned – where one process has been developed that uses the plastic components for generating energy and the glass fibre as a raw material for making cement.

Sustainable waste management company Geocycle has developed and honed this process at LafargeHolcim's cement plant in Lägerdorf, North Germany. The process starts at the wind farm, where blades are chopped into more manageable lengths. These are then taken to a pre-processing plant where they are shredded, with magnets extracting the metals. The remaining blade powder is mixed and bound with a humid substrate material consisting of other recycled items, including paper waste.

At Lägerdorf, the polymer matrix is recovered as thermal energy in the waste-to-energy plant. The mineral content, from the ground glass fibre, is used as a part substitute for the silica and carbon clay used to make cement. Using this process means that one tonne of blade waste enables a reduction of 110 kg of CO_2 emissions and saves 460 kg of raw materials in cement production. In 2020, Geocycle processed 15,000 tonnes of composite waste, of which 10,000 tonnes were from wind turbine blades. The company is now looking to implement this cement co-processing, also known as the cement kiln route, in other European countries.

Unfortunately, the cement route is only suitable for glass fibre-reinforced composites because of the health risks of grinding carbon fibre composites, which would produce asbestos-like fibres. Industry and academic innovation programmes worldwide are working on numerous other approaches, with various end uses (see table).

Of these, mechanical grinding is an effective, low-cost and low-energy approach for thermoset composites. The recycled products can be used as reinforcement or fillers, but there is also 40% material waste generated during grinding. It is not yet price-competitive, so at the moment, it is not a widely used option for blade disposal.

With pyrolysis, chopped up blades are incinerated at 500 to 600°C until the composite fibres separate from the polymer matrix in the oven. While the fibres can be reclaimed and reused with a slightly reduced strength, the polymer byproducts, such as syngas and oil, can be used as an energy source – for example to power combustion engines. However, the high investment and running costs mean that it is currently only economically viable for retrieving carbon fibres, as glass fibres degrade too much at the high temperatures used.

TECHNIQUE	USE
Thermal (such as pyrolysis) High temperatures used to separate fibre from polymer matrix	• Energy (breakdown of polymer into oils and waxes) • Carbon fibres can be recovered, albeit at a slightly reduced strength
Mechanical grinding Composites turned into a fine powder	• Additives • Cement kiln co-processing (as in Geocycle's process)
Reprocessing Includes recovering whole mats; or milling or chopping material and reusing as is or compressing into pellets	• Reuse in thermoplastics for injection moulding (pellets) • Additives with tailored electrical and thermal conductivity (milled fibre) • Automotive industry (chopped fibre)
Chemical solvolysis Dissolving the polymer matrix with heated water or a chemical solvent	• High-quality glass and carbon fibres produced (however, technology still being scaled up)

BLADES IN PUBLIC SPACES

Some blade manufacturers have combined with artists and architects to creatively reuse blades for public spaces. In 2017, one 28 tonne, 75-metre blade was installed as a monumental sculpture in the heart of Hull for 11 weeks when it was the UK City of Culture. In Rotterdam, a children's playground has been made from five discarded blades. Blades have also been used to construct bus stops, cycle sheds and public benches.

© Siemens Gamesa

Some projects have repurposed whole sections of blades as construction materials for playgrounds, bridges and roofs (see 'Blades in public spaces').

But despite all of this, new solutions are needed: in the UK, 90% of fibre-reinforced plastic waste was sent to landfill between 2018 and 2019. By 2025, there will be 25,000 tonnes of new blade waste every year, and that this amount will double by 2030.

Looking to the future, a potential game-changer is if the cross-linking of the chemical bonds in making these polymers could be reversed, making it significantly easier to extract carbon fibre intact. Siemens Gamesa, one of the world's top three wind turbine manufacturers, has recently made this breakthrough.

RECYCLABLE BLADES

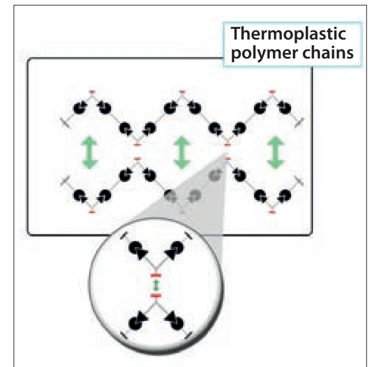
Siemens Gamesa launched the world's first recyclable wind turbine blade in September 2021. The first six 81-metre blades were built in Denmark, and now more are being constructed in the company's UK factory in Hull. Later in 2022, the giant blades will be installed at the RWE Kaskasi offshore wind farm in the North Sea.

Jonas Pagh-Jensen, Siemens Gamesa's Environmental Health Specialist, has been closely involved with the project since 2018, helping it progress from being a research-based proposal to an accredited, commercially viable product.

Jonas says that to make the journey short, and to minimise changes to the manufacturing process, Siemens Gamesa worked closely with the materials science R&D team at the Aditya Birla Group, a partner manufacturer that produces chemicals, on changing the resin that binds all the components of a blade together. It did not seek to alter the design and build of its IntegralBlade – its flagship blade, cast in one piece from fibreglass-reinforced epoxy resin. Instead, the project set out to alter the durable thermoset resin that fuses the fibreglass, plastic, wood, and metal – usually rendering these components permanently inseparable.

Aditya Birla's testing facilities and labs worked on resin and recyclability options using the company's existing Recyclamine technology. The new resin has a slower reactivity that improves processability. By enabling it to cure faster than existing materials, it cuts blade manufacturing times to about the same as 'normal' blade manufacturing times. As the blade manufacturing process is the same, then there is no increased implementation risk with the new resin system.

The groundbreaking element of the resin is in the change in its chemical structure. Ordinarily, the polymer chains of the regular thermoset resin crosslink irreversibly when brought to high temperatures. In the new resin system, the polymer chains crosslink into a network with cleavage points that can be chemically



The RecyclableBlade's resin has cleavage points that can be opened with a mildly heated acidic pH solution – thus breaking the cross-linked network. The resin dissolves and separates from the rest of the materials enabling all a blade's constituent parts to be recycled © Siemens Gamesa

The assembly of the wind turbine blades at the Hull factory is done entirely by hand, with rolls of fibre shaped to create the composite structure that makes up the blades © Siemens Gamesa opened in the right conditions. When the time comes for the RecyclableBlades to be decommissioned, they will be cut up and immersed for a few hours in a heated mild acidic solution. Jonas says that this is similar in strength to the "ones you make to pickle cucumbers to go with your burgers. The resin then dissolves and separates out material waste streams consisting of plastics, fibres and core materials."

Because of the relatively low temperatures used to heat up the mild acids, the strength of the waste stream materials are not compromised, so have a high reusable value. The reclaimed plastics could be used for sporting goods or household appliances; while the carbon fibres will still be strong enough for applications such as storage tanks, skis, automotive or aviation industry uses. The glass fibres won't be as strong, as their strength decreases owing to the loads that they will have carried over the lifetime of the blade. However, they could still be turned over to the car industry as filler material for doors and seating. They could even be reapplied with new fibres and made into new blades – completing a full blade-making circle.

Siemens Gamesa is not the only wind sector player that has come up with a solution to this problem. In early 2022, the ZEBRA (Zero wastE Blade ReseArch) consortium announced the making of a prototype blade using thermoplastic resin. The 62-metre blade will now undergo structural testing and a validation of its end-of-life recycling with the aim of reusing all of its components.

There are also newer projects and initiatives seeking solutions for blade recycling (see 'Strengthening recycled glass fibre').

A 62-metre-long blade made by the ZEBRA consortium, based on a recyclable thermoplastic resin made by Arkem © ZEBRA consortium

ON THE HORIZON FOR BLADES

There is growing pressure to extend the life of existing blades through maintenance and innovation to maximise their working potential. In Europe, it is increasingly becoming a requirement for blade manufacturers to outline how they will deal with end-of-life recycling before being allowed to start a wind power project.

However, it is not only a wind industry problem: blade waste represents just a fraction of all estimated thermoset composite waste. The relatively low volumes of composite blade waste make it difficult to build a dedicated blade recycling business based just on this waste stream. Engagement from a variety of composite-using sectors, such as automotive and construction, will be required to develop cost-effective solutions.

At least, and at last, there is now a momentum to increase recycling rates and deal with waste pollution. This impetus has been helped by waste legislation. There now seems to be an overwhelming public and business desire to increase resource efficiency and help develop a more circular economy. Finally, progress is being made that could spell an end to the 'graveyards' such as those in Wyoming.

STRENGTHENING RECYCLED GLASS FIBRE

Many wind turbine blades based around the UK will reach the end of their 20 to 25 year working lives by the mid-2030s. Researchers within the Advanced Composites Group at the University of Strathclyde have been given a grant of £1.3 million by Innovate UK to find a way to recover and recycle the glass fibre components of discarded blades. Working with five industrial partners, who have contributed more than £700,000 to the project, the Strathclyde team will commercialise a new method that it has developed to separate glass fibre and resin components in composites.

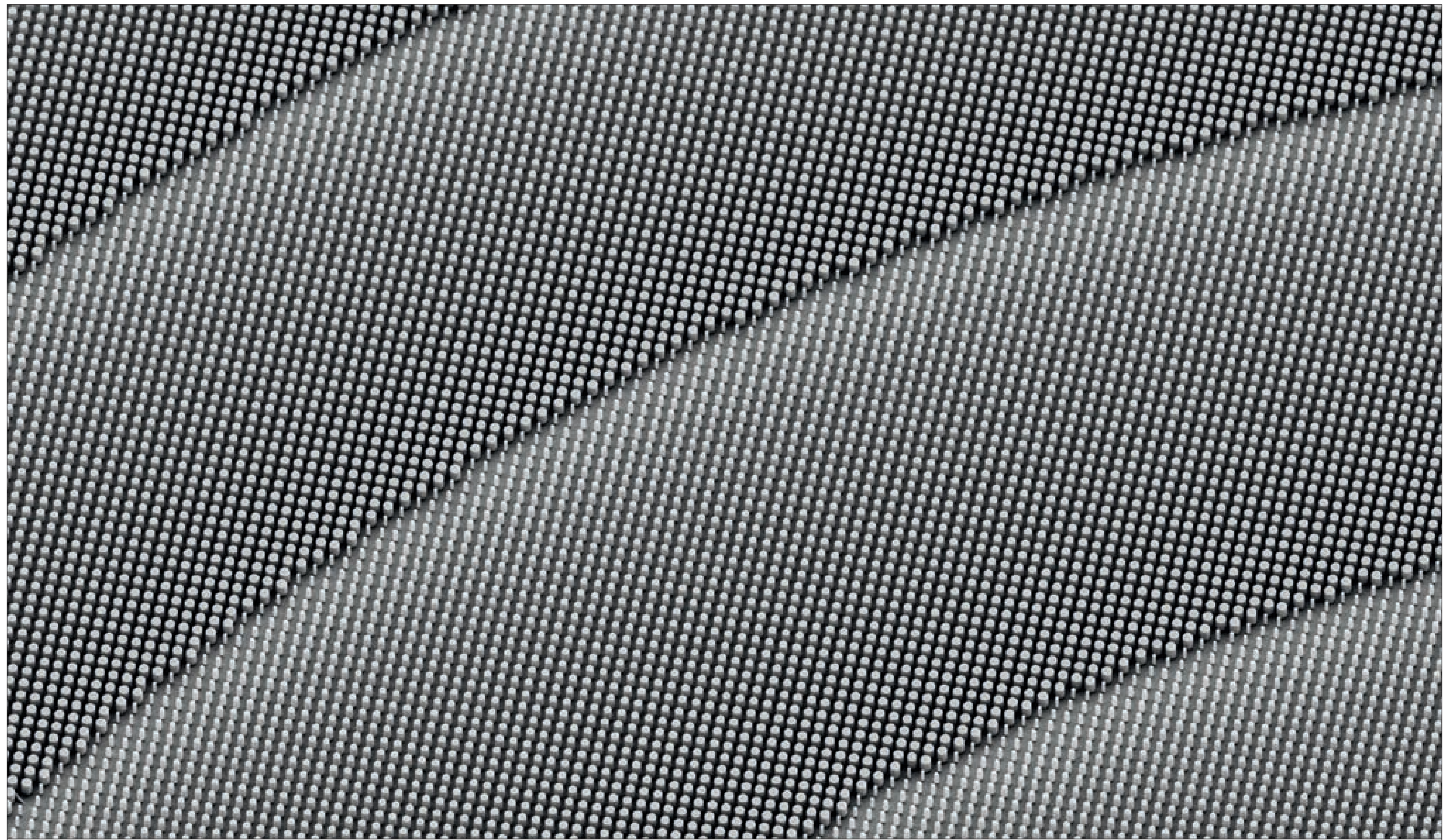
Ordinarily, the loss in strength and surface functionality during the recycling process diminishes the attraction of using recycled glass fibres. The Strathclyde researchers have developed a proprietary approach that uses a fluidised bed process and regenerative treatment to significantly increase the tensile strength of these fibres – by about 300%. Further work has established that improved recycled glass fibre strength and fibre–polymer adhesion can be achieved with a mixture of new regeneration treatments under development.

Dr Liu Yang, Head of the Advanced Composites Group and recipient of a Royal Academy of Engineering Industrial Fellowship, has said of the three-year project: "Retaining and redeploying the embodied energy in the fibres will be essential as we move to a more circular economy. These components can then be reprocessed, moulded and reused in industries such as automotive and construction."

Dominic Joyeux spoke to Jonas Pagh-Jensen, Siemens Gamesa's Environmental Health Specialist, for this article.

METAMATERIALS, METALENSES AND BEYOND

For thousands of years, humans have been making optical components by melting, casting, grinding, and polishing commonplace materials. Manufacturing techniques borrowed from the semiconductor industry are now being used to make ultrathin 'metalenses', which could slim down cameras still further, and even allow handheld devices to sense all kinds of things beyond the visible spectrum. Dr Eric Plum from the University of Southampton explains how these have developed.



A metalens closeup: scanning electron microscope image of a meta-optical element designed and manufactured by NIL Technology, made up of arrays of pillars smaller than 100 nm in height. The variation in diameter of the pillars slows light by different amounts © Image courtesy of NIL Technology

Did you know?

- Most current smartphones have a stack of six or seven lenses in their cameras
- Metalenses can be 100x thinner than a human hair, and focus light with nanopillars rather than curved glass
- They could replace stacks of lenses in current cameras and even help us see smaller than the diffraction limit of light

Made from volcanic glass, the first known artificial mirrors date back 8,000 years; while Egyptian hieroglyphs suggest that lenses were already used in ancient Egypt. One of the earliest known lenses, made in about 750 to 710BCE, is a polished quartz crystal that may have been used as a magnifying glass. A few hundred years later, Greek writers reference burning-glasses used to make fire – to the detriment of enemy ships if Archimedes is to be believed. The Roman Emperor Nero was even said to have used a concave emerald to watch the gladiators (thought to be for correcting near-sightedness or perhaps a kind of sunglass).

Optical technologies have clearly come a long way since then. Today, lenses can be mass-manufactured and precisely shaped to fit any number of functions, whether it's capturing macro images on a smartphone, observing the very large or very small with telescopes and microscopes, or simply correcting astigmatism. But despite this huge progress in optical engineering, the basic principles have remained the same.

Modern optical technology – such as cameras, microscopes, or telescopes – is still largely based on lenses and mirrors, and this is key in determining their size and weight. Indeed, the ever-decreasing thickness of the modern smartphone is partially determined by the thickness

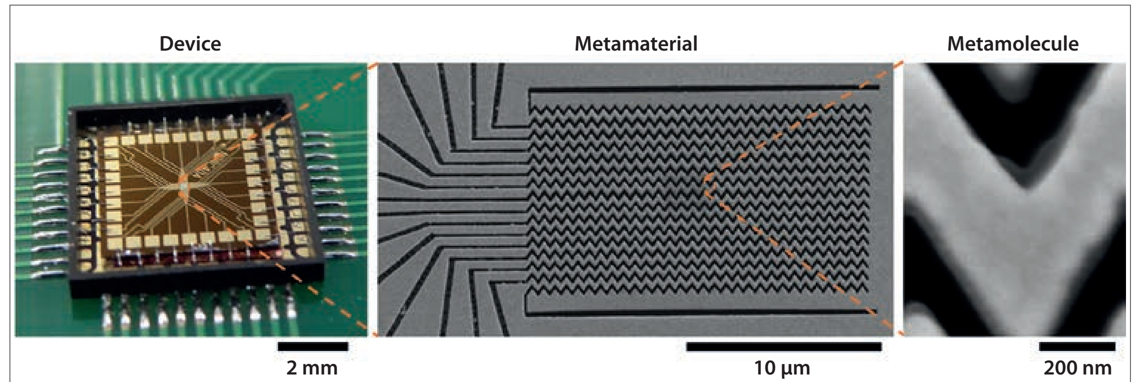
(Main image) The Morpho butterfly's iridescent blue wings are made up of thousands of scales © Unsplash. **(Inset) The Christmas-tree-like nanostructures, seen here through a scanning electron microscope, are responsible for its vivid colour because of the way they interact with light** © Shinya Yoshioka, Osaka University

of the stack of lenses within its camera. This is the reason for the so-called 'camera bump' on most phones – where the lens of the camera protrudes beyond the flat body of the phone.

About two decades ago, early research into metamaterials began. These materials have unusual properties not found in nature, thanks to the shape, symmetry and composition of their nanoscale building blocks. Now, the same nanofabrication techniques that have enabled manufacturers to pack increasingly more transistors onto computer chips are being explored to make metamaterials with exciting optical properties. Not only could these make smartphones and cameras even more compact – they could also bring new kinds of sensing out of the lab and into entirely new places.

MICROSCALE OPTICS AND METAMATERIALS

The optical properties of materials are controlled by their structure on the sub-wavelength scale. For light, with wavelengths of hundreds of nanometres (nm) – billionths of a metre – this is the arrangement of atoms, molecules, and the repeating lattice structure of crystals. Structural features this size interact with light in unique ways. For example, calcite's crystal lattice produces birefringent properties, meaning that it doubly refracts light (which creates a double image of objects seen through the transparent crystal). A Christmas-tree-like nanostructure is why the *Morpho* butterfly's wings



Controllable metamaterial: an artificial metamaterial that can be reconfigured to control its properties in specific areas. When an electrical current is applied to an individual nanowire (zig-zag-shape), the nanowire is heated, thermally expands and is displaced. This change in the metamaterial's structure on the nanoscale results in a change of its optical properties. This 100 nm-thick metamaterial, made from gold on silicon nitride, was made using focused ion beam milling at the University of Southampton
© Nanophotonics & Metamaterials Group, University of Southampton

appear so vividly blue, as light diffracts on the nanotrees and interferes.

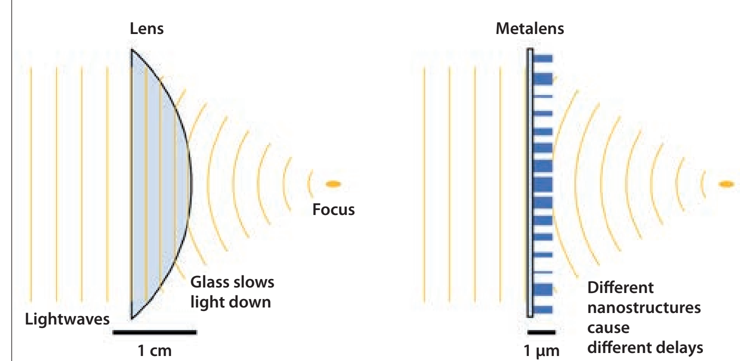
Using nanofabrication to engineer the structure of materials on this scale allows us to make metamaterials. When metamaterials emerged at the beginning of the 21st century, initial excitement was driven by the opportunity to engineer exotic properties: in particular, cloaking materials, and zero and negative refractive index materials. Cloaking materials have received much fanfare in the press as a way to make an object invisible by guiding light around it to hide it from view. Meanwhile, zero refractive index materials can be used to enhance nonlinear optical effects, for example to make artificial materials that can efficiently change the colour of light. On the other hand, a material with a refractive index of –1 could be used to make a perfect lens (with infinite resolution).

Arranging the same nanoscale components in different ways can result in drastic changes in a material's properties. This can be easily understood by considering carbon atoms, which can form the soft, black graphite found in pencils, or brilliant, transparent, and hard diamond (not to mention fullerenes, graphene, and carbon nanotubes, which all have radically different properties again).

Metamaterials consist of metamolecules, which may be reconfigured to change the metamaterial's properties. 'Controllable metamaterial' (above) shows an example of a device in which individual nanowires can be moved independently by electrical currents. Although the device shown is a proof of principle, with careful engineering, similar metamaterial devices could be used as spatial light modulators (like those that manipulate light in projectors) for creating holographic videos. Structures like this have been shown to respond to temperature, electric or magnetic fields, sound, and even light. This provides an opportunity to develop smart materials and sensors typical for applications like magnetic field sensing or radiation detection with very high spatial resolution.

THE LIGHTEST LENSES YET

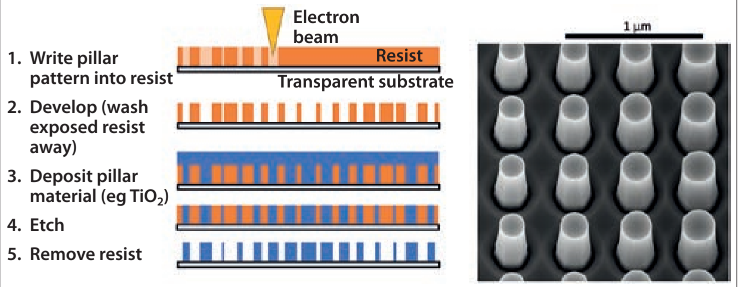
Today however, the metamaterials advance that's



Slowing down light: a convex focusing glass lens slows down light for longer at its centre (the more glass, the more delay), than at its edges, bending the wavefronts of the light towards a focal spot. A large-diameter lens that focuses light strongly must be thick as it needs to delay light a lot at its centre. In contrast, a metalens uses nanostructures that reradiate the incident light with the right delay. Thanks to the nanostructures, the thickness of the lens is less than 1 µm. For comparison, a human hair is typically 70 µm thick.

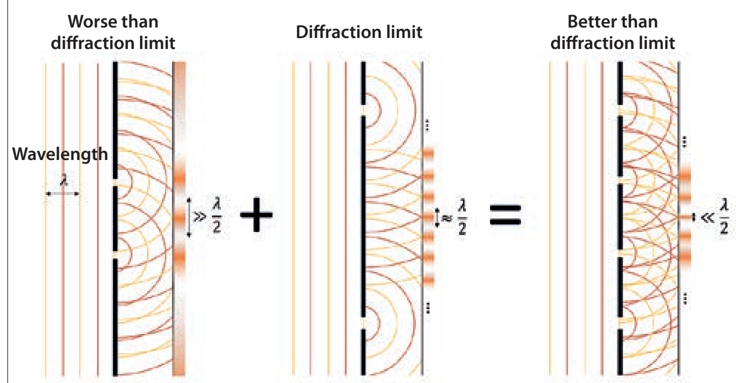
on the brink of making a commercial impact is the metalens, which could transform the size, weight and complexity of optical systems. If cameras and phones are to continue on their trajectory of miniaturisation, conventional glass or plastic lenses won't cut it. As illustrated in the 'Slowing down light' figure (above), these refractive lenses work by slowing down and therefore bending wavefronts of light, which requires them to be thick in certain regions.

Shrinking a lens down to an essentially flat surface requires a different approach. In a typical metalens, a surface (such as a flat, ultrathin piece of glass) is covered in nanoscale pillars. The size of the pillar determines how much it will delay light. To be able to delay the light field efficiently, the pillars need to be made from a material with a high refractive index, while low absorption is needed to make a transparent lens. Typical metalenses for visible light use titanium dioxide (widely used



Making metalenses: metalenses can be prototyped using electron beam lithography (left), which offers the flexibility to try many different designs:
1. A beam of electrons exposes a layer of resist where pillars should be formed.
2. The exposed resist is washed away.
3. The pillar material is deposited with sufficient thickness to fill all the gaps and produce a flat surface.
4. Excess pillar material is etched away.
5. The remaining resist is removed and the metalens remains.

Right: gallium nitride pillars made by electron beam lithography at Kelvin Nanotechnology (Glasgow). Metalenses can be mass produced by either using the pillars as a stamp (called nanoimprint lithography) or by replacing the first step with deep-UV lithography, for example by STMicroelectronics (Crolles, France).



Beating the diffraction limit: waves have alternating crests (yellow) and troughs (red) that repeat after a distance known as wavelength λ. Light waves consist of an oscillating electric (and magnetic) field, with crests and troughs corresponding to the largest field in opposite directions. If light waves pass through a pair of slits, they will form a series of dark lines (crest meets trough, white) and bright lines (crests or troughs meet, orange). The lines become narrower as the slits are moved further apart until they reach a minimum width of half a wavelength: the diffraction limit. Smaller, indeed arbitrarily small, lines or focal spots may be achieved by combining several pairs of slits.

as white pigment) or gallium nitrude (used in LEDs) and metalenses for infrared light use silicon (used in electronics).

This means that just like a conventional lens, a nanostructured film less than a micrometre thick can direct light into a focal spot on an image sensor. It can even be used to generate a hologram with any desired distribution of light, for example, as a security feature for bank notes or passports. But while conventional lenses are made by moulding and polishing glass or plastic, metalenses and metamaterials can be made with the same manufacturing techniques as the semiconductor industry uses to make computer chips. Prototypes can be made using electron beam lithography (see 'Making metalenses' above), while deep-UV lithography provides a cost-effective solution for mass production of thousands of lenses in parallel.

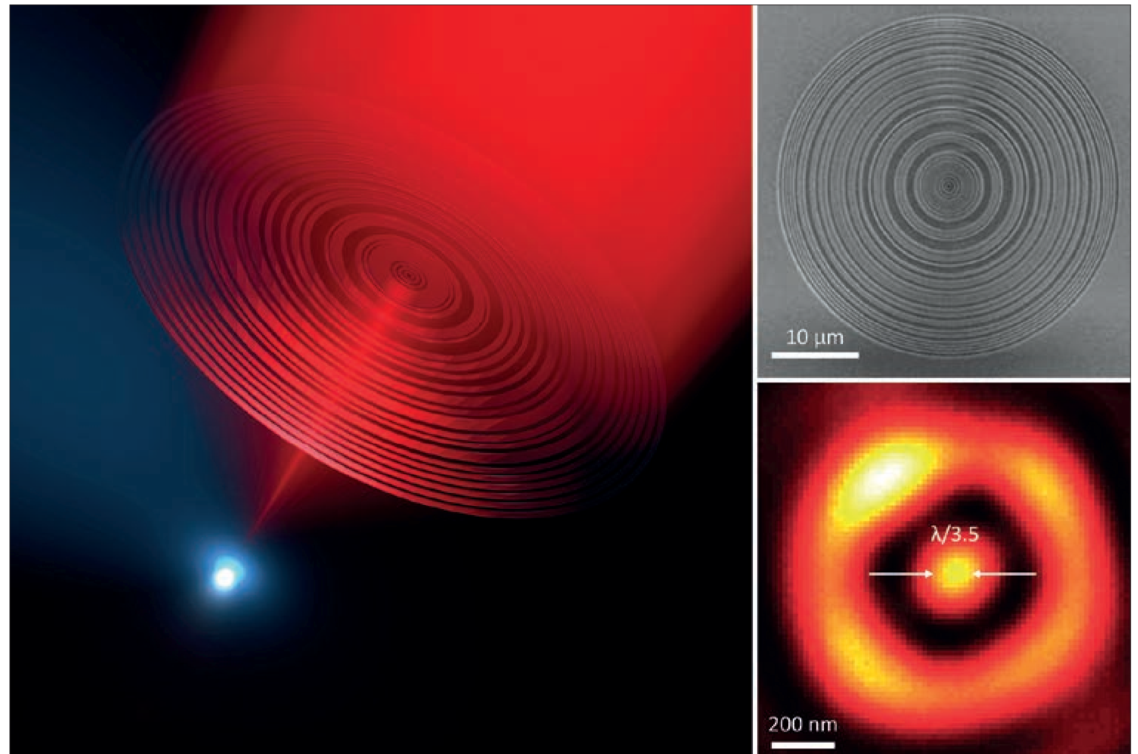
However, a metalens can be more than an extremely thin and light version of a conventional lens. With the right nanostructure engineering, the shortcomings of normal glass lenses can also be avoided. These shortcomings are why a stack of six or seven conventional lenses is required in a state-of-the-art mobile phone camera: to compensate distortions and aberrations. Metalenses promise not just thinner lenses, but also fewer of them, which could spell the end of the camera bump. They might also surpass the image quality of today's cameras with sharper, brighter images.

ZOOMING IN ON VIRUSES

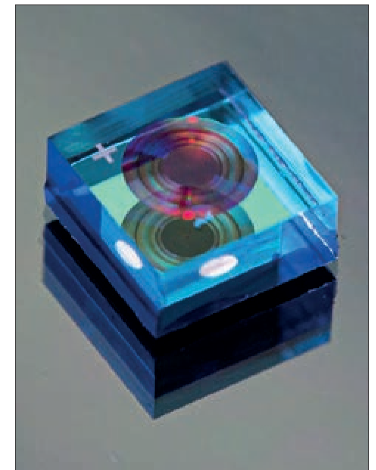
Another major challenge for conventional lenses is resolution. Much of our understanding of the biological world is based on what we can see through optical microscopes. Conventional lenses can focus light to a spot that is approximately half a wavelength in size, which is about 250 nm for visible light. This so-called 'diffraction limit' is what prevents us from seeing viruses and proteins using light microscopes, as the resolution isn't high enough. Focusing light into smaller spots is the key for seeing these smaller objects. (Other imaging techniques allow imaging of things this size, but samples must undergo harsh treatments such as being crystallised or cryogenically frozen. One example is electron microscopy, as seen in images in this article, which requires samples to be placed in a vacuum.)

Fortunately, metalenses may be engineered to circumvent the diffraction limit, enabling light – or any other wave – to be concentrated in much smaller spots. The key to beating the diffraction limit is a concept known as superoscillations. The sum of slowly oscillating waves can have features that oscillate fast. 'Beating the diffraction limit' (above) shows an example: light waves passing through slits in a screen, forming an interference pattern of bright and dark lines. The lines generated by a pair of slits have a width of at least half of the wavelength. However, if we combine pairs of slits, the superposition of the light fields can have much smaller features. Careful engineering of such structures allows light to be concentrated into lines or spots of much smaller size.

The final figure (next page) shows a superlens consisting of concentric ring slits in an aluminium film, which concentrates red light into a spot of less than 200 nm diameter. The price to pay is that tiny focal spots will only contain some of the incident light, but that has not prevented the development of super resolution microscopy far beyond the diffraction limit, for biology and beyond. Indeed, recent experiments at the Nanyang Technological University



(Left) Artistic impression of a superoscillatory lens focusing light. (Top right) SEM image of a superoscillatory lens consisting of many circular slits in an aluminium film; (bottom right) the focal spot of 185 nm diameter that it produces when illuminated by red light of wavelength λ=640 nm © Nanophotonics & Metamaterials Group, University of Southampton



A single NIL Technology meta-optical lens, incorporated into a camera module
© NIL Technology

(Singapore) and at the University of Southampton demonstrate that tiny superoscillations can be used to create an 'optical ruler' that detects movements as small as 1 nm, corresponding to a resolution of λ/800 (where lambda, λ, is the wavelength). This indicates even atomic-scale resolution may be within reach.

SHRINKING DOWN DIAGNOSTICS AND VR

The shared vision of thin smartphone cameras and their enormous market potential has accelerated the transition of metalenses from university labs towards mass manufacture. Startups such as Metalenz and NIL Technologies (NILT), large manufacturers such as STMicroelectronics, and major global consumer electronics companies such as Samsung are all working to drive the quality of metalenses up and their cost down.

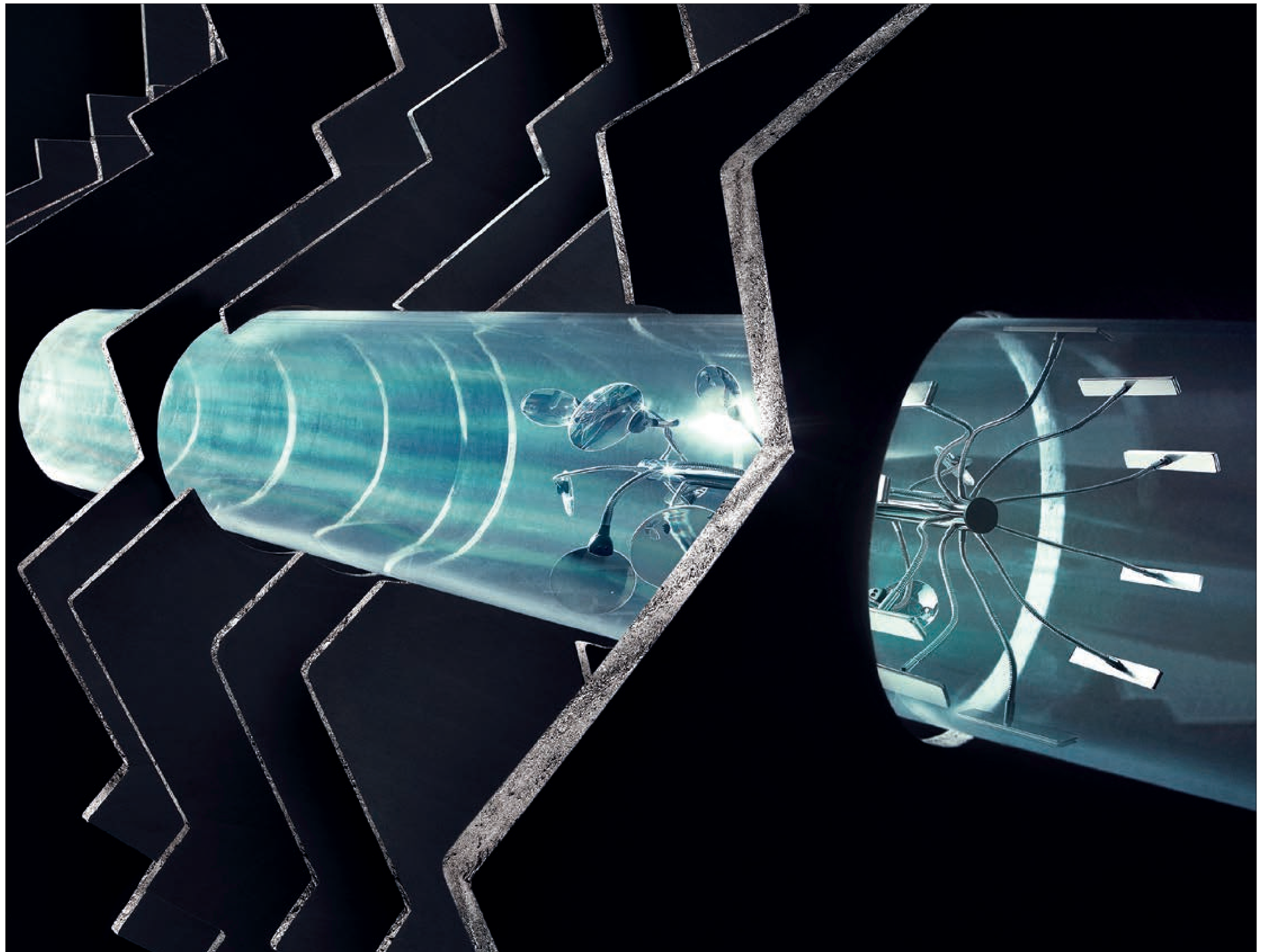
Both Danish optics startup NILT and Harvard spinout Metalenz are on the cusp of mass production of their metalenses. NILT's first commercially ready metalenses are targeted at 3D sensing for face identification and assisting autofocus in smartphones. Meanwhile, Metalenz is working with device manufacturers on 3D cameras for mobile devices and has said its lenses will be in consumer devices in 2022. The company has partnered with European semiconductor specialist STMicroelectronics to develop a manufacturing process for the lenses, and also plans to develop lenses for lightweight augmented and virtual reality systems.

This consumer technology focus is shared by NILT. "[Metalenses] have powerful capabilities beyond traditional optical lenses as they have completely flat surfaces, reduced thickness, and improved quality compared to classic refractive lenses," explains Theodor Nielsen, NILT's CEO and Founder. "They will be a game-changer for optical applications in consumer products, smartphones, and augmented, virtual and mixed reality devices."

The growing industry traction in these areas is likely to act as a catalyst for the wider application of metalenses and metamaterials, resulting in new applications altogether. Beyond making smartphone cameras lighter, cheaper, and better, what about shrinking large scientific or medical imaging equipment down to a device that fits in the palm of the hand? Metalenz has said that with the right sensors, smartphones could identify specific molecules in blood for diagnostics, monitor air quality or tell whether a piece of fruit is ripe. Metalenses could improve LiDAR, robotic and machine vision, and even medical imaging, says NILT. Work from Harvard's Capasso group (from which Metalenz spun out of) has suggested the possibility of turning a contact lens into a compound microscope. While we may not be there yet, it's safe to say we've come a long way since Nero's emerald.

BIOGRAPHY

Dr Eric Plum is a Principal Research Fellow at University of Southampton. After studies in Aachen (Germany), Southampton (UK) and Socorro (US), he joined Southampton's Optoelectronics Research Centre, where he has been leading research on metamaterials since 2010. He is a Marconi Young Scholar, Institute of Physics thesis prize recipient, and has been a Fulbright Scholar and Advanced Leverhulme Trust Fellow.



Ruptures in underground oil and gas pipelines could be extremely damaging, with fractures running at up to 2,000 metres per second over tens of kilometres. British Gas's 'intelligent PIG' (pipeline inspection gauge) investigates the pipelines, being pushed along inside by flowing gas or other liquid and can accurately detect defects so maintenance can be arranged (image commissioned as part of a conceptual photography series to commemorate the 50th anniversary of the MacRobert Award, which British Gas won with this innovation in 1989) © Ted Humble-Smith

ADDING VALUE THROUGH MAINTENANCE

Did you know?

- System failures result in reduced profitability, but can also cause disruptions to services and sometimes have more serious impacts
- Preventive maintenance can help to avoid or minimise such disruptions before a system fails
- Various technologies are being employed in combination to support this approach and deliver successful maintenance strategies

Failures of transport, power and other essential services cost many billions a year. It is the role of maintenance engineering to minimise those disruptions and to keep society running smoothly. Professor John Andrews from the University of Nottingham explains how sensor technology, remote sensing, big data, artificial intelligence, robotics, and other technologies play increasingly important roles in maintenance strategies.

No component in any system lasts forever. For example, in a radio the components include resistors, transistors, capacitors, inductors, integrated circuits, and more – all of which are built to last several years and when any of these fail, the radio will more than likely stop working. On a bigger scale, such as in transport and other infrastructure, the knock-on effects of a failed component can cause a wider system failure that results in lost productivity and income at best. At worst, failures in safety critical industries can lead to injuries and fatalities to the workforce or the general public. Maintenance engineering brings together a growing suite of technologies to ensure that the systems that we rely on operate safely and at an acceptable cost. And those costs can be high. For example, organising maintenance to ensure a safe and reliable railway network is a massive and costly undertaking. In 2019/20 Network Rail spent more than £1.7 million on maintenance.

Other major engineering industries, such as aviation, nuclear power, and offshore oil and gas production, also spend staggering amounts to keep their infrastructure operating safely and reliably. For example, nearly a third of the total expenditure of Severn Trent, one of the largest regulated water and sewage companies in England and Wales, goes into maintaining reservoirs, treatment works, pumping stations, and pipes.

Poorly performed or ineffective maintenance can also prove costly in other ways, sometimes contributing to accidents. In aviation, about 12% of aircraft accidents cite maintenance as a factor. Public inquiries showed that poor maintenance played a part in train derailments at Hatfield in 2000 and Potters Bar in 2002, both resulting in fatalities. The Hatfield accident, caused by cracked rails, might not have happened had engineers maintained the rails following the appropriate comprehensive procedures. A Health and Safety Executive report into the Potters Bar accident indicated that bolts in a poorly maintained set of points had come loose causing the derailment.

For many years, maintenance was simplistically viewed as a responsive process, fixing components as and when they failed. Today, there is better understanding of maintenance's impact on costs and profitability. Most industries now try to avoid, or minimise, system failures by moving from responsive, 'fail and fix' maintenance to a more sophisticated 'predict and prevent' approach.

This approach taps into broader advances in engineering, such as artificial intelligence (AI) and data management, to analyse and control the state of the components in a system and to understand how to optimise the processes involved in supporting systems and devices in service and operation.

PREVENTION BEFORE FAILURE

Preventive maintenance aims to replace components as they approach the end of their expected useful life – the closer the replacement is to the end of its life, the more efficient the process – to avoid the cost and inconvenience of breakdowns in service. Determining when to replace a component is a delicate compromise between its discarded life, the risk of system failure, and choosing the most convenient and least disruptive time to perform the work – closing a system for maintenance incurs costs for spares, equipment and workforce labour, and also impacts on the system's ability to generate revenue. However, without this preventive maintenance, there could be more system failures and breakdowns that incur maintenance costs and lost revenue – which could be passed on to the general public through an increase in rail ticket fares, for example.

Using this approach gives engineers early warning of likely failures and dictates the type and frequency of the maintenance that they should carry out. Such strategies can determine the state of the system or structure, control its rate of deterioration and remove components before they fail. It will also define when maintenance will become ineffective and, for example, the system gets to a point where maintenance provides little improvement.

Engineers may also choose to carry out opportunistic maintenance: when a system is taken out of service for maintenance, they may take the opportunity to work on several parts of it. While one component could be degraded, other parts may not have reached the point that would normally need work, but early maintenance can prevent having to take the system out of service again when another part fails. This approach also proves to be cost-effective when specialist equipment is available for work on similar components, avoiding the need for the same specialist equipment in future.

MONITORING BEFORE MAINTENANCE

Manual inspection or some sort of monitoring of the system and its components is an essential element of maintenance. Inspection establishes the components' condition and is used to decide interventions. For many, manual inspection guides when to do maintenance and what should be done; while for others, monitoring a key performance characteristic, such as vibration, can establish the system's condition and how close it is to failure, issuing alerts when the system reaches specified levels of degradation.

Most of us are familiar with this strategy in the shape of the annual car service, which follows a checklist of things to examine – tyres, brakes and exhaust, for example. However, many car-makers are moving away from this rules-based scheduled check-up in favour of predictive maintenance. BMW Group, for example, makes increasing use of sensors, data analytics and AI as an alternative to the annual health check, to forecast when a car needs maintenance, when it is time to replace components and when premature replacement would be wasteful.

BMW also employs the same predictive maintenance approach to its production lines. In bodyshops, for example, it has welding guns performing 15,000 spotwelds a day. Welding guns around the world feed their data into a cloud-based computer system, where algorithms analyse what is going on and display the output on a dashboard to support the maintenance processes. A similar data-fed approach is also a part of the maintenance regime at BMW Group Plant Regensburg, where control units on conveyor systems send real-time data on electrical currents, temperatures and locations to the cloud. Again, predictive AI models analyse the data, detect anomalies and locate technical problems.

Manual inspection can be difficult when trying to monitor systems that are distant, difficult to reach or dangerous. In these cases, sensors can monitor an asset and report back on its performance to a data hub to establish the need for maintenance. The number of bridges worldwide is an obvious example of where remote condition monitoring could deliver significant benefits. In the UK alone, Network Rail is responsible for about 30,000 bridges while National Highways is responsible for maintaining around another 9,400. Sending engineers to inspect bridges is time-consuming and expensive; fortunately, research is making rapid advances in monitoring bridges and interpreting the data to establish management needs.

One challenge is that each bridge spans a unique obstacle: a road, river or railway line for example. One size doesn't fit all when it comes to the analysis strategy. For some critical structures, sensors can measure movement and vibration. However, the large numbers involved means that installing sensors on all bridges, like performing manual inspections, is expensive. Researchers are tackling this challenge by putting sensors on vehicles that pass over bridges. In this way, vehicles can monitor the condition of structures as they travel over them, providing a substantially simpler and cheaper way to establish a bridge's condition.

In some systems, an alternative to embedded sensors is for autonomous systems to remotely monitor assets. The petroleum industry has used uncrewed aerial vehicles (UAV) in this context to inspect pipelines.

DATA-DRIVEN

The key to effective decision-making on maintenance of any asset is to understand how it deteriorates with use. For this, data is needed, an area that has benefited from the availability of cheap sensors and the ability to collect, store and process large quantities of data.

Industry makes increasing use of data-driven approaches to maintenance. A prime example is Rolls-Royce, which has many years of experience in collecting data from its fleet of aeroengines, and what it dubs the IntelligentEngine approach. The company's engineers use advanced data analytics, AI and machine learning to manage the maintenance of aeroengines and monitor their health. This process can generate some 70 trillion data points each year. The benefits are substantial: as well as providing knowledge of when an aircraft might fail if it doesn't receive maintenance, the data also feeds into engine design and operational fuel efficiency.

Omnicom Balfour Beatty and the University of York have developed computer software that uses AI and machine learning to digitise the inspection of railway lines. A camera on the front of train moves along rail tracks in need of inspection using machine vision to capture high-definition images of the rail track. The data is then transferred to a system that analyses it to highlight inaccuracies and faults on the tracks.

With knowledge of degradation trends, maintenance engineers can formulate mathematical models to predict a maintenance strategy's performance. Models can predict the future state of an asset and how many times each maintenance activity will be performed. From this, engineers can estimate a strategy's expected cost. Once formulated as a model, this approach can be embedded into an optimisation framework to minimise lifecycle costs and maximise an asset's future condition. The more sophisticated approaches can also take account of uncertainties and make the selected strategy robust to changes in the system's future and the costs of the maintenance resources such as spares and labour.

RECTIFYING RANDOM FAILURES

System failures can be inconvenient and expensive – and sometimes components cannot be fixed or replaced beforehand. However, engineers are using innovative approaches in some areas to control when to take the system out of service for maintenance. One example is in aviation, where any need for repair can result in cancelled flights and stranded passengers. An aircraft may also be a long way from a maintenance hub, making the logistics of repair challenging and costly. In this situation, it would be preferable to continue with the flight, deliver passengers to their destination and perform maintenance at the operator's own base. This need was met by full authority digital engine control (FADEC) systems, which were introduced to commercial aircraft to control all aspects of their engine performance.

When first used, FADEC systems took a conservative approach to the fault conditions under which aircraft could not fly. The system was more reliable than its predecessors, but delays and cancellations increased. This was solved by time-limited dispatch, which allows aircraft to fly for a defined period of flying hours with certain known faults present in the engine control systems based on FADEC's high reliability and redundancy features. This is restricted to a limited number of flying hours, known as the dispatch period. When that period has passed, the fault must be rectified before further flights. This gives a window during which the aircraft can be taken out of service, at a convenient time and at a preferred location, to avoid disruptions to the service and high repair costs. To ensure safety, the dispatch period is set to ensure an acceptably small likelihood of other failures. Depending on the fault, a short or long time period is set, after which the fault has to have been corrected or the aircraft is grounded.

Another innovative approach devised to address problems associated with the randomness at which component failures occur, uses maintenance-free operating periods (MFOP). Random failures hamper the planning of both the operational and maintenance periods. More certain knowledge of these two periods would benefit any industry but they have added significance in the military, where it is impossible to plan missions in detail, if the number and types of platforms, for example tanks, aircrafts, ships, or UAVs, are uncertain.

The UK's Ministry of Defence put forward an idea that led to the concept of MFOPs in the 1990s. During this period, equipment can usually carry out missions without maintenance and without system faults or limitations restricting the operator in any way. Following each MFOP, during time known as a maintenance recovery period, equipment is maintained to a level so it can perform until the next MFOP. This means that forces can plan military missions with confidence that the equipment they need will be available. They will also know

Rolls-Royce has also adopted robot technology in its IntelligentEngine concept for engine maintenance. This combines robotics and digital technologies to speed up inspection and to remove the need to take an engine off an aircraft for maintenance. One concept that Rolls-Royce is working on with researchers from Harvard University and the University of Nottingham is that small 'swarm' robots would crawl through an engine to visually inspect hard to reach areas. Another possibility is to permanently embed a network of 'periscope' cameras in an engine so that it could inspect itself and report any maintenance requirements © Rolls-Royce in advance what maintenance resources will be needed and at what time.

To implement this strategy, the system must be designed to account for the need to carry some faults for the rest of the current MFOP. The system will need to tolerate these faults so that they won't require immediate maintenance, which will need higher levels of redundancy (duplication of components so that if one fails the others will continue to work and allow the system to function – such as engines on an aircraft). This is one reason why this strategy has not been adopted for military aircraft where added redundancy would increase weight and reduce performance. However, while this approach has limitations as far as military aircraft are concerned, there are many other applications where MFOP proves beneficial, such as ships and submarines, where limited maintenance can be undertaken during a voyage.

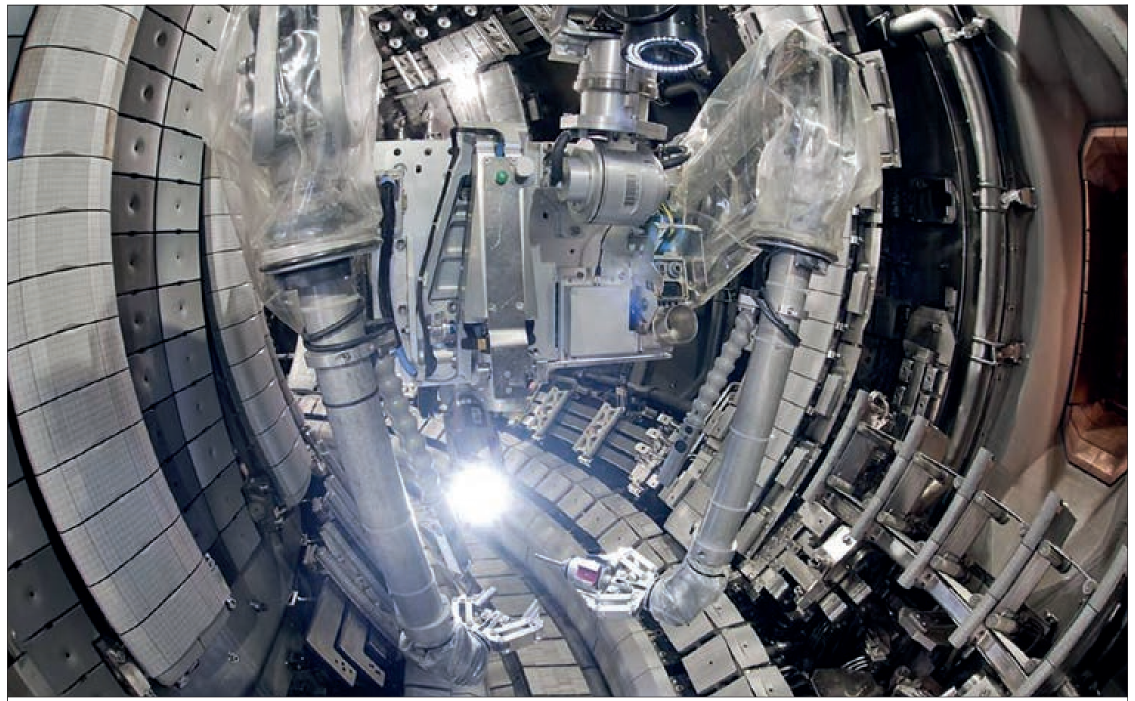
DECIDING ON A STRATEGY

The quality of maintenance depends on the skills and ability of the engineer performing the work, the degree of repetition and boredom involved, and how long it takes to complete. This type of activity is where robots can deliver better performance and precision than human counterparts. Consequently, robots are increasingly employed in maintenance work.

Beyond fulfilling tedious tasks and improving accuracy, robots can carry out maintenance in dangerous environments. For example, nuclear power plants are clearly hazardous environments where robots can perform inspection and maintenance while avoiding human exposure to radioactivity. For example, the JET fusion facility at Culham recently announced new records for fusion after robot handling systems completed a refit of the radioactive tokamak device.

And effective approaches to maintenance depend on using the best combination of techniques. Maintenance strategies are themselves the subject of research. At the University of Nottingham, for example, the Resilience Engineering Research Group has developed mathematical and statistical methods to support decisions of what maintenance to do and when to do it. Statistical and AI methods allow engineers to understand how a component's condition will degrade with use, which can then integrate into a maintenance strategy that specifies how to respond to different levels of degradation.

Maintenance engineering has made considerable advances over the past two decades. Sensor technology, remote sensing, big data initiatives, AI, robotics, and system autonomy are multidisciplinary areas that have contributed to the maintenance revolution. These are also areas where research continues to make rapid progress, promising a bright future for the maintenance discipline. These new capabilities will deliver solutions to the new demands and opportunities that evolve from the wider technological advancements and the rising demands for maintenance.



When the Joint European Torus (JET) recently set a new record for power output in fusion research, it did so after a maintenance and upgrade campaign that relied on robots. Since 1991, JET has conducted a series of experiments with deuterium-tritium (DT), the mixture of hydrogen isotopes that will fuel commercial fusion power plants. DT fusion creates neutrons that make the inner parts of JET radioactive. Only robots can safely enter the main chamber for maintenance operations © EUROfusion

BIOGRAPHY

Professor John Andrews is the Head of the Resilience Engineering Research Group at the University of Nottingham where he was appointed to a Royal Academy of Engineering Research Chair in Infrastructure Asset Management. His research is focused on the development of mathematical models to predict system risk, resilience and failure likelihood, enabling the evaluation of alternative designs and maintenance regimes.

© Photo by Nick Fewings on Unsplash

ENGINEERING BIODIVERSITY

Did you know?

- The UK has the worst biodiversity record of all G7 countries, with only half still intact
- A new law, introduced in 2021, will require developers to increase biodiversity when working on any new infrastructure projects
- Teams that include engineers, ecologists, developers, and construction workers are key to achieving these biodiversity targets

If engineers planning, designing or implementing new infrastructure works are not already familiar with the concepts of natural capital and biodiversity net gain, they will have to learn fast. Under the Environment Act, new developments are required by law to demonstrate 'biodiversity net gain', which will require important changes to the way engineers work. Engineer and writer Hugh Ferguson talked to the multidisciplinary teams behind some of the projects already making this gain.

Biodiversity is the variety of living species on Earth in both natural and built habitats. It is decreasing at an alarming rate worldwide and the UK is behind many other developed countries in tackling the issue. Britain has strong ecological protections through, for example, Areas of Outstanding Natural Beauty and Sites of Special Scientific Interest (SSSI), and the current planning system discourages biodiversity loss from new developments. Yet the UK has only half of its biodiversity still intact, the worst record of all G7 countries: 40% of the UK's most important habitats are still declining, and more than 40% of UK wildlife species have declined since the 1970s. There are many reasons why this is such a concern, with just one being the enormous value that nature provides to the UK's economy and wellbeing.

In a bid to reverse this trend, the 2021 Environment Act requires all new developments to make a 10% biodiversity net gain (BNG) – an approach to development that aims to leave the natural environment in a better state than it was beforehand (see 'Measuring biodiversity'). It also introduces a metric to measure BNG. The law doesn't require full implementation until at least November 2023, but pilot schemes have been underway for several years, with Network Rail and National Highways (formerly Highways England) among the 'early adopters'. These early trials give a good idea of the changes to come in the planning, design and implementation of infrastructure projects.

The likely lessons for engineers include the value of establishing multidisciplinary delivery teams early on; the importance of involving ecologists at the earliest stage of planning; and the need for engineers themselves to develop a greater knowledge and understanding of ecology.

SIGNIFICANT GAINS

The largest infrastructure project so far to commit to 10% BNG is the £1.2 billion phase two of East West Rail (EWR2). East West Rail is a new line linking Oxford and Cambridge. Phase one from Oxford to Bicester was completed in 2016; phase three awaits the result of a public consultation last year on the line of the new railway from Bedford to Cambridge. Meanwhile, the East West Rail (EWR) Alliance of Atkins, Laing O'Rourke, VolkerRail, and Network Rail is building phase two from Bicester to just past the West Coast Main Line at Bletchley, with a spur to Milton Keynes. It includes 48 kilometres of new rail infrastructure, all along existing antiquated or disused railway, including 15 new bridges, 23 bridge refurbishments, new and extended stations, and a key intersection with HS2.

Achieving 10% BNG on such a large scheme meant challenging existing design methods and putting collaboration at the heart of the process. EWR Alliance decided from the start that the most cost-effective solution would involve taking every opportunity to retain or improve existing habitat within the site boundary – the 'mitigation hierarchy' (see box) – so limiting the amount of new (and generally more expensive) off-site habitat needed to reach 10% BNG. From the start, this required multidisciplinary working between ecologists, engineering designers and construction teams.

Indeed, starting early was crucial. Although the route was

MEASURING BIODIVERSITY

In his 2021 review of the economics of biodiversity, British economist Professor Sir Partha Dasgupta argued that conventional economic models that govern policy and decision-making focus on produced capital (including machines and infrastructure) and human capital (health and education) but completely ignore natural capital (nature). For example, destroying woodland to build a shopping centre would be recorded as an increase in gross domestic product, accounting for the increase in produced capital. But it wouldn't account for the loss of natural capital that absorbs carbon, prevents soil erosion, creates a habitat for much-needed pollinators, and provides direct benefits to us.

In 2012, the Department for Environment, Food and Rural Affairs (DEFRA) produced a metric to quantify a development's impact in terms of 'biodiversity units'. This has been refined into the Biodiversity Metric 3.0, in conjunction with Natural England, which is now enshrined in the Environment Act.

For the purposes of the metric, habitats are used as a proxy for biodiversity. The area of land within each proposed site's boundary is divided into distinctive parcels (such as woodland or grassland). Each parcel's size is measured, and the quality is assessed and quantified. 'Size' is normally area but can be length for linear habitats such as rivers or hedgerows. 'Quality' is a combination of 'distinctiveness', with habitats that are scarce or declining scoring higher, and the 'condition' of the habitat relative to others of the same type. Developers can multiply the area of each parcel by the scores for distinctiveness and condition, and then sum the figures for each parcel to produce the number of biodiversity units in the site before development. For example, the baseline 'score' for the EWR2 project was 1,612 units.

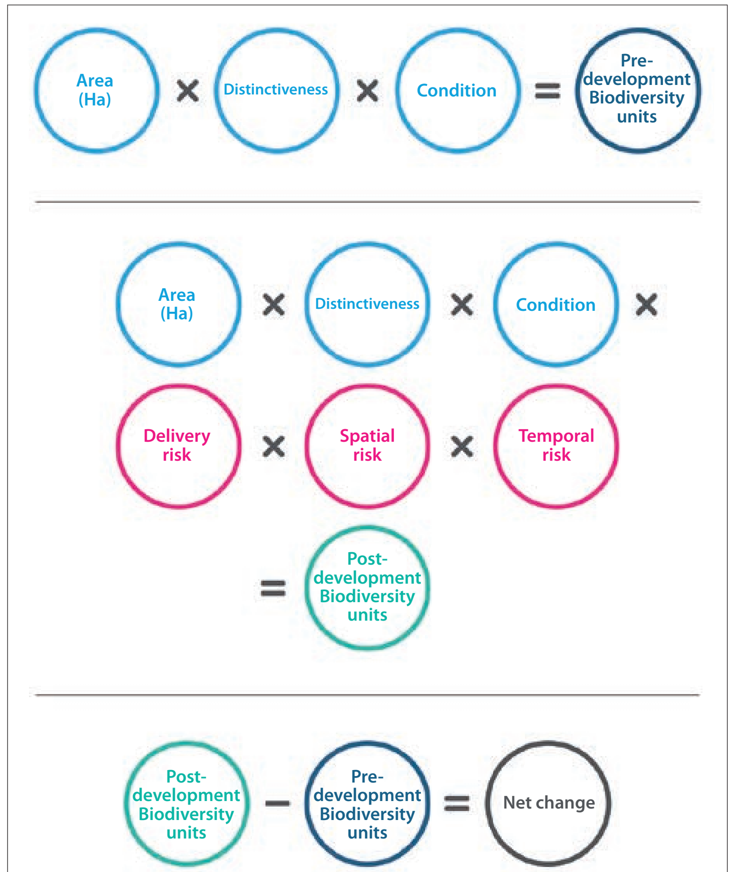
After assessing, developers apply the 'mitigation hierarchy': can the habitat damage be avoided by choosing a different site? Can it be minimised by, for example, rerouting a road through farmland rather than scrub or woodland (which has a higher nature conservation value)? Can it be compensated for by replanting affected habitat elsewhere on the site? On pilot projects, many sites achieved their BNG through these measures alone. If not, then compensation through biodiversity offsets is required, by identifying alternative sites to establish new habitats that improve biodiversity enough to gain enough extra units.

Developers then calculate biodiversity units for the 'after case', including any 'offset' sites, only this time adding preassigned factors that reflect the risks of establishing new habitats. These are: the difficulty of restoring or replacing the habitat; the time it will take for the new habitat to establish; and (for offsets) the distance between the habitat loss and where the new habitat is being created. The metric is intended to encourage habitat replacement as close as possible to the habitat loss.

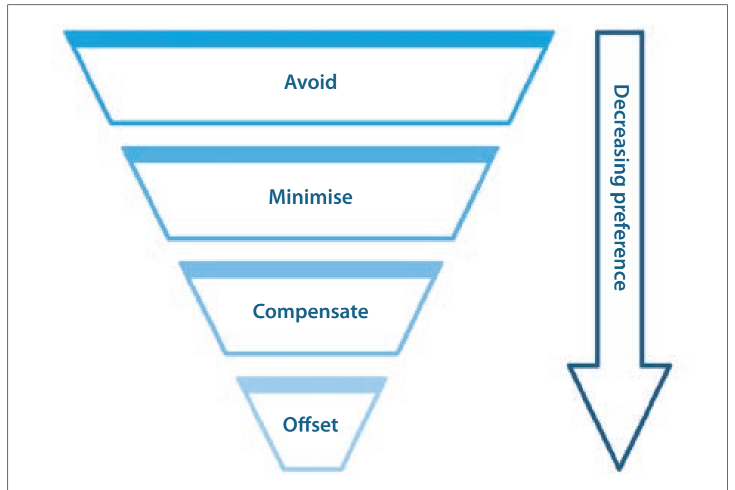
The metric is useful for quantifying how large an offset is needed to achieve BNG, but it comes with a warning: developers must consider other factors such as species composition, habitat structure and people's use of the land. And BNG is additional to existing habitat and species protections.

If developers cannot achieve 10% BNG, perhaps because no offset sites are available locally, the legislation permits the purchase of 'statutory credits' instead. This is intended as a last resort and will be at a premium price.

BNG is not a substitute for striving to achieve net zero: the two goals will run in parallel. Measures to improve biodiversity are likely also to reduce carbon emissions, but the reverse is not necessarily so: planting new woodland will have carbon benefits, but the wrong kind of conifers planted in the wrong area could reduce biodiversity. Achieving 10% BNG is also likely to become a corporate goal embraced by many organisations.



The formulae for calculating biodiversity net gain © Atkins



The 'mitigation heirarchy' for minimising biodiversity loss © Atkins

Three of the six new ponds in the Station Road ECS, all of which are already occupied by breeding great crested newts © EWR Alliance

largely fixed by the line of the disused and abandoned railway, there was plenty of scope for habitat improvement. The team carefully examined every metre of the route for potential gains, before the 'red lines' defining the boundary of the construction site were confirmed. Many of the gains were very small, such as filling in small gaps in existing woodland, but together they added up.

The 'red lines' had to include space, for example, for constructing new bridges or compounds for construction work. It was also possible to add in some areas adjacent to the railway to create a series of 'ecological compensation sites' (ECSs). This meant that, long before the Works Order enabling compulsory purchase of the land within the red lines was granted, the EWR Alliance could offer individual landowners a deal: lease the land to us for five years and we'll create the new habitat; then we'll hand it back but still pay a rental for you to maintain it, subject to annual ecological inspection, for another 25 years. Some declined, preferring to wait to see whether the project went ahead. Others agreed, allowing construction of some of the ECSs to begin three years before the main construction works, which helped reduce the time lags for key larger habitats such as meadows, hedgerows and woodland, and act as receptor sites for the translocation of legally protected species.

This included the 8-hectare Station Road ECS. Here, the team created six ponds on former pastureland, as mitigation for great crested newts – a species protected throughout Europe because of rapid decline in population, and known to be breeding in numerous local ponds. This ECS was a key receptor site for displaced and translocated great crested newts from nearby habitats lost to a new overbridge. It is also designed for other amphibians, such as toads and smooth newts, and provides a stepping stone between other well-established wildlife sites.

The ponds and the surrounding wildflower meadows provide a source of food and refuge for a variety of wildlife, from voles and field mice to bees and butterflies. Surrounding scrub has been planted with blackthorn, a food for the larvae of the nationally rare black-and-brown hairstreak butterflies that thrive locally. New hedgerows provide habitat for hedgehogs, another declining species, as well as commuting routes for bats, with the whole ECS already a large foraging area for a range of bat species.

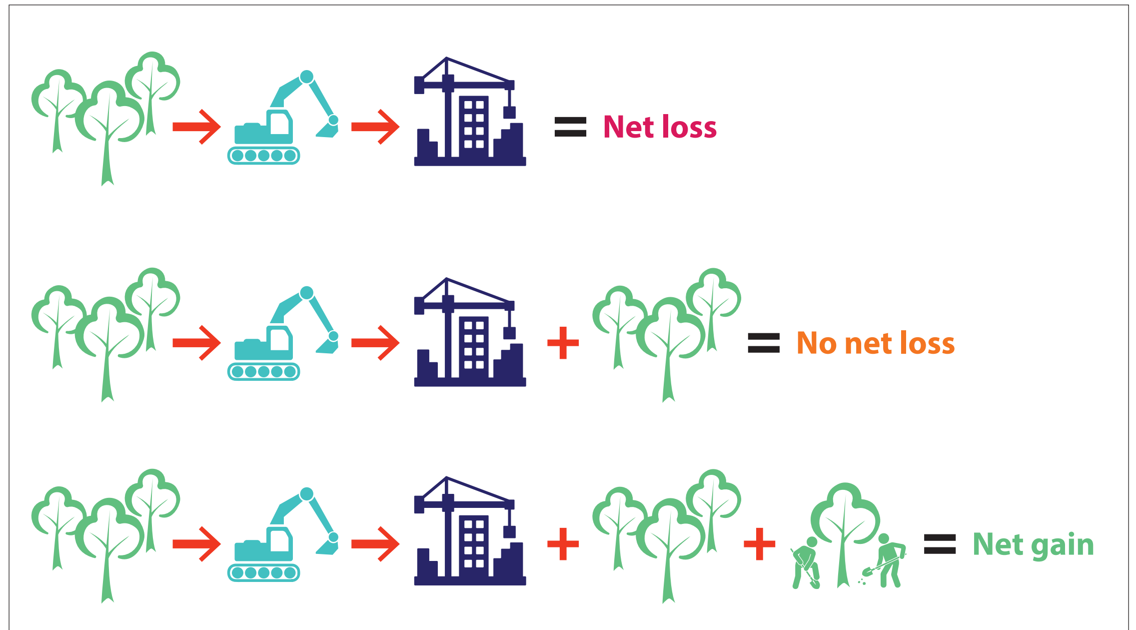
Applying the BNG matrix shows that, with the mitigation initiatives, EWR2 has transformed what would have been a substantial loss of biodiversity to almost no loss. Some extra off-site initiatives are needed to achieve the required 10% net gain – but much less than would have been the case without the mitigation, at a much lower cost, without compromising the scheme's benefits to nature.

From an engineering viewpoint, more of the existing earthworks for the old railway were retained and stabilised where necessary, than had originally been planned. This also retained more existing vegetation, which also increased BNG, and saved money. Flood resilience was another major factor, so exceptionally good drainage was essential. Although good for longevity, concrete-lined drains are bad for BNG, so engineers opted for open ditches with stabilised banks instead.

A new market is emerging for buying and selling biodiversity units. Wildlife trusts can fund improvements or expansion; other organisations such as water authorities or the National Trust may find a new source of income, without compromising their main purposes

OFFSETTING

On other infrastructure projects, where the scope for mitigation may be less, the need for biodiversity offset sites becomes more important. A new market is emerging for buying and selling biodiversity units. Wildlife trusts can fund improvements or expansion; other organisations such as water authorities or the National Trust may find a new source of income, without compromising their main purposes. Some farm owners may judge that selling biodiversity offsets will be a more profitable use of their land than conventional farming. All such sites must be secured for at least 30 years, subject to regular reporting and inspection to ensure that the habitat is being properly maintained. Like all new markets, prices vary wildly and are highest where new development is concentrated.



How biodiversity net gain is achieved (adapted from the WSP BNG toolkit)

The Oxford–Cambridge corridor is such an area, and local property consultant Bidwells has been seeking out possible sites. Key factors include potential for biodiversity uplift and proximity to existing established wildlife habitats, while the highest grade of agricultural land and land scheduled for later development are avoided. One of the selected sites is the 140-hectare Lower Valley Farm, 8 kilometres southeast of Cambridge, owned by Cambridgeshire County Council.

Close by is the site of the planned new four-platform Cambridge South Station on the main line to London, and likely to be on the last stage of East West Rail. Subject to a public inquiry that opened earlier this year, the new station will serve Addenbrookes Hospital and the flourishing and expanding biomedical campus alongside it. Network Rail has already secured an option to buy 56 biodiversity units from Lower Valley Farm if the station goes ahead.

The farm is currently arable with boundary hedgerows and some woodland, situated within the Cambridge Nature Network and adjacent to a SSSI. The plan is to convert this to biodiverse habitats of 'good' condition, as defined by the DEFRA matrix (see box). Exactly how this will happen, and how fast, will depend on market demand for biodiversity units. Parts may remain as arable farmland for some time, or alternatively new habitat may be developed as a 'habitat bank', for future sale at an uplifted price as the biodiversity will be more fully developed.

THE ROAD TO BNG

Land, which is in short supply, is needed for roads but is also a fundamental resource for many other things – including biodiversity, agriculture, landscape quality, water quality, and flood alleviation. The key challenge is developing decision-making processes that optimise land use across these functions, while providing value for money. Roads have historically been a

The new A14 Cambridge to Huntingdon road achieved 11.43% biodiversity net gain, largely through converting the borrow pits (which supplied material for embankments) into woodland, grassland, wetland and open water habitat © National Highways

source of biodiversity loss, but National Highways is on course to move into no net loss across its network by 2025, moving after to reach net gain.

The £1.5 billion A14 Cambridge to Huntingdon scheme, completed in early 2020, considered biodiversity during planning. However, the new biodiversity metric was only applied retrospectively after the design was complete, largely to provide evidence for future schemes. The result was that the road had achieved a remarkable 11.43% BNG, although there were details that, with hindsight, could have been improved to benefit key habitats. The main factors contributing to the high score were the fact that most of the land taken was agricultural, with low biodiversity value, and that some of the borrow pits required to provide material for embankments were subsequently converted to woodland, grassland, wetland, and open water habitat, with high biodiversity value. Overall, the project created 220 hectares of new wildlife habitat, including landscaping of roadside verges, and planted some 860,000 new trees and 40 kilometres of hedgerow. There are also 24 wildlife tunnels across the road, to allow animals such as water voles and otters to cross safely.

Other lessons from the A14 project replicate many of those from the EWR Alliance. This includes the value of having an integrated delivery team including client, consultants and contractors – in this case, National Highways and joint ventures of Atkins/Jacobs and Balfour Beatty/Costain/Skanska – in place from an early stage. The project team also tested for BNG when planning, involving ecologists from the start.

Clearly, one effect of the new legislation is that ecologists will need to be involved in infrastructure projects from the earliest stages of conceptual design, rather than just consulted after initial decisions have been taken. But the main issue, as one of the EWR Alliance design team puts it, is that engineers themselves need to change: "It's about us as engineers learning about ecology and nature. It will help us to be better designers."

For this article, Hugh Ferguson spoke to team members from East West Rail Alliance and the A14 Integrated Delivery Team, as well as contributors from National Highways, Bidwells and WSP.

INVENTING A COMMUNICATION REVOLUTION

Professor Lucy Rogers FREng © Karla Gowlett

Professor Lucy Rogers FREng's career is not typical of many engineers: starting with engineering bubbles for firefighting, it has taken in television, animated dinosaurs and livening up university teaching, along with inventions that put the fun in engineering. And when she wanted to polish her communications skills, she turned to stand-up comedy for help.

Keen on maths and physics, Rogers hadn't yet worked out what she could do with them. The next nudge came on an 'Insight into Engineering' course run by Women in Science and Engineering and her fate was sealed

Professor Lucy Rogers FREng says that her engineering career started with a bang. Her physics teacher ran a club based on the BBC's *Great Egg Race* – a TV series that challenged participants to invent ways to complete various tasks, like seeing how far rubber-band propulsion could move an egg without breaking it. Rogers's challenge was to set off a party popper from a distance using anything she could find in the lab. Rogers was working on her design – using a trolley, some weights and a lab stool with a hole in the middle – as the teacher marked homework. Roused by a bang from the back of the classroom, the teacher looked up and, as Rogers recounts it, said: "Lucy, you might need to be an engineer".

"That was when engineering first hit my radar as a career," she says. Keen on maths and physics, Rogers hadn't yet worked out what she could do with them. The next nudge came on an 'Insight into Engineering' course run by Women in Science and Engineering and her fate was sealed. But there was a family connection to engineering: Rogers's grandfather was a clockmaker and 'play' involved watching him making things on a lathe. Messing around in a workshop still comes naturally to Rogers, although it is more likely to involve electronics and computers than cogs and wheels.

PHD IN BUBBLES

After A levels, Rogers studied a general engineering degree at Lancaster University and graduated in mechanical engineering. The sandwich course split time between lectures and industry, with a year in Newcastle "learning about industrial power and big power stations". After graduation, Rogers took a postgraduate Advanced Course for Design Manufacturing and Management at the University of Cambridge and then earned, as she calls it, "a PhD in bubbles" as a part of the teaching company scheme (TCS) run by the Engineering and Physical Sciences Research Council (EPSRC). This knowledge transfer project, supervised by Lancaster University, involved research in a company that made firefighting equipment to deal with petrochemical fires. Pouring water on a petrochemical fire causes the burning oil to rise to the top, so firefighters must smother fires with bubbles. The company had made foam-making equipment for years. "They wanted to refine it," Rogers explains, "but didn't quite know how it worked." So, she set out to discover.

Foam creation, or bubble blowing, was far removed from egg race projects but it did involve using imagination to adapt existing tools and techniques. Rogers made Perspex copies of the company's nozzles so that she could see what was happening in foam creation. She then adapted a high-speed video camera, running at 40,000 frames per second, to record her experiments so she could see in slow motion how bubbles were made. Rogers's experimental kit filled the back of a Volvo estate car. The screen was massive and there was a VHS video recorder, another large device, but the carload of hardware achieved its purpose. "I was the first one to use high-speed video to see how bubbles are made." The videos showed that there are three different ways to make bubbles, a discovery that led to the PhD in bubbles, or more formally "foam formation in low expansion firefighting equipment".

"I wasn't expecting to do a PhD," she explains. But as part of the TCS course, she wrote up her research, which resulted in a PhD. It could have been a stepping stone for an engineering career, but Rogers disliked the sometimes sexist nature of the profession in the 1990s. She took on a different challenge: the fear that when clocks ticked over from 1999 to 2000, the world's IT infrastructure would grind to a halt. This caused lurid headlines and near panic among computer users, but it was good work for IT professionals. Rogers set up a consultancy with a friend to tackle this and other IT problems. "It was lucrative, but it was boring," she adds.

REINVENTION AS AN INVENTOR

In 2011 Rogers decided to reinvent herself again and took an intensive crash course at Singularity University. She explored 'exponential technologies', ideas that, while they may have seemed irrelevant at the time, had the potential to change the world. Two Silicon Valley luminaries, Ray Kurzweil and Peter Diamandis, set up this 'boot camp' "to help leaders navigate a world of accelerating change". During her time there, Rogers encountered Google's early autonomous vehicles, along with other technologies that, a decade later, have started to become mainstream, such as 3D printing, artificial intelligence and gene mapping.

Singularity University, she says, "was all about looking ahead with a different perspective. I have got my eye on the future, but I no longer just look straight ahead with the blinkered view that I used to. I've got a fly's eyes. There's something over there and something over here that can help to solve this problem in the middle if I bring them together."

Rogers returned to the UK and into a career that resembled her egg race days. "I like to say I am inventor with a sense of fun," she says. More formally, she describes herself as an innovation consultant who solves problems, as well as an 'engineering designer'. "Well, the Institution of Engineering Designers thinks so," she says with a laugh. It has just offered her an

Testing the robot dinosaurs at the manufacturers in China

Honorary Fellowship, in recognition of her work "in promotion of engineering and design to the public". Communication has become another key component of Rogers's multifaceted career. It was this role that led to her election as a Fellow of the Royal Academy of Engineering.

Another label that Rogers works under is 'freelance engineer', a move made much easier by a significant engineering development: the development of the credit-card-sized Raspberry Pi computer ('Chips that changed the classroom', *Ingenia* 72). A device designed to rescue IT teaching in the UK has given birth to a global community of engineers using Pis as the 'brains' in a multitude of technologies. "The Raspberry Pi is really brilliant," Rogers enthuses. "When it came out in 2012, I found that electronics and computing were actually much better than I had thought at university."

With the Pi Rogers could, as she puts it, "see a way to make gadgets and gizmos as a living". Combining electronics and computing with mechanical engineering allowed Rogers's creative imagination to run riot. She began with a toy dinosaur that responded when a tweet arrived, an invention that proved to be a great career move as toy dinosaurs soon gave way to bigger challenges.

At the time Rogers lived on the Isle of Wight. The owner of the island's Blackgang Chine theme park heard about her toy dinosaur and asked for help with a life-sized robot. The park's animatronic T-Rex sat on a vibrating platform, driven by computer-controlled loudspeakers. Although "surprisingly effective for a kid's theme park", as Rogers says, with the tourist season approaching, T-Rex's electronics needed attention. Rather than waiting for electronics to arrive from China, the park invited Rogers to apply her Raspberry Pi skills to the robots. This original project has had a continuing impact on the animatronic T-Rex, with Pi computers now monitoring the robot's motors. If the motor takes too much or too little current, it sends a tweet to alert the maintenance team before the motors seize up and customers start complaining about a defunct dinosaur.

Working with robot dinosaurs sucked Rogers into the wider world of the Pi and a role on television. The Raspberry Pi Foundation told the Pi's global community about Rogers's T-Rex and it resulted in a role as a judge on the BBC series *Robot Wars*. She admits that, as she said in an interview, "I kept thinking, 'what am I doing here?' The other two judges were professors, and I was Lucy who had played with robots in a theme park. But, by the third series, I realised that I didn't need to be a professor – I was an engineer who had made stuff and could actually say what would and wouldn't work."

ENGINEERING COMMUNICATION

The television role was part of a move by Rogers to transform the way in which engineers communicate; it also gave her the 'professor' title that had intimidated her as a TV judge. In 2019, the Royal Academy of Engineering appointed Rogers as a Visiting Professor of engineering, creativity and communication at Brunel University. She says that it took her years to learn how to communicate engineering knowledge to other people. "I thought that everything you need to know from the piece of work was in the report. You paid me to write the report, that's job done. Promotion would follow, or at least a pat on the head. I was wrong. People don't read reports; they want summaries and someone to explain what the summaries mean."

To remedy her self-diagnosed lack of communications skills, Rogers took comedy, storytelling and writing courses.

QUICK Q&A

What inspired you to become an engineer?
The *Great Egg Race* TV show and a physics teacher recreating it as a club at school.

Favourite project you worked on?
Current one. Always. Whatever it is.

Who influenced your engineering career?
Heath Robinson, a cartoonist, illustrator and artist, who drew whimsically elaborate machines to achieve simple objectives; Mr Scanlon, my school physics teacher; and my grandad.

Most admired historical bit of engineering/engineer?
My grandad – he made steamboats, rebuilt veteran cars, and was a clock maker who made the first scale model of John Harrison No 1.

Which engineering achievement couldn't you do without?
My current work relies a lot on the internet. It allows me to collaborate with others around the world. I also like chisels.

Most impressive bit of engineering to look at?
Falkirk Wheel

Overlooked engineering successes?
Canals

What do you do in your spare time?
Learn new stuff (currently German, juggling, hula hooping); enjoy water (Canadian canoe, kayak, row, paddleboard, swim); make things with my hands; walk Encke the black Labrador; and take close up photos of flowers.

Rogers with Sir Killalot from *Robot Wars*

She worked for four weeks at the *Guardian* as a media fellow, a scheme that exposes engineers and scientists to life in a busy newsroom. The paper's science editor, Tim Radford, recognised that, contrary to her own assessment, Rogers could write. He encouraged her to write her first book *It's ONLY Rocket Science*, a maths-free account of the engineering of space flight.

In her Brunel professorship, Rogers set out to expose engineering students to her enthusiasm for creativity and communication and to encourage them to cast aside past attempts to suppress their creativity. At school, she complains, "if you were good at exams, you weren't encouraged to make things or be more creative. I found that I had to give permission back to the engineering students. You are allowed to fail. You're allowed to try things.

"I define creativity as the ability to imagine new things and act on those thoughts. The difference between creativity and innovation is you can have 1,001 creative ideas, but it's only really innovative if it is actually usable."

At Brunel, Rogers also set out to shake up how engineering students learn about communications. Unlike her, their undergraduate training would convince them of the need to be communicators and to develop the appropriate skills.

The Brunel timing fitted well with changes in the curriculum for undergraduate engineers. The Engineering Council's new guidelines on the Accreditation of Higher Education Programmes now requires engineering courses are to train students to "communicate effectively with technical and non-technical audiences". As Rogers puts it: "industry says some of what students are learning at university isn't meeting industry's requirements." Companies want to recruit creative engineers who not only know about engineering but who can also communicate that knowledge.

This new approach is happening when education itself is changing, with a move to more remote teaching reinforced by lockdown. Rogers was already working on online courses before COVID-19 prompted lockdowns and restrictions on in-person teaching. She had already started to prepare videos that students could watch before coming together for workshops where they would implement the lessons from the videos. In the event, most teaching moved online.

Rogers's videos, many of them available on YouTube, started with the basics. They could be as simple as a checklist of things for students to look out for when preparing videos of their own work. The effects were immediate. "I watched the next year's videos. They were all a grade higher in video and audio quality as well as presentation. It's probably the same content, but more understandable."

Rogers is turning her work at Brunel into a series of syndicated online courses. This is partly in recognition that it isn't easy for engineering departments to teach 'life skills' such as communications. "Most universities have a professor of fluid dynamics, but few have an engineering professor with expertise in communication skills." This is where online courses help.

Rogers has also called on industry experts so that her videos have plenty of engineering. Engineering departments rarely have enough resident working engineers who can pass on frontline experiences. Lecturers can insist on the importance of project management and Gantt charts in engineering, for example, but students don't always relate that to the real world. Rogers tackled this by recording videos of engineers from industry talking about their work.

It isn't just the university world that Rogers covers in her communications work. She now chairs the Academy's *Ingenious* public engagement awards for projects that engage the public with engineers and engineering. "The 'E' in STEM is often silent – and currently many engineering stories from across the UK are not being told," she says. "Engineering can mean different things to different people. *Ingenious* projects can broaden perceptions of engineering to encourage more people from diverse backgrounds to engage with the profession and access future-shaping careers."

Also on the public engagement side of things, Rogers is the host of two podcasts: *The Engineering Edge*, which looks at using every day engineering in extraordInary ways; and *DesignSpark*, which mixes comedy with STEM.

However, Rogers is wary of trying to do too much herself. Like all women engineers she is often asked to promote the profession to young women. She warns women in engineering against getting the balance wrong between communication and other parts of their work. The last thing we need, she says, is that outreach activity is regarded as "something that women do". Industry can still regard time spent 'out of work' on outreach activities as a sideline that doesn't count highly in the promotion race. After all, she says, the issue with getting the right gender balance in engineering is also down to the men who make up most of the profession. Rogers's contribution is to give all engineers, men and women, the communications skills they need to reach out to everyone.

THE INVENTION OF FUN

The Raspberry Pi has enabled many of the inventions from the workshop where Professor Lucy Rogers likes to spend time as an "inventor with a sense of fun".

While at IBM's Internet of Things headquarters in Switzerland, Rogers wanted to produce a simple version of the 'smart building' technology where a "very expensive bespoke piece of kit" with CO_2 sensors alerted people when the place was getting stuffy. Rogers created a simpler, and cheaper, version that would work in normal buildings. She went online and bought a USB plug-in sensor, attached it to a Pi and programmed the sensor to feed data to IBM's cloud system. Rogers put an LED in a ping pong ball to read that cloud data and warn people of rising CO_2 levels.

It turned out that the sensor didn't just monitor CO_2, it also detected many volatile organic compounds (VOCs) such as ethanol, alcohol and benzene. "I discovered, and I am blaming the cat for this, it can also work as a fartometer," says Rogers. "I think it's the only time that, the word fart has made it to the IBM home page."

Like many, Rogers was intrigued when Banksy decided to shred a valuable artwork as the auctioneers gavel fell. Not convinced by the artist's own 'explanations', she decided to make her own artwork demolition device, adding battery power and a remote control to a commercial shredder. This was one of several fun inventions that Rogers has posted as a part of her collaboration with DesignSpark, the website for engineers, students and hobbyists run by RS Group.

Another DesignSpark project is Rogers's crowd-sourced satellite ground station. Turning again to the Raspberry Pi, and putting it in 3D-printed case, Rogers built a £150 ground station. "It was gratifying to see the little orange blob of my station appear on the ground station map." As she says on the project's web page "Listening to spacecraft from my back garden … and being able to access other people's antenna in their back gardens around the world, means we can hear satellites for most of their journey as they circle the globe."

Other projects have included turning Rogers's LED boots into an Internet of Things gadget that she could control from anywhere without having to use a mobile phone. "The solution was so cheap (less than £4) that I am now using it to enchant all my 'things'."

CAREER TIMELINE AND DISTINCTIONS

Studied mechanical engineering, Lancaster University, **1995**. The Duke of Edinburgh's Award: Gold, **1996.** PhD in foam formation in low expansion firefighting equipment, Lancaster University, **2001**. Wrote and published *It's ONLY Rocket Science*, **2008**. Attended Singularity University, **2011**. Served as a judge on *Robot Wars*, **2016–2018**. Fellow, Royal Academy of Engineering, **2020**. Fellow, Institution of Mechanical Engineers, **2011**. Honorary Fellow, Institution of Engineering Designers, **2022.**

INNOVATION WATCH

UNFOLDING CLOTHES THAT GROW

By the time they reach the age of two, babies go through seven clothing sizes, only adding to the fashion industry's impact on the planet. London-based Petit Pli is on a mission to lessen the burden, with childrenswear that grows with the wearer.

The fashion industry consumes more energy than aviation and shipping combined, while vast dumping grounds of discarded clothing pollute the Earth. Innovators worldwide are working to change this, with materials that consume less resources, clothing rental models and second-hand marketplaces all helping to solve the problem.

Focusing on childrenswear, the Petit Pli team – led by aeronautical engineer Ryan Mario Yasin, CEO, and neuroscientist Arabella Turek, Chief Operating Officer (COO) – is using space technology-inspired designs to clothe the next generation, with garments that can expand through seven sizes.

FROM AIR TO CHILDRENSWEAR

It was Formula One – and his fascination with air – that led Ryan into engineering. "I was totally enthused by how air could carry a plane into the sky or keep a car going around a corner at 300 kilometres per hour or more." His path took him to an aeronautical engineering degree at Imperial College London, where he fell in love with unravelling the inner workings of wind turbines and jet engines.

But it wasn't just flight dynamics or structural mechanics that fascinated him; it was the way that engineering could help push humanity forwards. His curiosity was also sparked by engineering feats that ultimately weren't commercially viable, such as Concorde. "It's almost as if you had a peek into the future," says Ryan.

He continued to explore the bounds of the possible in his master's thesis, which looked at miniaturised satellites called CubeSats. The problem: onboard a satellite so small, how do you make the best use of any gaps being wasted? Could you install more solar panels, or more powerful components to transmit radio waves further? The idea to solve this used origami to create folded structures that could sit in the gap and self-deploy once in orbit.

Then, on a master's in global innovation design at the Royal College of Art (RCA), Ryan began applying his engineering knowledge to fashion. "The more I looked into the industry, the more I realised that it was really unethical and wasteful. So, I came up with six different projects that would try and tackle different elements of the fashion sector's pitfalls." One of these was to become Petit Pli.

Petit Pli's childrenswear comes in three ranges: one for newborns (up to a year old); another for one- to four-year-olds, and another for four- to nine-year-olds

Petit Pli's waterproof material has its structure facing downwards like roof tiles, to ensure no crumbs get stuck, making it the perfect outerwear for children

PROTOTYPING IN THE OVEN

The idea was sparked by the birth of his nephew, Viggo, but it was nanosatellites that inspired the solution. By the time Ryan's gift of baby clothes had reached Viggo in Denmark, they were too small for him, which he thought was "absolutely ludicrous. I just thought, there must be a better way, and naturally started implementing those engineering learnings, from deployable structures into garments that would essentially deploy out as the child grew."

He made a prototype with a sewing machine, put some shape memory structures in it and "almost melted it in the oven" to get something that could be modelled by both his newborn nephew and two-year-old niece. Responses from parents showed him the idea had traction, and he did everything possible to accelerate its development, including starting a company. "I was having meetings with patent lawyers and (asking them to) fund my patent application … When I was a student, that conversation was very different to when I was a CEO of a company – which only cost me £10 to form."

Simultaneously, he was exploring how different structures could affect the material's auxetic properties – meaning how pulling lengthways on the fabric caused it to grow along its width, too. To perfect this, he used data from children's growth charts, looking at things such as height and arm length.

In the studio: Ryan Mario Yasin, CEO of Petit Pli

To ensure a new aircraft's airworthiness, engineers put materials through fatigue testing. Similarly, Ryan used equipment to push and pull different textiles to see which could be repeatedly opened and closed without it permanently affecting the textile's growth. After making a few tweaks to the embedded structure, he got parents involved for longer-term testing with their children, to get the clothing market-ready.

After he graduated from the RCA, built a website, and began searching for investment and supply chains, COO Arabella joined, fascinated by the social ideas behind executing engineering projects, which she says are "as important as learning the mathematics behind it".

GROWING WITH THE TIMES

Although Petit Pli has received much fanfare in the last few years, including winning the Dyson Award in 2017, the team says "the challenges came from every angle".

One was choosing the right material, as some parents weren't keen on their children wearing synthetic textiles. "So then we focused on outerwear, which generally uses synthetic materials for their fantastic water repellent properties and durability. If you can create fabrics made from recycled waste and then turn that into a useful product with a long lifespan – and think about its lifecycle use – actually the environmental gains could outweigh the stigma," says Ryan. Each Petit Pli garment is made from at least six recycled plastic bottles and can be recycled at the end of its life.

Ryan was also motivated by a challenge he set himself: to create something that would be successful in the real world, rather than just in his portfolio. Challenge resoundingly met. Now, Petit Pli has sold tens of thousands of products in over 60 countries. Following a successful Regent Street pop-up in 2021, the team plans to open a London shop. Its Clothes That Grow will also be permanently exhibited in the Young V&A museum, opening in 2023. Petit Pli has released maternity wear, and a face covering named one of *TIME*'s Best Inventions of 2020. Aspiring to become the next GORE or 3M, the team plans to expand its designs to even more applications .

When discussing Petit Pli's future, Ryan and Arabella's plans are different to most companies. "For us, it's less about what products we want to make. It's about asking, how can we use our existing knowledge, supply chains and team to actually add value to the world?" says Ryan.

Arabella agrees: "We're looking forward to growing and changing with the changing times."

EYES ON THE INNOVATORS

***Ingenia* is keeping a close eye on the startups using their engineering know-how to disrupt the status quo.**

Aceleron continues its green revolution: Dr Amrit Chandan and Carlton Cummins' recyclable lithium-ion battery features most recently in the *Guardian*.

Exciting times as **Nyfasi's** Deluxe Detangler, featured last issue, has become available for preorder (but be quick – there only 5,000 available).

Watch out for **Notpla**'s plastic-free takeaway boxes on your next JustEat. The coating is 100% compostable, unlike the plastic films typically used.

Scotland's space industry continues to thrive – **Orbex** is lifting off from the Highlands, having revealed its first full-size prototype.

Need a boost for those hills? **Swytch Technologies**' smartphone-sized battery kit, which can convert bikes into e-bikes, is here for you.

HOW DOES THAT WORK?

NFTs

Love them or hate them, NFTs took the art world by storm in 2021. But even this far into their explosion in popularity, many people still have no idea what they are and how they work.

Over the last few years, the hype surrounding non-fungible tokens (NFTs) has snowballed as investment in them has skyrocketed. While it may bring to mind pixelated GIFs of flying cartoon cats, accusations of a huge Ponzi scheme, and a very real carbon footprint, some consider them a genuinely useful technology for a future moving increasingly into the digital realm.

In a nutshell, an NFT is a unique digital signature used to prove ownership of an item, typically something collectable such as a digital artwork. NFTs are traded using blockchain: a distributed database, permanently stored and continually updated across a network of computers (see 'How does that work?' *Ingenia* 72). 'Blocks' represent transactions and can be locked onto the rest of the blockchain after verification. Tokens traded can be fungible or non-fungible.

This concept of fungibility is key to NFTs. Money is fungible: you could give a friend a £5 note in exchange for them sending you £5 on PayPal and you would still end up with £5. On the other hand, a Picasso painting is non-fungible. Even an exact replica of it wouldn't be worth the hundreds of millions that the original is worth. Essentially, if something is non-fungible, it means it cannot be substituted for another similar item.

Returning to blockchain, a fungible token (such as cryptocurrency) stores value, whereas NFTs store metadata associated with the item in question. This metadata includes a unique ID and blockchain contract address, and usually, the creator's wallet address. It is what separates an NFT of, say, an algorithmically generated image of a cartoon monkey, with what you'd download if you were to right-click and 'Save As' that image from a website. A bit like a receipt or the deeds to a property, it proves who owns it, who sold it, and when the transaction took place.

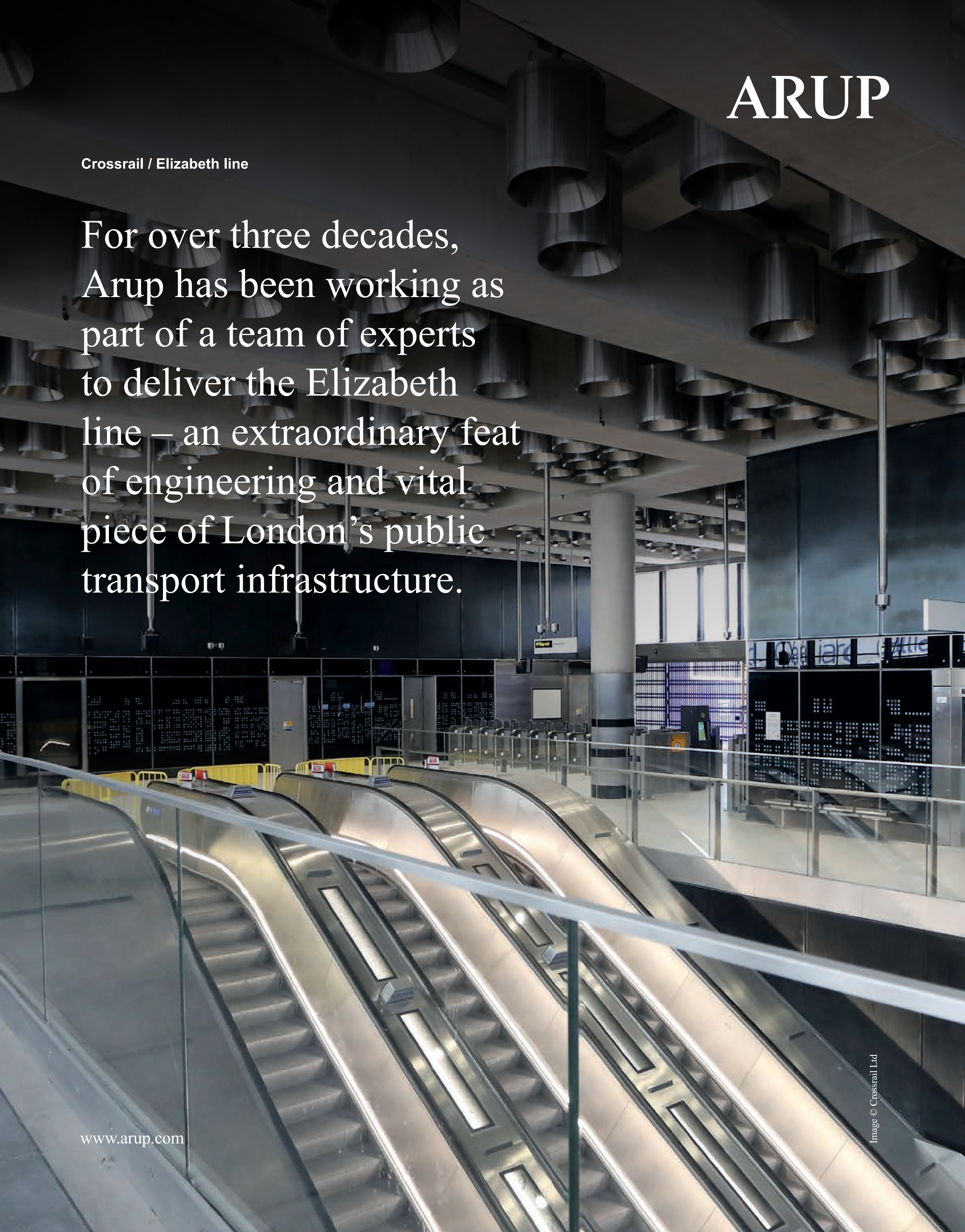
"What's the point in them?" is a question being asked by many. The answer differs. For digital artists, NFTs are a way to sell their work. This wasn't possible until now, as without an NFT, files could be copied without anyone knowing which one the original was. Despite fluctuating demand, the UK's first NFT gallery opened its doors earlier this year; while in March 2021, Christie's hosted an auction for an NFT that sold for $69 million.

The cynical say they are a gimmick, perhaps partially because of celebrity support from the likes of Paris Hilton and Gwyneth Paltrow. There's also the status symbol element: perusing the Twitter accounts of Eminem, Madonna or Jay-Z will show you an NFT profile picture bought for hundreds of thousands of dollars.

However, beyond expensive JPEGs (some depicting stick figures and cartoon stones), the market is growing for NFT-traded goods for the metaverse – the virtual world. Virtual property and avatars are being created and sold, and so is a virtual clothing line from Adidas.

Real-world applications for NFTs are being proposed, too. Associating an NFT with a high-value physical object, such as a rare whisky, could help to verify its authenticity. An even more interesting idea is using NFTs to give patients better control over sharing their electronic health records for medical research, by publicly recording who requests access.

And what about the carbon footprint? Blockchain transactions are notoriously energy intensive. An analysis of 18,000 NFT artworks estimated that the average carbon footprint of each amounted to an EU citizen's energy consumption for two months. In April, the Ethereum blockchain, which reportedly uses as much power annually as the Netherlands, conducted its first major trial of a new mining system that uses 99% less energy. Although it says it will transition to the new system by autumn 2022, this move has been on the cards for six years. If NFTs are indeed to become the economic foundation of the virtual world, this is a problem that needs solving, if it is to coexist with an intact physical world.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