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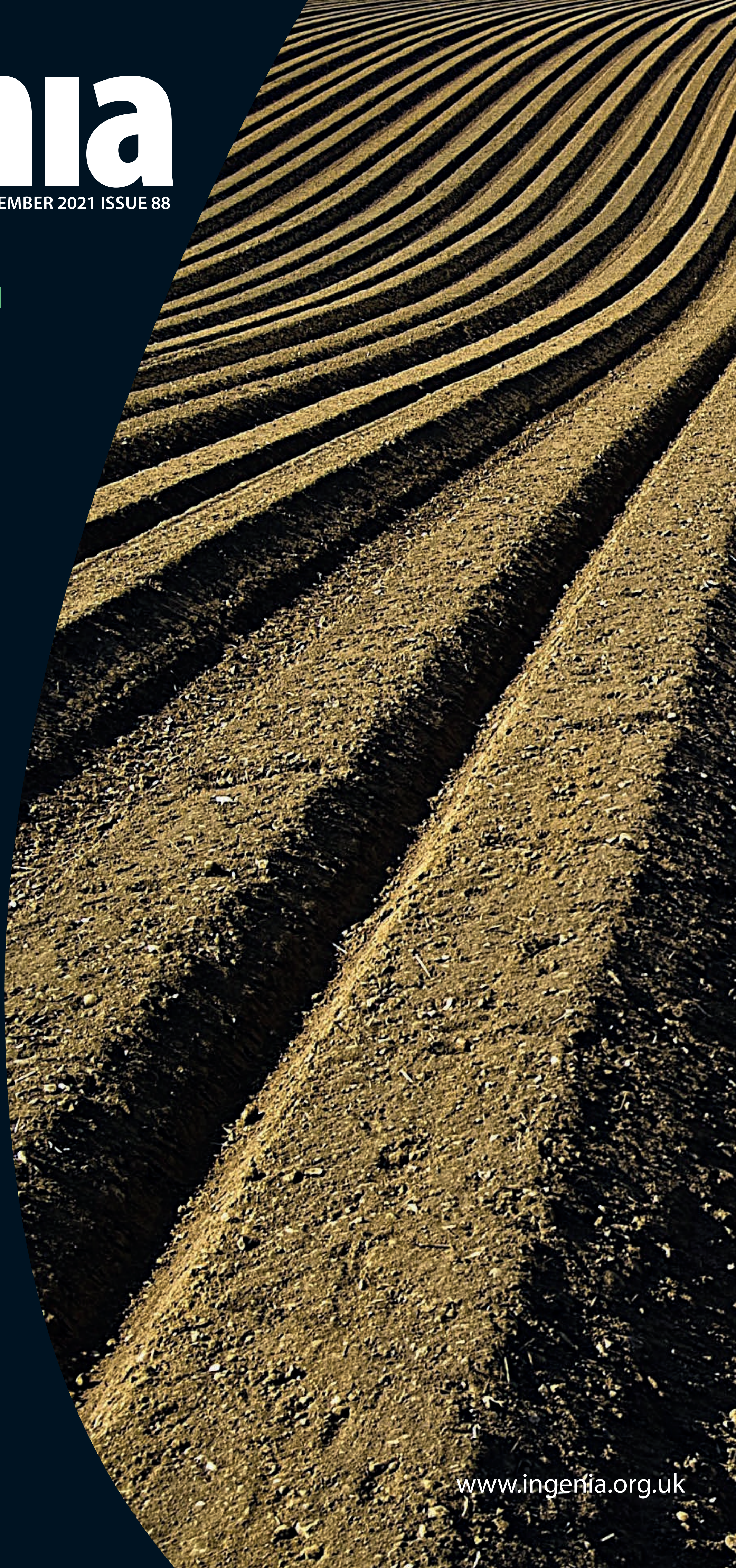
SEPTEMBER 2021 ISSUE 88

CIRCULAR ECONOMY CONSTRUCTION
ZERO-CARBON AIRCRAFT
IMMERSING AUDIENCES
SPACE SENSORS
SOIL ENGINEERING



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Front cover

Ploughing of fields brings organic matter to the surface, releasing CO_2. Agricultural engineers are tackling this with tillage practices © Free Photos/Pixabay

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WELCOME

In November, the UK and nearly 200 other countries who signed up to the 1994 United Nations Framework Convention on Climate Change meet in Glasgow for COP26. As heads of state, climate experts and campaigners meet to agree urgent, coordinated action to tackle climate change, the engineering profession is pushing boundaries to move us closer to achieving a thriving, low-carbon economy and reaching the net zero future required to stabilise our climate.

In this issue, we want readers to be inspired by the diversity of engineering fields and careers, the exciting innovations and the fulfilling work that engineers pursue. Learn about hydrogen-powered aircraft, discover how agricultural engineering is reducing, capturing and storing carbon emissions from soil, and see how we can transform rather than demolish buildings to achieve significant reductions in greenhouse gas emissions.

Creativity and motivation are displayed through profiles of this year's Academy Silver Medallists, a Q&A with early-career engineer Michelle Watiki, and the fascinating story of Dr Agnes Kaposi FREng, who from a childhood in Nazi-occupied Hungary, went on to shape the field of systems engineering. In our 'Opinion', Professor Roger Kemp FREng picks up the theme of systems and resilience to call for engineering education to step up to the net zero challenge.

The past year has accelerated innovations in all things virtual, and 'Entertaining audiences of the future' reveals the engineering creating immersive environments in theatre and sport. We look at the design of sensors for space exploration onboard NASA's Perseverance rover, and Innovation Watch highlights the remote identity verification software that could revolutionise cybersecurity.

Enjoy discovering how the engineering profession is stepping up and playing its role in delivering a sustainable and net zero future.

Faith Wainwright

Faith Wainwright MBE FREng
Editor-in-Chief

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UP FRONT

IN BRIEF

ENGINEERING EXCELLENCE RECOGNISED

In July, the Royal Academy of Engineering celebrated its 2021 award winners at its first in-person event since the start of the COVID-19 pandemic. The awards recognised engineers who have made a remarkable contribution to the industry.

The Academy's Royal Fellow, Her Royal Highness The Princess Royal, presented the MacRobert Award to winner DnaNudge. The London startup was honoured for the development of its pioneering consumer genetics technology, pivoting and adapting the technology to deliver a rapid, lab-free RT-PCR COVID-19 test to NHS hospitals. The MacRobert Award, supported by the Worshipful Company of Engineers, is the most prestigious and longest-running prize for engineering innovation in the UK. Finalists Creo Medical and PragmatIC were also recognised at the event.

Dr Larissa Suzuki was presented with the Rooke Award for public promotion of engineering. Dr Suzuki is a technologist, entrepreneur and engineer who is now Data and AI Practice Lead at Google Cloud. She is working with Vint Cerf to develop the Interplanetary Internet, as well as leading on sustainability and smart cities.

The Major Project Award was won by the team behind the Mega Amp Spherical Tokamak Upgrade (MAST-U), the UK's national fusion experiment based in UKAEA's Culham Science Centre in Oxfordshire. The machine has the potential to provide a cheaper, more efficient means of generating energy, vital to the development of commercial power from nuclear fusion.

The three Silver Medallists were also announced. See page 36 for more about the winners.

The week before, HRH The Princess Royal presented awards to five young engineers who have been outstandingly successful in their respective fields at an early stage of their careers during a specially arranged visit to the Thames Tideway Project in London. All five are winners of the RAEng Engineers Trust Young Engineer of the Year competition, awarded by the Academy with support from the Worshipful Company of Engineers. Each received a prestigious award and a £3,000 prize.

The overall winner, Dr Marzia Bolpagni, also received the Sir George Macfarlane Medal for excellence in the early stage of her career.

Dr Larissa Suzuki, Rooke Award winner

The MAST-U team with David Eyton CBE FREng, Executive Vice President of Innovation and Engineering at bp, who presented them with the Major Project Award

The DnaNudge team with their MacRobert Award medals

STUDENT ENGINEERS WIN RACING CAR COMPETITION

A team of engineering students from the University of Sheffield won the Formula Student 2021 racing car competition, beating off fierce competition from over 30 teams at an event held at Silverstone Race Circuit in July.

Team Sheffield Formula Racing joins 2017 winners Cardiff University as the only British winner of the competition, which gives students a real-world challenge to design, build and race single seater cars. It includes events designed to test their vehicle as well as formal presentations to show their engineering knowledge.

Team Sheffield's winning design © Institution of Mechanical Engineers

The competition, which is organised by the Institution of Mechanical Engineers (IMechE), returned to the track after a purely online event in 2020 because of the pandemic.

For UK and international teams unable to attend the track event in Silverstone or running as Concept Class teams, the IMechE organised an online competition with virtual racing simulation heats and finals. India's Institute of Technology Bombay picked up awards for both Concept Class design and Concept Class overall.

Formula Student's artificial intelligence (AI) competition, which launched in 2018, continues to attract new teams to develop autonomous driving systems and now has a second purpose-built prototype autonomous car for university teams to develop their systems. University of Bath's Team Bath Racing Electric and the University of Edinburgh's EUFS were winners of the AI competition's two classes.

BIOWASTE INNOVATION WINS AFRICA PRIZE

In July, chemical engineer Noël N'guessan won the 2021 Africa Prize for Engineering Innovation with a biowaste equipment innovation.

N'guessan and his team designed and patented Kubeko, a set of low-cost biowaste processing equipment; its composter and biodigester are both specifically designed to ferment agricultural post-harvest by-products into solid and liquid compost, and cooking gas.

The Kubeko team has made progress in reducing its production costs and installed two biodigesters running on cassava farms, with 50 composters installed to date on cocoa, palm oil and mango farms. Kubeko has also been commissioned by the Ministry of the Environment and Sustainable Development in Côte d'Ivoire to train stakeholders as part of the department's national composting and biowaste strategy.

Four finalists were selected from a shortlist of 16 African innovators for their ability to use engineering to solve problems for African communities. They were chosen after receiving eight months of training, mentorship and support through the Africa Prize, with expert volunteers.

Africa Prize winner Noël N'guessan and the Kubeko biowaste innovation

IMPROVING REPRESENTATION OF BLACK PEOPLE IN UK MOTORSPORT

Sir Lewis meets young engineers at the Royal Academy of Engineering in 2019

In the summer, the Royal Academy of Engineering and seven-time Formula 1 World Champion Sir Lewis Hamilton MBE HonFREng published the findings of The Hamilton Commission, which set out to identify the key barriers to the recruitment and progression of Black people in UK motorsport.

The research specifically focused on engineering positions within the industry, as they represent a major group of occupations and offer the biggest opportunity for change. Now, through its report, *Accelerating Change: Improving Representation of Black People in UK Motorsport*, the Commission has provided 10 recommendations that aim to address the issues limiting Black students' progression into engineering careers, as well as barriers within the motorsport industry.

The evidence-based report includes chapters exploring Formula 1 and the UK motorsport sector; young Black people's interest in engineering and motorsport; and the attainment and progression of young Black students in STEM subjects at school, in post-16 education, and in higher education leading to motorsport jobs. The Commission, which was co-chaired by Sir Lewis and Academy CEO, Dr Hayaatun Sillem CBE, also engaged a 14-strong Board of Commissioners from relevant fields including motorsport, politics, education, and engineering, who have each helped to inform and shape the report and its findings.

Upon publication of the findings, Sir Lewis said: "Given the right opportunities and support, young people can excel at whatever they put their minds to, but our research shows that many young Black people are being closed out of opportunities within STEM and having their full potential limited. While I have enjoyed a successful career in motorsport, it's been a lonely path as one of the few Black individuals within Formula 1 and, after 15 years of waiting for the industry to catch up, I realised I had to take action myself.

"In order to do that, I needed to understand what was preventing the industry from being as diverse as the world around it. Through the Commission's research, we can see there are clear meaningful steps the motorsport industry needs to take towards creating a more inclusive environment where diversity can thrive but also that we must tackle the barriers facing Black students that exist throughout their educational journey. Some of these barriers I recognise from my own experiences, but our findings have opened my eyes to just how far reaching these problems are. Now that I'm armed with the Commission's recommendations, I am personally committed to ensuring they are put into action. I'm so proud of our work to date, but this is really just the beginning."

The Hamilton Commission has been in development since December 2019 but was publicly launched in June 2020 to coincide with the heightened media and public interest in the Black Lives Matter Movement and greater scrutiny of race inequality in society. To find out more and read the report, please visit **www.hamiltoncommission.org**

GET INVOLVED IN ENGINEERING

Faraday's original electric motor from 1821 © Paul Wilkinson

200 YEARS OF THE ELECTRIC MOTOR

September onwards

From September, the Royal Institution (Ri) is running a year-long series of events and activities to mark the 200th anniversary of the world's first electric motor, developed by Michael Faraday in his basement lab at the Ri.

Activities to celebrate the anniversary begin with an opportunity to name one of 200 seats in the Ri's famous theatre, with a series of talks exploring the modern application of Faraday's many discoveries, videos and short films, and a Faraday-themed family fun day to follow throughout the 12 months.

The Ri has recently hosted a return to live events in its London theatre, marking the first stage in its reopening to public audiences after 18 months of closure.

Also from September, the Ri will be running a full theatre programme for adults and families, alongside its livestream events, launched during lockdown to increase accessibility to its talks from world-leading scientists. Tickets for all events are available via the Ri website at **www.rigb.org/whats-on**

SUSTAINABLE FUTURES

October 2021 to February 2022

The Royal Academy of Engineering is inviting young people to become engineers and share their ideas for innovations that work towards a sustainable future for our planet and our goal of reaching net zero. The challenge asks for creative solutions to tackle some of the biggest problems that are creating carbon emissions and impacting our environment.

All teams who enter have the chance of being invited to events across the country where they can share ideas with engineers. Entrants will also have the chance to win £1,000 for their school and classmates.

To enter, visit **www.stemresources.raeng.org.uk/this-is-engineering-sustainable-futures** or to find out more about the competition or the Connecting STEM Teachers programme, contact **education@raeng.org.uk**

THIS IS ENGINEERING DAY

3 November

The third *This is Engineering Day,* a day dedicated to celebrating the engineers shaping the world around us and to challenging the narrow public stereotypes of engineering, takes place on 3 November. This year it lands at the start of COP26, when vital conversations about what we need to do to tackle climate change and become net zero by 2050 will be in the public eye.

The day will paint a picture of what a net zero world will look like in 2050, a world that has been shaped by engineers to mitigate the effects of climate change and help us live a more sustainable life tomorrow. Working with a digital artist, these pictures of the future will be released for COP26 to illustrate how experts envision our landscapes, cityscapes and seascapes through sustainable engineering.

To get involved or for further information, please email **contact@thisisengineering.org.uk**

ASK THE ENGINEERS – THE PATH TO NET ZERO

October and November

Meeting the COP26 ambition of making the world net zero by 2050 will affect us all. From how we heat and light our homes, to how we produce our food, how we build our houses and cities to how we travel around, our future daily lives will be shaped by engineers and engineering.

Join the Royal Academy of Engineering and partner organisations before, during and after COP26 for a fascinating series of online discussions on how engineers can help.

To find out more and register, please visit **www.raeng.org.uk/events/online-events/ask-the-engineers-cop26-webinar-series**

CLIMATE CROSSROADS – LONDON TRANSPORT MUSEUM

Until 31 January 2023

London Transport Museum's Climate Crossroads programme imagines what the future could look like for London and aims to inspire visitors to take action that helps us get there together. Sponsored by Mott MacDonald and Cubic Transportation Systems, over the next 18 months, the museum has school holiday family activities, green-themed After Dark events, thought leadership debates for business leaders and policymakers, and skills and employability support for young people.

The programme will shine a light on sustainable cities, travel, transport, and greener skills for the future.

To find out more, visit **www.ltmuseum.co.uk/about/climate-crossroads**

HOW I GOT HERE

Q&A

MICHELLE WATIKI
CHEMICAL ENGINEER

QUICK-FIRE FACTS

Age: **23**

Qualifications: **BEng chemical engineering (Hons), Aston University. MSc advanced chemical engineering, Cranfield University.**

Biggest engineering inspiration: **Katherine Johnson.**

Most-used technology: **phones.**

Three words that describe you: **fun, logical, inquisitive.**

Postgraduate student Michele Watiki is studying a master's in advanced chemical engineering as a Net Zero Scholar at Cranfield University.

WHY DID YOU FIRST BECOME INTERESTED IN SCIENCE/ ENGINEERING?

I've always loved sciences. Chemistry was my favourite as I used to watch a lot of science-based TV shows such as Brainiac and MythBusters. I didn't know what an engineer was until the end of my GCSEs when my economics teacher recommended that I investigate it as a future career. The fact that it included science and maths had me sold almost instantly.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I studied AS maths, further maths, chemistry, and physics but dropped physics at A level as we were limited to three subjects. During this period, I participated in about four different summer schools while touring a variety of universities, which was particularly insightful.

I completed my first internship as a Nuffield Research Placement student at Xerox in Year 12, then was awarded a scholarship with EY (Ernst & Young) in Year 13, which included a summer internship within its advisory office.

I went on to study chemical engineering at Aston University and spent my placement year at Rolls-Royce Civil Aerospace as a manufacturing intern. I received an offer to return for a three-month summer internship within Nuclear Defence, which was great as it was within the chemical engineering field, as a thermo-fluid system design intern. Unfortunately, my offer to return the following summer was withdrawn because of the pandemic.

During the summer internship, I realised my passion for engineering education and outreach so spent a month interning abroad at Jomo Kenyatta University of Agriculture and Engineering, Kenya, where I helped support women engineering students.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

Graduating from university with a first-class degree and receiving a full scholarship for my master's degree. I worked a lot during university to financially support myself, even during my placement year (working six days a week was not fun!), so being able to see it all pay off was extremely rewarding.

I also currently sit as a Trustee Board Member for the Engineering Development Trust and I'm an Executive Board Member for the Association for Black and Ethnic Minority Engineers.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

The flexibility and creativeness when solving problems plus the fact that I can use maths to do so! Maths was always my favourite subject growing up and I love solving a good equation.

Michelle undertook two placements with Rolls-Royce

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

I'm currently completing my thesis, which looks at the feasibility and techno-economics of exploiting geothermal power in contribution to 'global net zero' within developing countries situated across East Africa. I spend most of my day working on my report and liaising with my partner company. This includes computational simulations, a lot of Excel and reading through tons of research papers.

Outside of academia, I work with a variety of different organisations (in different capacities), while also providing mentoring services so I block out time to complete any outstanding tasks/respond to emails. These organisations are all centred around engineering and/or education so this is my favourite part of the day.

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

Spend your time in education really exploring your interests. Engineering is such a broad field but the skills you learn are extremely transferable. During my placement year, I organised my own rotations and moved from mechanical to operations and even software design (I had never coded a day in my life prior to that moment). I did all of this although my undergraduate degree was in chemical engineering.

WHAT'S NEXT FOR YOU?

I'm due to start a graduate scheme and get hands-on with my career. I've taken a keen interest in sustainability, especially net zero.

I'm also in the middle of creating a one-stop platform to support engineering students during their time at university. I was often confused or lost during my undergraduate degree and only really gained confidence in engineering as my future field of work during the final years. I would like to create a hub that has all the quirky information that engineering students want to know but nobody really addresses.

OPINION

PREPARING FUTURE ENGINEERS FOR THE NET ZERO CHALLENGE

Engineers will face ever-growing and ever-changing challenges as they tackle climate change and build a sustainable future. There is now an urgent need to ensure they will be equipped with the knowledge and skills to do so, writes Professor Roger Kemp MBE FREng.

Professor Roger Kemp MBE FREng

Complex systems play an increasingly important part in people's lives: supply chains providing fresh food from around the world to local supermarkets; power systems extracting energy from wind, sunshine, tides, biomass, and fossil fuels, and making it available 24/7 in sockets around our homes; international data networks connecting phones, computers, search engines, and media; the financial system allowing international credit card usage and providing finance for business and industry. The list of complex systems essential to our way of life is long and continually growing. But perhaps the most important are the interconnected systems of atmospheric dynamics, the carbon cycle, ocean salinity, and other parameters that control the earth's climate, on which all others depend.

Some complex systems are *engineered* – that is to say there is a plan, the participants are known in advance, and there are protocols and regulations in place. A city metro system may be complex, but there is little ambiguity over its geographical extent, assets, operations, or responsibility for the safety of the network. Other complex systems can be *ad hoc* – there is no central authority, players join and leave at will, and regulation may be covered by multiple jurisdictions. The 2008 financial crash brought home the complexity, interdependence and riskiness of financial organisations.

From time to time, people find themselves in a complex *system-of-systems* that, until it failed, no one had thought of as connected. When, in 2015, Storm Desmond took out the electricity system in Lancaster, people were surprised how many other services – phones, health and social care, lifts and water supplies in tower blocks, cash machines, card payments, petrol stations, garage doors – were all affected, as detailed in the 2016 Royal Academy of Engineering report, *Living without electricity*.

For half a century, the UK has been subjected to a mission, exercised with almost religious zealotry, to improve efficiency. Government appoints *Efficiency Tsars*; privatisation and contracting-out are justified by claimed efficiency benefits; shareholders demand greater efficiency to improve returns; efficient cars and heating systems produce less greenhouse gases; efficient farming produces more crops per hectare.

Within 10 years, we need to be well on the way to a zero-carbon society. Mass production of internal combustion engines will be running down: novel transport systems, electric vehicles, cycling and walking will be the 'new normal'

But efficient systems are often brittle and at the opposite end of a spectrum from resilient. An agricultural monoculture might be the most efficient way of producing food but, as was found in the 1840s Irish potato famine, can be a brittle solution, prone to fracture. Establishing a society that copes efficiently with the unpredictability of complex systems, achieves zero-carbon targets, and is resilient to natural and human-made disruption will not happen by chance. It will require careful analysis, different priorities, an engaged population, and, above all, a differently educated workforce.

Within 10 years, we need to be well on the way to a zero-carbon society. Mass production of internal combustion engines will be running down: novel transport systems, electric vehicles, cycling and walking will be the 'new normal'. New homes will be built to *Passivhaus* standards (using little energy) and teams of technicians will be involved in converting existing houses from gas central heating to heat pumps, hydrogen or district heating. Research groups will be developing carbon capture and storage and renewable technologies. Energy storage will be high on the research agenda along with the design of networks of control systems to balance the demands of heat pumps, electric vehicle charging and smart appliances with whatever flow renewables are available. Control systems for 'the smart grid' will constitute a multi-faceted, heterogenous and hugely complicated network of complex systems, both above and below the meter.

To cope with this dramatic shift in technologies, we will need a dramatically different engineering workforce – different not only in technical skills but also in creativity, interdisciplinarity, flexibility, and motivation. Decarbonising a complex industrialised society is not something that can be planned meticulously in advance – it is easy to predict that life will be very different to today, but no one can predict how the challenges will evolve or how resilient solutions will be developed.

Over recent decades, engineering education has become conformist with narrowly defined learning outcomes and curricula, accredited standards and all their associated bureaucracy. The curriculum in some areas has been largely unchanged for decades, despite the rapid growth in analytical tools and changes in technology and the structure of careers. In the near future, the problems engineers will face in tackling the climate crisis and its impacts will be novel, unique, complex, and unbounded. Many will be in outwards-facing roles, working closely with sociologists, environmental scientists and politicians, requiring a very different set of competences and motivations. Understanding complexity and the balance between resilience and efficiency will be essential skills.

The usual cycle for making changes to what engineers learn takes many years, from the painstaking negotiation of changes to UK-SPEC (the UK Standard for Professional Engineering Competence, which sets out the competence and commitment required for professional registration), through universities introducing changed curricula, to graduates emerging with new skills and becoming integrated into the workforce. This ponderous evolutionary cycle will not equip tomorrow's engineers with the competences needed to tackle the global emergency in the timescale needed. Three urgent actions are required:

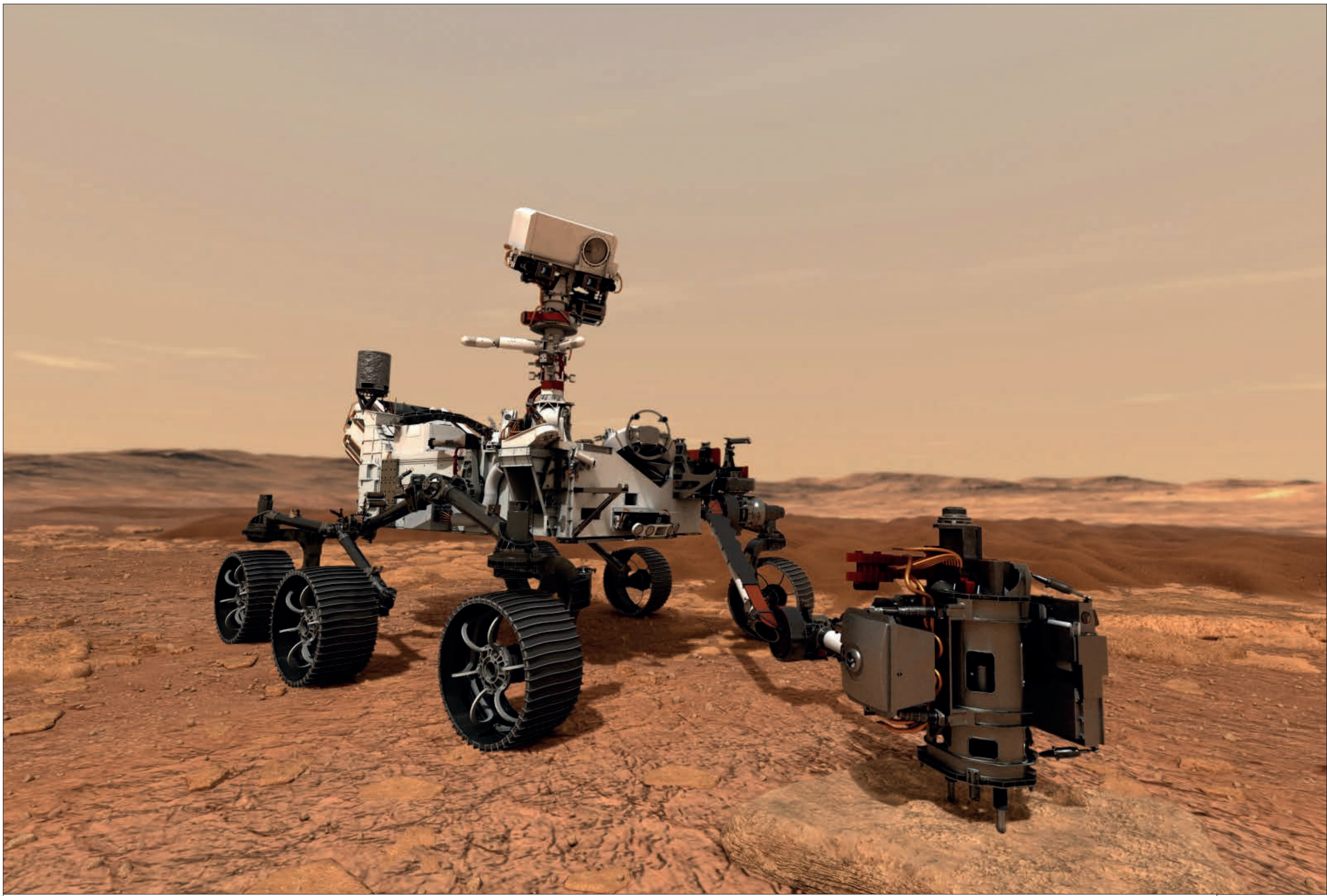
1. The engineering profession, working with industry, needs to establish a realistic plan of how net zero will be achieved and to produce an estimate of the numbers of engineers and technicians who will be needed in different areas and the core skills they will need.
2. A team, mainly drawn from the professional engineering institutions and universities, needs to analyse the knowledge, expertise and skills decarbonisation will require and how engineering syllabi need to change to deliver these.
3. The Department for Education needs to work with industry and further education colleges to ensure there are suitable courses, apprenticeships and funding, both for young people joining the net zero workforce and for reskilling the many thousands of technicians and skilled workers in existing high-carbon industries.

To meet the challenge of net zero will require a revolution in engineering education – and that needs to start now.

BIOGRAPHY

Professor Roger Kemp MBE FREng spent his early career in the rail industry, most recently as UK Technical and Safety Director of Alstom Transport. He joined Lancaster University in 2003, where he ran a master's in safety engineering and researched decarbonisation of heating and transport. He is now an Emeritus Professor of Engineering and heavily involved in the Royal Academy of Engineering's work on the safety of complex systems.

Professor Kemp's opinion was also published as a blogpost on the Royal Academy of Engineering's website: ***www.raeng.org.uk/news/blog-posts***



NASA's Perseverance rover, here in an artist's impression using its drill to core a rock sample on Mars, has seven scientific instruments on board. CCDs are integral to two of these © NASA

AT THE FRONTIER OF SPACE EXPLORATION

Did you know?

- CCDs have been used in astronomy and planetary science for decades
- CCDs are at the heart of scientific instruments onboard NASA's Perseverance rover
- These instruments are discovering if rocks on Mars show evidence of past or present living organisms on the planet
- The CCD sensors on Perseverance are designed to withstand the intense cosmic radiation present in space and on the surface of Mars

In February 2021, NASA's Perseverance rover landed on Mars, fitted with a suite of seven instruments designed to search for signs of past and present life. Tereza Pultarova spoke to Paul Jerram, Chief Engineer at Teledyne e2v, about the CCD technology at the heart of two of these cutting-edge scientific devices.

The CCD, or charged coupled device, is a type of microchip that can turn photons, the elementary particles of light, into electronic charge, then read the resulting signal pixel by pixel and translate it into visual images or light spectra.

Invented in the late 1960s by Americans Willard Boyle and George E. Smith (who were awarded the Nobel Prize for Physics for the invention in 2009, with Smith also receiving the Queen Elizabeth Prize for Engineering Innovation in 2018 – see 'Image revolutionaries', *Ingenia* 73.), CCD technology ushered in the era of digital imaging and photography. Although consumer cameras and camcorders eventually switched to cheaper mass-manufactured CMOS (complementary metal-oxide-semiconductor) sensors, demanding scientific imagers still rely on CCDs.

In astronomy and planetary science, CCDs have been a mainstay for decades. CCD sensors enable the famous Hubble Space Telescope to take breathtaking images of distant galaxies. CCD sensors were on both the comet-chasing Rosetta spacecraft as well as the lander Philae. They sat inside the instruments of NASA's Mars explorers Curiosity, Spirit and Opportunity. They enabled the Kepler Space Telescope to detect the minuscule dips in brightness of distant stars caused by transits of orbiting exoplanets. CCD technology inside the cameras of NASA's New Horizon spacecraft provided humans with the first detailed look at Pluto, the most distant large body in the Solar System.

Nearly every mission that has carried cameras and various kinds of imaging instruments in the past three decades has had CCD sensors on board, and many of these sensors have been manufactured by UK-based engineering firm Teledyne e2v.

"For space applications, the number one criterion when choosing a technology is whether someone has flown it already and proved it reliable," says Paul Jerram, Chief Engineer at Teledyne e2v. "Space agencies are very conservative and often prefer technology that is many years old."

When NASA decided in 2012 to develop a new Mars rover, with the grand goal to search for traces of life on Mars, the agency's engineers again turned to Teledyne e2v to provide its tried and tested CCDs.

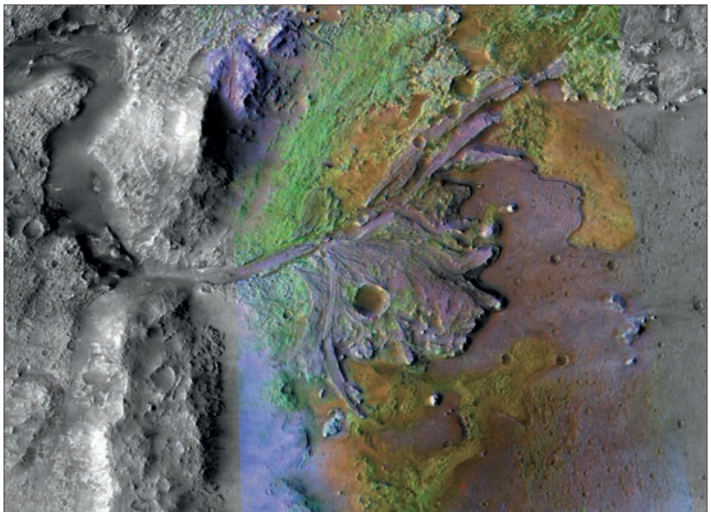
SHERLOC AND SUPERCAM

SHERLOC and SuperCam are two of the seven scientific instruments on board of the Perseverance rover. Both instruments are complex, consisting of optical cameras and analytical devices

PERSEVERANCE

Since 8 February 2021, NASA's Mars Perseverance rover has been traversing Jezero, a 50-kilometre-deep crater created by the impact of an ancient meteorite. Scientists believe that Jezero, which means 'a lake' in several eastern European languages, was once flooded with water. This past presence of water is what makes Jezero an intriguing target for a mission, the goal of which is to search for signs of past life and potentially habitable conditions. About the size of a small car, Perseverance is equipped with seven scientific instruments.

The Perseverance mission is the first step in a chain that will ultimately bring a sample of Martian soil to the Earth at some point in the early 2030s. Equipped with a small drill, Perseverance will scoop dirt from Jezero and prepare over 30 sealed samples for a later mission to collect. To ensure the samples have the highest scientific value, and the best probability to harbour traces of past life, the rover uses a suite of sophisticated instruments that analyse the chemical composition of rocks and look for organic compounds. Perseverance also carries a device that makes oxygen from carbon dioxide in the Martian atmosphere, a key technology for future human exploration, and another tool that analyses weather in the crater.



This image of Jezero Crater, the landing site for the Mars Perseverance rover, was taken by instruments on NASA's Mars Reconnaissance Orbiter © NASA

Taken in February 2021, this image from the Mastcam-Z instrument on NASA's Perseverance rover shows the first target for analysis by the rover's SuperCam instrument © NASA

called spectrometers. These spectrometers detect light reflected by materials on the surface of the Red Planet and split it into to the wavelengths of the electromagnetic spectrum. Because different chemical materials absorb and reflect light differently, these spectral signatures then reveal to the scientists the chemical composition of whatever they are looking at. In the case of SHERLOC and SuperCam, the goal is to find out whether rocks on the Martian surface contain molecules suggesting past or present existence of living organisms on the planet.

"Our CCDs sit at the heart of these spectrometers," says Jerram. "As the light enters the detector, it goes through a diffraction grating that splits the spectrum across a range of wavelengths before it falls onto the CCD. Then you detect the signal across this wide wavelength range."

Since sending a rover to Mars costs a lot of money, the engineers want to squeeze as much information out of the instruments as technically possible. Teledyne's CCD42-10 product used in SHERLOC and SuperCam was designed to be sensitive to a range of wavelengths that exceeds that of the human eye – it includes the visible wavelengths of 400 to 700 nanometres, which the human eye can detect, as well as the near-infrared wavelengths of 700 to 1,000 nanometres. The devices turn light into a valuable scientific signal with nearly 100% efficiency, meaning they turn nearly every single photon that hits the device into an information-generating electron.

"We make the CCDs sensitive down to the ultraviolet and up into the near-infrared, from under 200 nanometres up to 1,100 nanometres," Jerram says. "Then you get a spectrum out of the instrument and you can see the various peaks and troughs that represent the various parts of the spectrum. That tells you about the presence of certain minerals and materials, especially organic materials."

INDESTRUCTIBLE SENSORS

Before setting off for its journey to Mars, the 2,000 by 500-pixel CCDs had to undergo a battery of tests designed to prove that the sensors would survive the shocks and vibrations of the rocket launch and Martian landing. They also needed to withstand the 100°C thermal fluctuations during the cruise to Mars as well as on the planet's surface, and the exposure to cosmic radiation, which is much stronger on Mars than on the Earth. The engineers also had to make sure that the sensors would perform flawlessly for at least for the planned mission lifetime of around 24 months despite the punishing conditions.

"When you produce a sensor for Earth, you make one and you deliver it," says Jerram. "But if we want one sensor to go into an instrument like SHERLOC, we might make something like 30 or 40 sensors and deliver two or three, the flight model and the spares. We would test the rest up to destruction."

The shocks and vibrations induced during the tests would be more violent than those expected during the journey, the thermal swings would be greater and the temperature would change faster. Failures in space are costly: it took a repair mission worth hundreds of millions of dollars to fix the short-sighted Hubble Space Telescope in the 1990s. But Hubble orbits merely 550 kilometres above the Earth. Mars is, at its closest, more than 50 million kilometres away, beyond the reach of any currently feasible human space mission.

The sensors inside Perseverance are essentially the same as those used in instruments on the earlier rovers Curiosity, Spirit and Opportunity, so much of the challenging engineering work had already been done ahead of the earlier missions. In addition to being tried and tested, the advantage of the CCD technology compared to CMOS, Jerram says, is the relative simplicity of its design, which makes it "inherently suitable" for space applications.

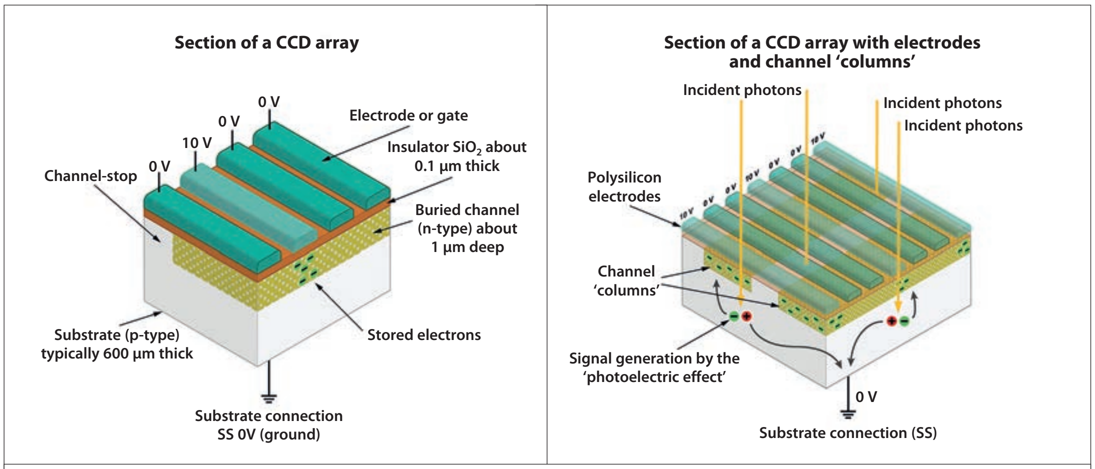
"A CCD is actually quite simple in principle and typically has something like two transistors on it and it just moves charge about, detects the charge and converts it to an output signal," Jerram says. "There is much more to consider with CMOS sensors."

WHAT IS A CCD

The CCD, or a charged coupled device, is a type of integrated circuit, a complex electronic circuit etched on a single small piece of silicon. The CCD is made of light-sensitive elements, called pixels. As photons hit the chip's surface, they generate electronic charge in the pixels. The number of electrons generated in the pixel after photon impact is directly proportionate to the intensity of the light on the pixel in the resulting image. By measuring the number of electrons in each pixel, the device reconstructs the scene in front of the camera.

The CCDs inside scientific instruments are designed to maximise what scientists can learn from the mission. In the case of CCDs in space telescopes and Mars rovers, the key is to capture every photon that hits the detector and turn it into an electron, a factor called the quantum efficiency.

Engineers can increase the quantum efficiency of CCDs by controlling how light illuminates the chip. If a chip is illuminated from the back, the light doesn't have to pass through the layer of polycrystalline silicon that usually covers the front of the chip, which might reduce the number of photons that pass through. To enable a chip to be used this way, however, requires sophisticated engineering techniques and increases the cost of the chip.



Charge collection within a CCD image sensor © Teledyne e2v

The CCD sensors on Perseverance are designed to withstand the intense cosmic radiation present in space and on the surface of Mars, which unlike the Earth has no protective magnetic field.

PROTECTIVE PACKAGING

It's not only the sensor itself that has to be robust. A CCD destined for space needs carefully engineered packaging that will not only protect it against the turbulences of space flight but also prevent cracks as both the packaging and the sensor expand and contract in the swinging temperatures.

"When we design a package for a CCD that will go to space, we have to do a lot of thermal modelling," Jerram says. "You have to make sure that the material has a good thermal expansion match to the silicon substrate of the CCD."

The packages protecting the CCDs in SHERLOC and SuperCam are made of the ceramic materials aluminium nitride and aluminium oxide. These can withstand temperatures of up to 150°C.

GERM-FREE

Teledyne e2v first developed this type of CCD sensor for an Earth-based telescope operated by the Royal Observatory in Greenwich. Since then, the technology has been included on 49 space missions (the number is still growing) and has been used in countless ground-based instruments.

Yet, making a chip for Mars does come with specific challenges. The mission of a life-detecting rover might be completely ruined if the vehicle brought living organisms with it from the Earth. Astrobiologists are concerned about the possible contamination of Mars with Earth's bugs and the threat they might pose to the Martian natives.

Unlike most of the Mars-bound equipment, chips don't need to be sterilised by chemicals or heat. Still, strict regulations apply to them as to how many bacterial spores and dust particles they are allowed to contain.

"Contamination is an important issue," says Jerram. "All the fabrication, packaging and testing is done in highly controlled clean rooms. The contamination that you are allowed is extremely low, so we have to keep the devices clean all the way through."

SHERLOC and SuperCam will ultimately help scientists select pieces of rock that the rover will then extract and place into small tubes. These tubes will be stored on the Martian surface and wait for a Sample Return Mission to collect them and bring them to the Earth at some point in the early 2030s. The UK-made technology will help answer the big question of whether life exists or has ever existed on Mars.

WHAT'S ON BOARD

Mastcam-Z: A set of two cameras located on the rover's mast that capture panoramic and stereoscopic images of the rover's surroundings. The instrument assists with rover operations and can determine the mineralogical composition of Jezero crater.

MEDA (Mars Environmental Dynamics Analyzer): A set of sensors that provide measurements of temperature, wind speed and direction, pressure, and relative humidity in Jezero crater, and analyse the size and shape of dust particles in the atmosphere.

MOXIE (Mars Oxygen ISRU Experiment): A technological demonstrator designed to show how future Martian explorers would manufacture oxygen for breathing from carbon dioxide in the atmosphere of Mars.

PIXL (Planetary Instrument for X-ray Lithochemistry): An X-ray fluorescence spectrometer combined with a high-resolution imager that can analyse fine elemental composition of materials on the surface of Mars with unprecedented detail.

RIMFAX (Radar Imager for Mars' Subsurface Experiment): A ground-penetrating radar measuring the geological structures in the subsurface of Jezero crater with 1 centimetre resolution. RIMFAX can detect water, ice or salty brines up to 10 metres under the surface of Mars. Water-rich environments hold the highest promise of harbouring traces of past or present life.

SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals): A spectrometer that will provide fine-scale imaging and uses an ultraviolet (UV) laser to determine fine-scale mineralogy and detect organic compounds. SHERLOC is the first UV Raman spectrometer to fly to the surface of Mars and will provide complementary measurements with other instruments in the payload.

SuperCam: An instrument that takes images of rocks in the Jezero crater and analyses their chemical composition. The instruments can detect organic compounds in the rock from a distance without having to interact with them.

BIOGRAPHY

Paul Jerram has worked in Teledyne e2v's imaging division for nearly 25 years, after roles in different technology areas at the company. As Chief Engineer for Space Imaging, he ensures that Teledyne e2v's imaging technology is developed to meet customers' needs. Paul has a PhD in atomic physics from University College London.

KEEPING CARBON GROUNDED

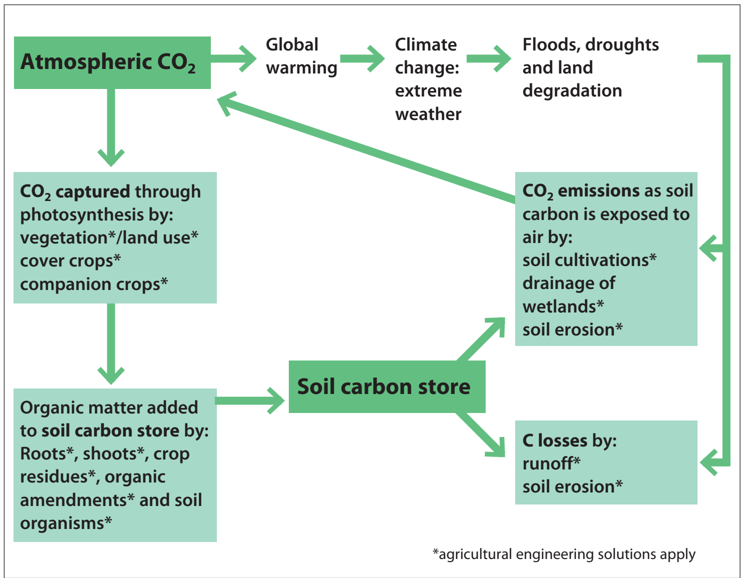
Agriculture started by trial and error but today, the fields we see are the result of an engineering system approach to manage fertility, crop production and, increasingly importantly, the carbon emissions and sequestration that are an inevitable part of the biosystem. Professor Jane Rickson, Professor of Soil Erosion and Conservation at Cranfield University, discusses the potential of agricultural soils to reduce carbon emissions; capture atmospheric carbon and store more terrestrial carbon; and how agricultural engineering is helping achieve this.

Ploughing of fields brings organic matter to the surface, releasing CO_2. Agricultural engineers are tackling this with tillage practices
© Free Photos/Pixabay

Did you know?

- Agriculture accounts for 10% of all greenhouse gas emissions
- Ploughing brings organic matter to the surface, releasing CO_2. This is being tackled with engineered 'conservation tillage'
- Agricultural engineering can also increase the removal of carbon from the atmosphere
- On steep slopes, field engineering structures control surface run-off and soil erosion

Severe land degradation (soil erosion) in Western Australia caused by high intensity rainstorms (for example, 40 millimetres of rainfall in one hour)



Agricultural engineering can influence carbon emissions and losses from farmland, and provide opportunities for carbon sequestration and storage

Environmental activists like Greta Thunberg argue that the world faces an existential crisis resulting from climate change caused by humans, with future impacts being disproportionately felt by young people. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land provides irrefutable evidence of the negative impacts of climate change on global natural resources (in particular soil, water and vegetation). Climate change results in desertification and land degradation, as observed in southern Europe, West Africa, and South and Central Asia, with adverse consequences for food security and terrestrial ecosystems. Ultimately, these impacts affect people's livelihoods and hinder progress towards the UNs' Sustainable Development Goals that aim to create a better and more sustainable future. Climate change has been linked to elevated greenhouse gas (GHG) emissions of nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2), which absorb heat from the Earth's surface and radiate it back, creating a greenhouse effect and warming of the Earth's atmosphere. This can result in extreme weather events, such as longer, more frequent, and more intense rainstorms and heatwaves, leading to damaging floods in winter and to severe droughts in summer.

The UK government has committed to reducing all GHG emissions to 'net zero' by 2050 (and by 78% compared to 1990 levels by 2035). Agriculture is one sector that could help deliver these ambitious targets. Currently, agriculture contributes about 10% of UK's total GHG emissions (around 45.6 million tonnes CO_2 equivalent), but this proportion will increase as other sources of GHGs, such as transport (27.5%) and energy (23%) reduce their emissions through decarbonisation. Both the UK Climate Change Committee and the Institute for European Environmental Policy include carbon capture and storage as critical levers required for agriculture to reach net zero. This has led to more scrutiny of agricultural soils' potential in achieving this target, as soil can influence CO_2 emissions and

Keeping soil carbon in place also improves soil health and condition over time, making the soil easier to work and requiring less energy (tractor power)

Deep ploughing exposes buried soil carbon to oxygen in the atmosphere leading to CO_2 emissions (left), but reduced tillage causes less soil disturbance, keeping the soil carbon in place (right)

losses from farmland, as well as provide opportunities for carbon sequestration and storage.

CONTROLLING CO_2 EMISSIONS

Soil and water engineering can affect carbon losses from agricultural land. For example, traditional deep ploughing inverts the topsoil [see images above], bringing soil nutrients and organic matter closer to the soil surface to improve soil fertility. However, exposure of the buried soil organic carbon to the atmosphere causes CO_2 emissions from the soil. To avoid this, cultivation tools such as discs, tines or chisels are engineered to reduce soil disturbance and minimise exposure of soil carbon. This is called 'reduced' or 'conservation tillage', also known as minimum, strip or zero tillage (cultivation of land for growing crops). These practices do not turn the soil over and only disturb the top few centimetres. Keeping soil carbon in place also improves soil health and condition over time, making the soil easier to work and requiring less energy (tractor power). This reduces fossil fuel consumption (and associated CO_2 emissions). However, there is some concern that in the short term and on some soil types, conservation tillage can lead to poor quality seed beds and compacted soils, which need to be repaired with additional energy-consuming field operations, such as subsoiling where soil is disturbed up to 14 to 20 centimetres below the surface and the disturbance aims to remove any compaction, at least in the short term.

Conservation tillage can also reduce soil erosion. Tillage is a process that removes surface topsoil and exposes buried soil carbon to the atmosphere, leading to CO_2 emissions. Soil erosion also causes losses of soil carbon in surface run-off. By disturbing the soil less and retaining ground cover on the soil (such as crop residues), conservation tillage can protect the soil from rainfall and wind erosion. Other field engineering practices are also used to control soil erosion and associated carbon losses. Some of these techniques originate from the US, where they were developed in response to the devastating effects of poor land management during the Dust

Discs and tines are designed to cultivate only a narrow seedbed so that buried soil carbon is not exposed to the atmosphere, which causes CO_2 emissions

Bowl era in the 1930s while others have been used for centuries. For example, terraces – widely used in rice, wheat and barley farming in east, south and southeast Asia – are field engineering structures that are designed and constructed on steep slopes to reduce slope length and steepness, so controlling surface run-off and soil erosion. Grass buffer strips, planted on the contour at regular intervals, act in the same way. Agricultural engineers also design and install lined channels and waterways on steep slopes to control soil erosion and prevent the associated carbon losses to the atmosphere and in surface run-off.

Significant CO_2 emissions are associated with the drying out of peat soils, which exposes soil carbon to oxygen in the atmosphere. Over the past 150 years, soil and water engineers have installed field drainage systems in carbon-rich peatland soils to increase the amount of agricultural land growing high-value horticultural crops, such as onions, carrots and potatoes. The resulting losses of soil carbon are dramatically shown by the Holme Fen posts in Cambridgeshire, where depletion of soil carbon through CO_2 emissions (oxidation), shrinkage and soil erosion has led to a loss of almost four metres of organic material. (see images on next page). To avoid these losses, 'smart' drainage systems can be used to control the water table underneath the soil surface, using valves installed at the outlet of a drainage ditch or subsurface drain to regulate drainage water outflow. Using state-of-the-art information and communications technologies such as the Internet of Things, farmers can be sent notifications for when they should open or close the valves, based on the weather forecast and soil moisture status, which are monitored in real time by environmental sensors. Controlling the water level in the soil ensures that the peat is at the optimum soil moisture content that allows crops to grow, while stopping the soil from drying out.

Field engineering practices (lined grass waterways) to control soil erosion and associated carbon losses in the UK. Over 19 kilometres have been installed in the UK since 2010 © R W Simmons

CARBON CAPTURE AND STORAGE

As well as controlling CO_2 emissions and carbon losses, agricultural engineering can increase the removal of carbon (or sequestration) from the atmosphere. In an arable rotation, farmers can decide in some years to grow crops that can capture carbon from the atmosphere through photosynthesis. This reaction between CO_2, water and light is promoted through soil management practices that maximise the amount of vegetation growing on the land, such as cover crops (which are grown during fallow times between harvesting of one commercial crop and planting of the next one) and companion crops (where a carbon capturing crop is grown between the rows of the main commercial crop). Species include mustard, radish, turnip, vetch, clover, oats, and ryegrass. The carbon sequestered by the plants via photosynthesis is returned to the soil, either as the plant material decomposes on the surface or is buried by subsequent cultivation operations.

It is estimated that global soil resources store around 1,600 Gt C (gigatonnes of carbon), compared to only 610 Gt C stored in above ground vegetation. In 2020, researchers at Cranfield University demonstrated the effects of different conservation tillage drills' geometry on levels of soil organic carbon. The systems that caused least soil disruption and left the highest amount of surface crop residue

In intensive agricultural systems, most of the atmospheric carbon captured by the plant during its lifetime is removed from the field when the crop is harvested. However, if the farmer decides to leave the residues in the field, some of the sequestered carbon can be incorporated back into the soil

Holme Fen was drained for intensive agricultural production. The top of these posts were at ground level in 1850, showing the loss of organic soil material through CO_2 emissions, soil shrinkage and soil erosion

showed the greatest increase in surface soil organic carbon after two years (up to 1.09 t C/ha (tonnes of carbon per hectare of land), compared to the more disruptive cultivation systems, which reduced soil carbon by 2.4 t C/ha. Carbon can also be stored in soil by growing deep-rooted crops and applying organic amendments. In intensive agricultural systems, most of the atmospheric carbon captured by the plant during its lifetime is removed from the field when the crop is harvested. However, if the farmer decides to leave the residues in the field, some of the sequestered carbon can be incorporated back into the soil by tillage and cultivation.

MEETING NET ZERO TARGETS

The IPCC warns that delay in addressing the impacts of climate change will increase the need for more widespread action in the future. As the impacts get worse with time, the number of cost-effective mitigation options available will reduce. Agricultural engineering has developed several technologies that help to decarbonise agriculture. Farmers are changing practices to reduce current carbon emissions, capture CO_2 from the atmosphere, and store carbon in crops and soils to mitigate the current climate emergency. Some measures are potentially highly disruptive for many UK farming businesses, so there needs to be robust evidence to show their practicality and cost-effectiveness. To be sustainable, these practices need to bring economic, social and environmental co-benefits too. Progress to net zero agriculture will be sensitive to future UK farming and environment policies. The recently passed Agriculture Act (2020) and Environment Bill offer opportunities for politicians to incentivise the adoption of measures that will address the current climate crisis.

One pass field operations and strip tillage enhance soil carbon storage by minimising soil disturbance and also reduce fossil fuel consumption

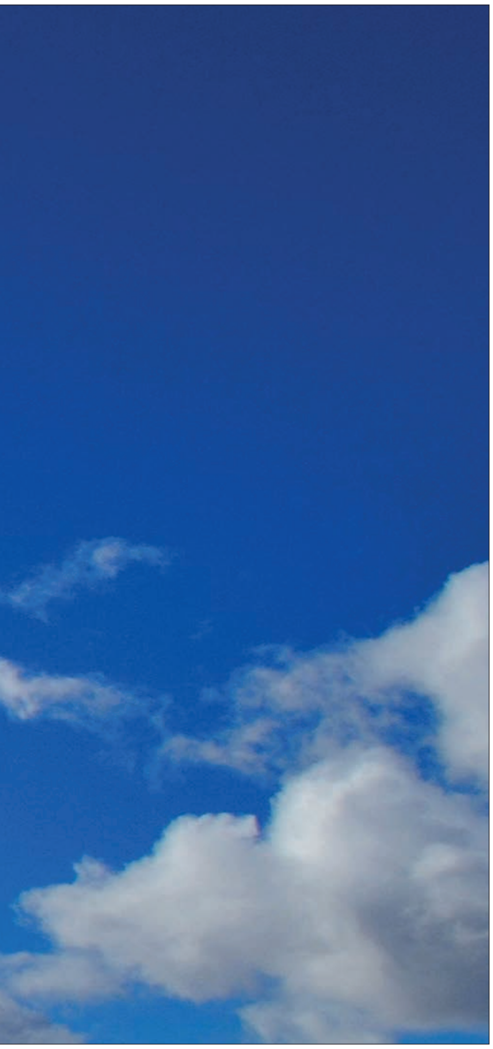
BIOGRAPHY

Professor Jane Rickson has over 35 years' experience of research, consultancy and teaching in soil and water engineering in the UK and abroad. Her work investigates the causes and consequences of soil erosion and other forms of land degradation, which annually costs the UK economy over £1.5 billion. She is Past President of the Institution of Agricultural Engineers, a Chartered Environmentalist and a member of the Institute of Professional Soil Scientists.

From 20-seat regional trips to over 100-seat long-distance flights, ZeroAvia aims to provide scalable, sustainable aviation by replacing conventional engines with hydrogen–electric powertrains

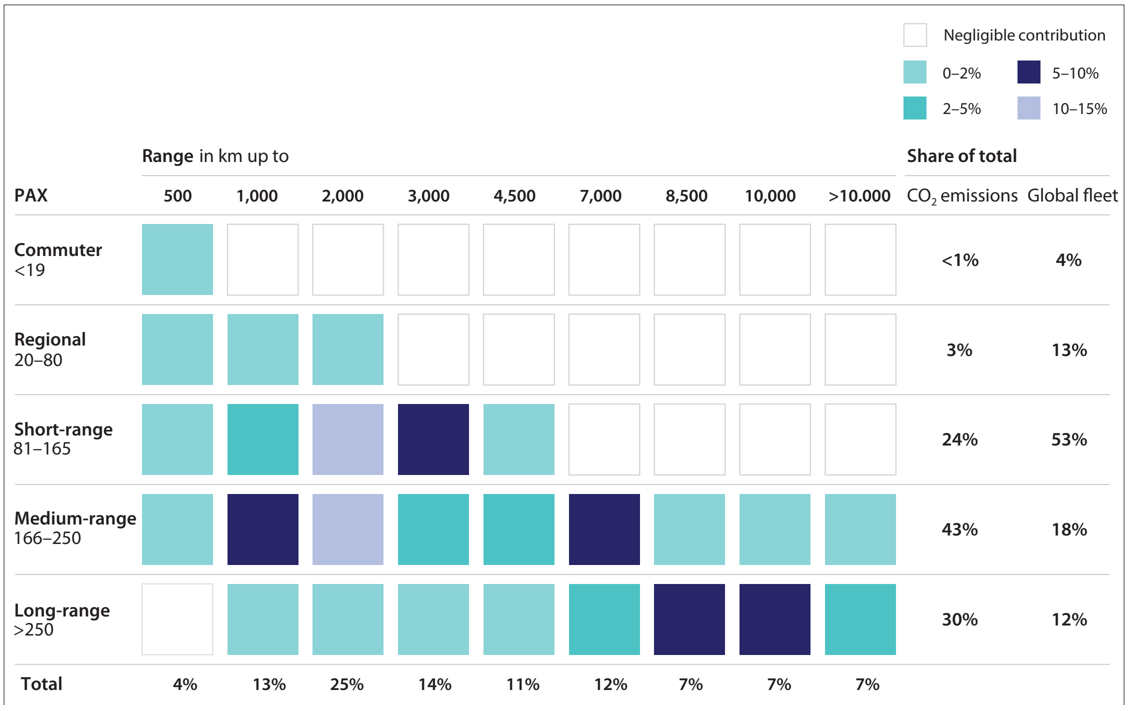
TOWARDS ZERO CARBON AVIATION

The aerospace industry has a problem. It's the same problem faced by every other energy-using industry: find a way to eliminate carbon dioxide emissions by 2050. No industry will find it easy. However, for several reasons, the aerospace industry may find it the hardest of all. Stuart Nathan talked to Val Miftakhov, Founder and CEO of California-based startup ZeroAvia, about the first step on the road towards hydrogen-powered aircraft.



Did you know?

- Commercial aviation accounts for 2.5% of global CO_2 emissions
- Hydrogen can be produced from resources including natural gas, nuclear power, biogas, and renewable power like solar and wind
- Hydrogen has more than three times the energy density of jet fuel
- 20 years from now, hydrogen could power a 200-seater aircraft over a 5,000 nautical mile flight



Passenger aircraft CO_2 emissions per segment and range from 2018 (graph taken from *Hydrogen-powered aviation: a fact-based study of hydrogen technology, economics and climate impact*, prepared by McKinsey & Company for the Clean Sky 2 JU and Fuel Cells and Hydrogen 2 JU in May 2020 https://bit.ly/3geal3Q)

In late 2019, the European Commission launched its Green Deal with an aim for decarbonisation: net carbon neutrality across all sectors and EU member states by 2050. This target is even more ambitious for the aviation sector, which is also working towards the Air Transport Action Group's (ATAG) goal for carbon-neutral growth from 2020 onwards and a 50% reduction in emissions by 2050 relative to 2005 levels.

The sector has become more carbon efficient over the past three decades: more seats are being used, and operational and technology improvements have boosted fuel efficiency for the number of kilometres travelled by paying passengers by around 50%.

However, before the COVID-19 pandemic, rising demand for air travel led to a significant increase in direct CO_2 emissions from aviation – 34% over the past five years. The easing of travel restrictions across the globe, growing populations and prosperity are again leading to increased demand and more measures, including alternative fuel sources, will need to be taken to accelerate the decarbonisation of aviation.

HIGH ENERGY

A lot of energy is needed to propel a vehicle weighing hundreds of tonnes through the air at high speed. A fully laden Airbus A350, weighing 280 tonnes, requires 215.5 GJ (gigajoule) an hour to stay in the air. Therefore, aerospace is perhaps more dependent than any other sector on the exceptional energy density of hydrocarbon fuels. Over a 16- to 18-hour flight, an A350 can burn 80 to 90 tonnes of fuel, and there aren't many energy sources that can pack as much punch into such a small mass. This dependency means that aviation is responsible

ZeroAvia's six-seater aircraft in flight, powered by the company's hydrogen–electric powertrain

for 2.5% of global carbon dioxide emissions – more than the whole of Germany. Most other sectors are turning to electrification to cut CO_2 emissions, but this isn't a viable solution for aerospace. Electric motors can power engines that generate enough thrust for flight, but the energy they need to do so has to be stored in heavy batteries, which are far heavier than full fuel tanks and, unlike fuel tanks, don't get significantly lighter over the course of a flight.

Onboard electricity generation may be the answer, and the technology that could provide this solution has a long history. Fuel cells generate electricity by converting the energy of the reaction between hydrogen and oxygen to produce water. They were first invented in the 19th century and proved their worth in providing electricity for the capsules that took humans to the Moon in the 1960s and 70s. Hydrogen has more than three times the energy density of jet fuel, and 100 times more than the most capable commercial lithium-ion battery. It would seem to be an ideal solution, but it is fraught with difficulties, dominated by the weight of the fuel cell and the ancillary equipment needed to operate it and the large tanks needed to store high-pressure hydrogen.

Despite this, several organisations, including Boeing, Airbus and Rolls-Royce, are all developing fuel-cell-powered aircraft with Boeing first flying a converted two-seater light aircraft in 2008. The German Aerospace Centre, DLR, is also leading development. But the first commercial-sized aircraft to fly using fuel cells, a converted Piper Malibu propeller-driven six-seater, used a powertrain developed by a smaller company, ZeroAvia. The twin-engine aircraft completed an eight-minute flight at Cranfield airfield in September 2020.

FUELLED BY FUNDING

ZeroAvia was formed in 2017 in California by Val Miftakhov, a Russian physicist and serial entrepreneur who has been based in the US since 1997. In 2019, Aerospace Technology Institute (ATI), a UK government-funded organisation, began a £2.7 million project called HyFlyer, led by ZeroAvia. The funding is shared by fuel cell manufacturer Intelligent Energy and Orkney-based European Marine Energy Centre (EMEC), which has access to renewably generated hydrogen from wave and tidal energy systems mounted in the Pentland Firth. HyFlyer's aim was to demonstrate a hydrogen fuel cell-powered passenger aircraft capable of flying 280 miles within a year.

Although the Piper flew under fuel cell power in its test flight in 2020, the fuel cell was supported by batteries, which helps to provide extra power for take-off. The batteries were operational throughout the flight, providing a safety margin, but ZeroAvia's goal is to develop a hydrogen powertrain capable of powering the aircraft for its entire flight (although Miftakhov indicates that batteries are likely to still be incorporated for safety).

The company is developing most of the powertrain's components itself. "So, fuel cell system, the power distribution, power electronics, motor, and overall control over that," Miftakhov explains. "And we're actually working on the fuel tank systems as well because today, there is no supply chain, really, for hydrogen fuel tanks for aviation. So, we work with a number of partners to create one."

"The biggest challenge is what we call balance of plant," he adds. "The fuel cell stack itself is actually relatively good from the weight perspective, we are getting good power density there. But to make it work, you also need air supply, hydrogen supply, humidification, heat exchange and other equipment, and together these are known as balance of plant. In automotive applications, fuel cell systems are significantly lighter than battery systems even with balance of plant. But we must push much harder than automotive, so reducing the weight in our balance of plant is crucial."

The company is currently working with compressed hydrogen fuel, which cannot be carried inside the wing of the aircraft (where conventional fuel tanks are located) because of the geometry constraints needed for tanks holding compressed gases. For the prototype aircraft, seats had to be removed to make space for the tanks, and previous prototypes had carried external tanks mounted on pylons above the wings. "The second step on our developmental roadmap is to switch to liquefied cryogenic hydrogen, and we have much more flexibility for the shape of the tanks for liquids, so we are hoping to develop tanks for inside the wings," Miftakhov says.

ENERGY STORAGE

ZeroAvia's next challenge is to go one better than last year's test flight and complete an entire flight without a fuel cell-only powertrain, which it plans to do before the end of 2021 with a 20-seat prototype flying from its new base at Cotswold Airport in Gloucestershire. This will use the hydrogen pressure vessels the company has developed itself, a task that proved unexpectedly difficult. "The sort of conventional compressed gas tank technology that's used today in cars has quite low gravimetric ratios, or mass of fuel inside relative to the mass of the tank," Miftakhov explains. "While it's still much better energy storage than a battery, it's not good enough for aviation. We have worked with partners to develop what some people call 'type 5 compressed gas storage tanks'." He claims that these allow for much better gravimetric efficiency. "We have about 11% of the mass of the filled tank as fuel, whereas type 4 tanks have a maximum of 7.58% fuel, with hydrogen at 350 bar."

The fuel cell also supports non-propulsion systems onboard the aircraft. These include systems to operate the aircraft's control surfaces, air conditioning, cockpit systems, and lighting. "We don't need the auxiliary generator that conventional aircraft run to supply ancillary power," Miftakhov says. "Those are pretty inefficient ways of producing energy and conventional aircraft use them to provide air conditioning at the gate or on the taxiway." The energy provided by the fuel cell will also be sufficient to move the aircraft on the ground, where the engines are at their least efficient, he adds.

SUSTAINABLE FUTURE

ZeroAvia's roadmap is ambitious. The company plans to be able to supply powertrains for regional turboprop aircraft, capable of carrying 50 to 90 passengers, by 2026, scaling up to 100 to 200 seaters with a 2,000 nautical mile range by 2030. Five years after that, it is targeting 200+ passenger capability across 3,000 nautical miles, and by 2040 it hopes for a range of above 5,000 nautical miles. The engines on these aircraft will have a similar engine core as turbojet engines, but instead of a propeller it spins a smaller fan with a large number of blades. Miftakhov says: "The electric motors we currently have are not capable of powering that kind of engine for longer range flight, but there is potential for motors with power densities almost an order of magnitude higher than the gas turbine engine. Motor capabilities are going to be developed and there is a relatively straightforward path to that. The fuel cell side of things for these use cases are a bit more convoluted. There are questions about the balance of plant again. How do you do air compression? How do you handle heat exchange? One thing we are looking at is higher temperature fuel cell technologies, which operate at about 200°C as opposed to the traditional sub-100°C operation. That would simplify heat management because you can exhaust heat more easily when there is a 200°C difference between your operating temperature and the ambient temperature, than when you are only 80°C different with a conventional fuel cell."

Using carbon-free fuel is obviously a major plus for sustainability. Miftakhov notes that, elsewhere in the powertrain, the fuel cell uses platinum as a catalyst, which, although 100% recyclable, still represents a high cost element of the technology. "We don't use any cobalt anywhere in the system, and we are pushing towards a magnet composition in the motors, which uses minimal amounts of rare earth metals, so overall our sustainability profile is pretty good."

The flammability of hydrogen is well known to the point of being notorious, so why is it necessary to go to the bother of using it in a fuel cell to generate electricity when it could be burned in a gas turbine in a similar way to kerosene in conventional aircraft? Miftakhov explains that this is a matter of controlling the other mechanism by which today's aircraft contribute to global heating and climate change. While the carbon dioxide emissions of fossil fuel-powered flight are well known, they only comprise about half of the radiative forcing effect of aviation (better known as the greenhouse effect). The other half comes from the other chemical product of hydrocarbon combustion: water vapour in the form of the contrails that track aircraft movement across the skies. When aviation was paused after the 9/11 terrorist attacks in 2001, climate scientists recorded a significant drop in global temperatures because of the absence of contrails. The problem with hydrogen-fuelled gas turbines is that they exhaust water vapour at a temperature of about 1,000°C, Miftakhov says. "That's so hot that you can't manage it on board the aircraft. You must exhaust it into the atmosphere and that is going to create contrails in the same way that today's aircraft do. You'd actually create about 40% more water vapour from a hydrogen gas turbine than from a hydrocarbon one. The fuel cells that we are flying now generate vapour at about 80°C, which is very easy to condense on board and exhaust as a liquid or ice pellets, which do not have a radiative forcing effect." Moreover, he adds, any combustion in air, regardless of the fuel, risks producing toxic nitrogen oxides, and combusting hydrogen for heat is a less efficient way of liberating its energy potential than reacting it chemically with oxygen in a fuel cell. "We are talking 25% efficiency for a gas turbine compared with 50% efficiency for a fuel cell."

The availability of a practical fuel cell-powered electric aircraft is, of course, only half the solution to improving the environmental profile of aviation. The other half is establishing the necessary infrastructure to supply zero-carbon hydrogen as a fuel. Currently, 95% of all the hydrogen produced globally is classified as 'grey' – that is, it is made by stripping the hydrogen away from hydrocarbons, leaving the problem of what to do with the carbon. Zero-carbon aviation can only work if the hydrogen

In August 2021, ZeroAvia's hydrogen powertrain successfully pulled a 15 tonne HyperTruck mobile ground testing platform across the tarmac. The HyperTruck is based on heavy-duty military trucks and is sized for the company's ZA-2000 2 MW+ powertrain, which can be used to test systems for 40- to 80-seat hydrogen–electric powered aircraft

is 'green'; that is, produced by electrolysing water using zero-carbon electricity.

While the powerful tidal turbines and wave energy converters can supply enough green hydrogen for ZeroAvia's current operations, they could not meet the demand of totally decarbonising aviation by 2050. Miftakhov envisages a future where a large installed capacity of zero-carbon generation provides electricity to airports, which would electrolyse water on site, providing the hydrogen that would then be used to fuel the aircraft and eliminating the risk of transporting pressurised hydrogen around road networks. This electricity supply would also have to power compression or liquefaction of the gas – an ambitious goal.

"We'd need something like 100 million tonnes a year of hydrogen to shift the entire aviation sector to zero carbon, which would need something like 600 GW of electrolysis capacity," Miftakhov explains. "That's about 10% of the worldwide electricity generation capacity right now so we would need a massive expansion of renewable capacity, and you have to take into account the losses in transmitting electricity from these generation sites, which are likely to be quite remote – out at sea, for example – to the airports. I am very interested in what companies such as Rolls-Royce are doing with developing small modular nuclear reactors (see 'Nuclear designs on a low-carbon future', *Ingenia* 87). That would give us the capability of housing energy generation right next to the airport. It's an intriguing possibility for the coming decades. Meanwhile, nuclear fusion is a hard problem, but we will solve it and it will be a game changer when it happens."

USING HYDROGEN SAFELY

The use of hydrogen in transport is tainted by the Zeppelin Hindenburg, which was destroyed in a fire on landing in New Jersey in 1937, with the hydrogen filling its envelope combusting in a spectacular conflagration. The disaster killed 36 people, although 62 passengers and crew survived. Film of the fire, the cause of which is still unclear, is the main reason that any proposal to use hydrogen is still greeted with scepticism.

It is true that hydrogen can be a hazardous substance. Any concentration between 4% and 74% in air is explosive, so it must be prevented from mixing with air inside any confined space. But does that mean that hydrogen-fuelled aircraft are too dangerous to be practical?

Miftakhov accepts that the aerospace industry may have a job on its hands to convince the public that the use of compressed hydrogen is safe. "We definitely have some education to do. But technology has moved on in the last 84 years. NASA and the US Federal Aviation Administration's safety analysis suggests that with a proper safety system around the hydrogen fuel, it can actually be safer than conventional jet fuel."

A fuel leak, whether from a tank of compressed or liquefied hydrogen, will always disperse instantly with the gas rising into the air due to its low density, unlike kerosene, which pools on the ground and produces an explosive vapour-air mixture. "To ignite hydrogen, you actually need a temperature source much higher than that needed for kerosene," Miftakhov adds. "Jet fuel is self-igniting at 200°C, so if it leaks out of an aircraft wing and drips onto the hot brakes of the landing gear, you can have an instant explosion. That could not happen with hydrogen. Even if hydrogen does ignite, the radiative heat production is far lower than that of a kerosene fire."

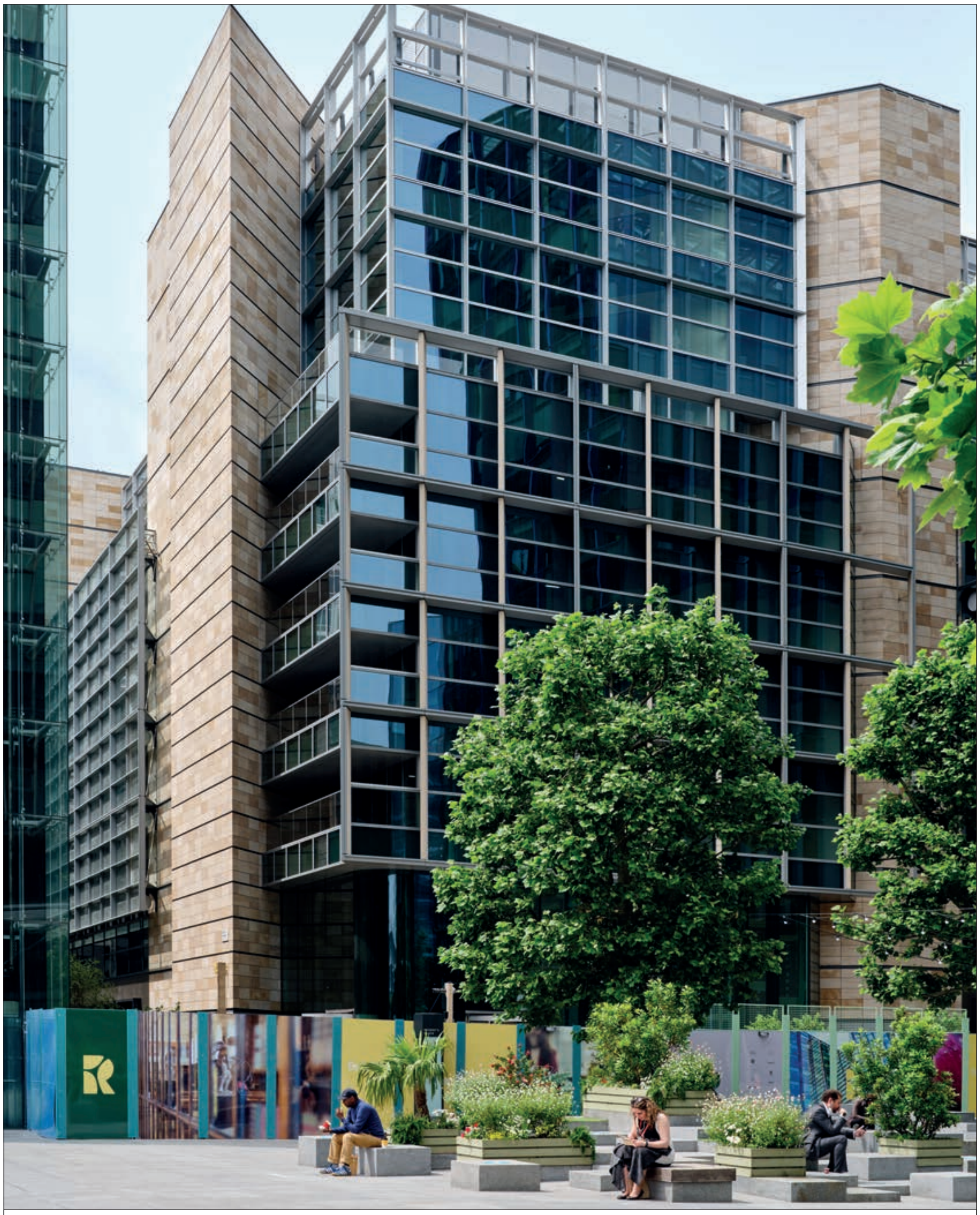
Miftakhov also points out that risk perception is notoriously inaccurate. "For example, gasoline is far worse than jet fuel. But there is an art to how to persuade people, with the right level of education and well-crafted messages that are rooted in physical reality and real data."

BIOGRAPHY

Val Miftakhov is a serial entrepreneur in electric vehicles. He has also held several senior business and product positions at Google and McKinsey & Company and was a nuclear researcher at Stanford Linear Accelerator. Val holds a PhD in physics from Princeton University, master's in physics from Moscow Institute of Physics and Technology, and was a two-time winner of nationwide Russian physics competitions. In his spare time, Val makes good use of his airplane and helicopter pilot licenses.

SUSTAINABLE SECOND LIVES

Demolishing old buildings and replacing them with new ones is a major source of carbon emissions. However, with some imagination and engineering ingenuity it is often possible to transform and reuse buildings that have passed their useful life. At One Triton Square in London, this resulted in carbon savings of 55% compared with a conventional rebuild – while saving money for the client and without compromising quality. Hugh Ferguson explored the roots of this success and how lessons can be exploited on other buildings.



The transformed One Triton Square office block reached practical completion in June 2021
© Arup

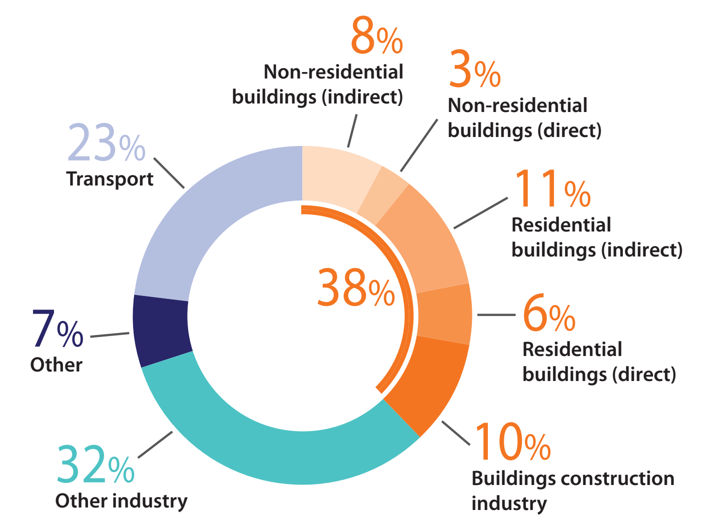
Did you know?

- Buildings are responsible for more than a quarter of greenhouse gas emissions
- Built in the 1990s, One Triton Square has been renovated and transformed, reusing many of its original materials
- A team of architects, engineers and other building professionals all brought their varying expertise to the project
- The project saved 54% of CO_2 emissions, reduced water use by 65% reduction and responsibly sourced 80% of its materials

Buildings are responsible for 38% of global greenhouse gas emissions [see image to the right]. This breaks down into 10% related to the materials and processes used in construction – predominantly cement production (6%) and steel in construction (4%), and 11% for gas and electricity used in operating non-residential buildings, (while the remaining 17% is for gas and electricity in residential buildings).

This presents a major challenge in building and construction: how to reduce the enormous amounts of embodied carbon in construction materials, and how to make buildings more carbon efficient in operation – without imposing impossibly large additional costs.

One Triton Square in London was a square 1990s office block with six storeys above ground and one basement level. Its structure was predominantly concrete framed with some steel, and its most remarkable feature was a huge central covered atrium from the first floor upwards. It was tired and unlettable, and ripe for redevelopment. Indeed, the local



Global greenhouse gas emissions, with the proportions related to buildings shown in orange. 'Direct' is from fuel burnt on site – mainly in gas boilers – while 'indirect' is electricity use

planners were initially bemused that the owner and developer should be considering anything other than demolition and rebuild.

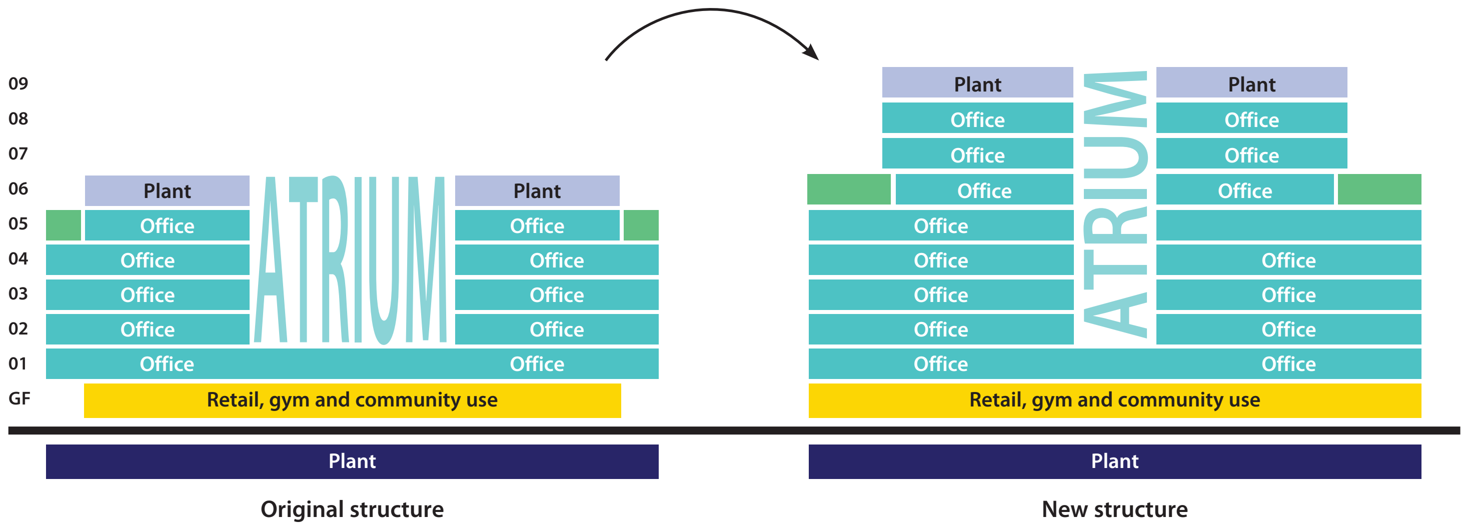
Property company British Land had other ideas. It brought in Arup Associates as designers and contractor LendLease. Together, they committed to a 'circular economy' philosophy: where possible discarding the conventional 'linear economy' approach of 'take, make, use, dispose, pollute' with a cycle of 'make, use, reuse, remake, recycle, make …'. This approach aims to keep assets at their highest possible value for as long as possible, even as staff and processes change, and impacts planning, business, design, and materials. It requires teamwork from people aligned to a common objective, since the solutions require imagination, common decisions and common actions from all parties – including the client, architect, engineers, and contractor.

It helped that Arup Associates is a division of Arup combining architects, engineers and other building professionals in an integrated team, so avoiding appointing multiple design consultants, and also that the firm designed the 1990s building and had kept excellent records. It was made more challenging by British Land's desire to nearly double the area of office space

REUSE AND RECYCLE

The existing building had plenty of scope for reuse. In particular, it had spare structural capacity by modern standards; infilling part of the vast atrium and taking advantage of changed planning rules allowing greater height meant that engineers could increase the area of office space considerably. The existence of extensive records from the original construction provided greater confidence in the design of strengthening works.

In choosing what to address to gain carbon (and cost) savings, designers of previous refurbishments have often gone for the 'easy wins' – one or two areas where the greatest gains can be made, which in this case would have included



Cut-through before-and-after diagrams of One Triton Square, showing the old square atrium reduced to half its width and three additional floors added, set back from the edges to minimise additional loads on the perimeter foundations

MARGINAL GAINS

In the early years of this century, Team GB's cyclists enjoyed an extraordinary period culminating in eight Gold Medals in each of the 2008 and 2012 Olympic Games, and their achievements were then replicated in road cycling by Team Sky. Much of this success was credited to the manager of both teams, Dave Brailsford, and his innovative concept of 'marginal gains': analysing data to tease out every possible area of improvement, however small, on the basis that the sum of these minor improvements would be a significant gain.

The team at One Triton Square adopted the same philosophy – even branding themselves as 'Team Triton' to make the point. Opportunities they identified saved carbon, or cost, or both, and included:

- 35,000 tonnes of concrete and 1,877 tonnes of steel reused and saved from demolition
- 3,000 square metres of refurbished and reused façade
- stairwells located outside the building's thermal core, requiring less heat and saving energy
- innovative strengthening solutions for existing columns and piles to allow three extra floors and an 85% increase in office space
- mini-piles and pile raft for the additional piling, saving 30% of new piling and £1 million in cost compared with piles and pile caps
- efficient mechanical and electrical plant design so that plant occupied no more space in the building, despite a near doubling of office space
- lightweight construction for new-build and moving heavy plant from roof to basement, to reduce amount of strengthening needed
- reducing embodied carbon in new-build concrete by extensive use of cement replacements, mostly 70% ground granulated blast furnace slag – a byproduct of the steel industry – resulting in 41% less carbon than standard concrete
- high-efficiency lighting with low-energy lights in lobbies and common areas, and maximum use of daylight, for example from the remodelled central atrium
- extensive energy modelling and plant optimisation
- old building plant upcycled and shipped to South Africa for sustainable retrofit
- Boiler efficiency increased to 94%
- 100% waste diversion during demolition
- low-energy ventilation systems and hybrid air-source heat pumps
- lifecycle assessment to further reduce embodied carbon
- sustainable urban drainage systems
- paving and other roof coverings reused from other demolished buildings
- 65% reduction in water use.

One Triton Square's original aluminium-and-glass façade was removed, refurbished off site, and then reused on the building, resulting in a 66% reduction in cost © Arup

saving much of the existing concrete and steel structure. But on this project the team went much further, seeking out and exploiting every possible area of saving [see 'Marginal gains'].

The most visible, and one of the most innovative, initiatives was to reuse most of the existing external cladding. On most previous transform-and-reuse projects, stripping off all the old, tired, inefficient cladding and replacing it with a modern, thermally efficient façade was a no-brainer, producing a more attractive building and making savings in operational carbon. Exceptions were where parts of the old façade had important historical or architectural significance.

Examination of One Triton Square showed that 3,300 square metres of limestone cladding could be retained (and extended upwards using the same French limestone), and that the aluminium-and-glass twin-skin façade units could be removed, refurbished off site and then reassembled. The plan was for the original manufacturer to refurbish them in Germany, but some 25,000 transport miles were saved by doing the work in a pop-up factory less than 30 miles away in Essex.

This meant dismantling 3,500 square metres of the aluminium-and-glass façade – equivalent to a dozen tennis courts. Each unit was inspected, deep-cleaned and refurbished, with new gaskets fitted and external-facing sections of the aluminium re-anodised. Advances in glass-coating technology mean the new units will be more thermally efficient. Reuse of the façade units resulted in a 66% reduction in cost compared with a like-for-like replacement.

The original structure was essentially circular reinforced concrete columns over individual concrete piles founded in the London Clay beneath, the columns supporting concrete floor slabs and stabilised by steel-framed cores in each corner above ground level. Despite some ingenious weight-saving measures, the extra weight of the additional offices would increase the load on most of the columns. Under the central atrium infill where the number of floors was increased from two to 10, the loading increased almost threefold.

For the foundations, availability of excellent records from the 1990s, including the as-built pile toe levels and the level at which each pile encountered the London Clay during the original piling, enabled the strength of each pile to be back-calculated. Their capacity proved to be much higher than the original specified design load. Some foundation strengthening was still required, and new piled raft was employed to minimise supplementary piling and cost.

Most of the columns were strengthened by conventional encasement with new high-strength reinforced concrete, increasing the diameter by 250 to 300 millimetres. However, for a small number of columns where the increase in loading was less, a more innovative technique was used: the columns were instead wrapped tightly with fibre-reinforced plastic wrapping, which increased their strength by 40%, saved concrete, saved time in construction, and, most important, increased the diameter by just 8 millimetres, so resulting in virtually no reduction in lettable floor area.

TEAM EXPERTISE

One change illustrates the close coordination between different professions on the project. The additional office floors have been set back from the perimeter of the original building. This has become an architectural feature of the new building but was driven by the engineering. Setting the new-build back meant that the columns and foundations around the perimeter carry virtually no additional load, and so required no strengthening – which would otherwise have been very challenging immediately adjacent to the façade and basement perimeter.

Another key feature of the success at One Triton Square was the use of building information modelling (BIM). BIM models are computer files digitally representing all the physical and functional characteristics of buildings – from the main structure to the smallest piece of pipework – which can be extracted, exchanged or networked to support decision-making. They also aid communication between all the parties – including client, architects, engineers, contractors, sub-contractors, and suppliers. BIM is not new to construction, but rarely is it used to full effect.

Development of the BIM model, with a virtual model of the existing building combined with the new structure, services and architecture
© Arup

On this project, Arup had excellent pre-BIM records of the geometry and calculations for the old building, which were used to create an accurate detailed 3D virtual model of what was there, as a basis for modelling, integrating and communicating any potential additions and changes. In Arup's real-time BIM environment, multiple models overlay and evolve together as the co-located team develop the design seamlessly. The model is open-access and used by all parties based on collaboration and sharing. It meant that the extensive historic data could be used fully, and design decisions involving multiple parties could be taken quickly and efficiently. Without a top-level BIM model, Arup believes many of the gains at One Triton Square would have been impossible.

CARBON SAVINGS

An estimated 40,000 tonnes CO_2e (carbon dioxide equivalent, a standard measure of the global warming effect of greenhouse gas emissions) has been saved on One Triton Square compared with a typical new London office

BREEAM is the leading method of certifying the sustainability of buildings, with most new buildings seeking a 'Very Good' or 'Excellent' rating. Few attempt to achieve 'Outstanding', due in part to a belief that the extra measures would add around 5% to the cost. One Triton Square has blown this myth, by achieving BREEAM Outstanding with an extra estimated cost of just 0.3%

– a 55% saving, or enough to heat and power nearly 10,000 average UK homes for a year.

This comprises just under 25,000 tonnes of embodied carbon, mainly by reusing 33,400 tonnes of the building's original concrete and 1,843 tonnes of the original steel. The remaining 15,000-tonne saving is in operational carbon over 20 years of use. Both benefited from multiple initiatives under the team's 'marginal gains' approach.

As a result, the building has emissions of just 465 kilograms CO_2e per square metre of embodied carbon, and 250 kilograms CO_2e per square metre of operational carbon over 20 years. In comparison, leading clients expect embodied carbon numbers of 800 to 1,000 kilograms for a new-build office building. However, some are now targeting lower figures and an industry standard for operational carbon is 570 kilograms (typical) or 360 kilograms (good) for the same 20-year period.

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Net office space has been increased by 85%, and the building is proving a commercial success –achieving the West End's biggest pre-let in more than 20 years.

Lessons from the success of One Triton Square include the importance of a client and delivery team committed to common objectives, single-team working with good BIM, and in particular the importance of keeping the original records of a building after construction is complete – not just the design drawings and calculations but also the on-site team's records of what was actually constructed. Without these, the transformation of One Triton Square would have been much more difficult, and some of the marginal gains would have been impossible. Yet frequently such records are not kept or get lost or destroyed over the years.

EXAMPLES OF TRANSFORM AND REUSE

Britain demolishes 50,000 buildings a year – 'a national disgrace' according to *The Times*. Not all could be saved and reused, but many could, and the best method of doing so depends on individual circumstances. Besides One Triton Square, other successful examples among London offices include: 1 Finsbury Avenue in Broadgate where not only the structure and façade of the original 1980s building were retained, but also 90% of the original plant; the iconic 1960s BBC Television Centre at White City was transformed into a multi-use neighbourhood, retaining much of the structure including existing double-glazed units; and the unloved 1980s Angel Building in Islington was scheduled for demolition before being transformed into an award-winning development ('Green facelift for concrete buildings', *Ingenia* 55).

Many of Britain's demolished buildings have historic value, and these too could be saved. The 1870s Grand Hotel in Birmingham, a fine example of Victorian architecture, was derelict and restoration was prohibitively expensive: some ingenious engineering greatly reduced the costs, and the refurbished hotel opened in May. London's Claridge's hotel in London has been expanded and modernised by adding five storeys of new basement beneath the existing 160-year-old building ('Going underground', *Ingenia* 77).

For very tall buildings, demolition and rebuilding is so costly and disruptive that virtually none have ever been demolished, worldwide. Transform and reuse is the only option: for example, the 45-floor AMP Centre was Sydney's tallest building on opening in 1976: it is now being turned into the 54-floor Quay Quarter Tower, while maintaining 68% of the existing structure.

BIOGRAPHY

Hugh Ferguson spoke to three Arup engineers:

Michael Beaven, Arup Fellow, co-leader of Arup Associates and services engineering lead on the project.

Richard Boyd, senior engineer and sustainability consultant.

Andrew Robertson, structural lead for 1 Triton Square.

During lockdown, the Royal Shakespeare Company hosted live theatrical productions of *Dream* that were transmitted online using motion capture technology and interactive storytelling. Avatars were created through real-time animation by actors, while viewers could add fireflies to the virtual forest via their computers or mobile phones © Stuart Martin/RSC

ENTERTAINING AUDIENCES OF THE FUTURE

Advances in engineering and technology are helping to change the way we consume culture. In 2019, a UK Research and Innovation (UKRI) Challenge Fund, Audience of the Future, was launched to explore how immersive technology could transform audience experiences. Dominic Joyeux investigated how the initiative's four demonstrator projects responded to the challenges created by COVID-19 and the ways in which technology brought immersive entertainment experiences into the home.

Did you know?

- Engineering innovations such as sensors, gyroscopes and computer processors are the basis of immersive technologies such as virtual, augmented and mixed reality
- Immersive technologies enable experiences that surround someone, allowing them to feel part of an alternative environment that responds to their presence
- The UK's virtual reality market is expected to grow to £300 million by 2023
- Modern digital technology is transforming arts and entertainment, enabling us to enjoy culture from our own homes

At the beginning of 2019, the government-funded UK Research and Innovation (UKRI) announced four demonstrator projects that would receive £16 million worth of support under its Audience of the Future (AotF) Immersive Technology Challenge. These cross-disciplinary large-scale programmes were in the fields of moving image, visitor experience, theatre performance, and esports.

UKRI had seen that immersive technology was shifting audience behaviour from viewing content to 'experiencing' and 'recommending' it. The four winners of the competitive process were chosen to show how in-house events – at stadiums, theatres and museums – could become more immersive so that audiences could feel that the occasion itself was responding to their presence.

The demonstrators were due to launch in 2020 but with the arrival of COVID-19 restrictions prohibiting in-person events, each had to pivot, rethink and reboot their initiatives. All managed to launch a new revised version of their original ideas in 2021 and UKRI will disseminate the collated outcomes of their experiences at the end of the year. The published results will allow others to benefit from some of the processes and innovations developed. They will show that the scheme initiated pre-commercialisation trials that triggered world-leading applied industrial research. The outcomes have also demonstrated that the coincidental arrival of a pandemic lockdown has, in fact, helped accelerate the digital disruption of sectors, such as education and entertainment, through immersive technology.

VR, AR AND MR

Immersive technology has transformed digital experience by bringing together the virtual with users' sight, sound and even touch. The word 'immersive' is used to describe experiences that surround someone, enabling to make them feel part of an alternative environment that responds to their presence.

The technologies enabling immersive experiences range from virtual reality (VR) using a headset to augmented reality (AR) applications on smartphones. There is also mixed reality (MR), an extension of AR, that allows real and virtual elements to interact within an environment. These innovative technologies have all been made possible by engineering advances in a wide range of fields. For example, modern VR headset displays are based on technology developed for smartphones such as gyroscopes and motion sensors that track head, body and hand positions; small HD screens that provide stereoscopic displays; and small, lightweight and fast computer processors. Similarly, the main components for AR are a processor, display, sensors, and input devices – also used in smartphones and tablets, which often include a camera and microelectromechanical systems (MEMS) sensors such as an accelerometer, GPS, and solid-state compass, making them suitable AR platforms.

The UK has the largest immersive market in Europe. The UK VR market is expected to grow to £300 million by 2023 with around 1,250 companies generating over 50% of their revenue from consulting, services or products within the immersive domain. Nearly 300 of these companies operate in the sports, media and arts sector. It was this corner of the market that UKRI targeted.

Matt Sansam, Head of Delivery for AotF, says that in addition to participating consortia having an academic/university input, "we asked that they had a globally recognised intellectual property (IP) to engage with audiences in presenting engaging and exciting experiences; that SMEs were involved; that their project reached 100,000 people; and that there was a certain amount of match funding from the private sector." In addition to UKRI providing £16 million the consortia contributed an extra £7 million for their four demonstrator projects.

ESPORT DEMONSTRATOR

The most spectacular demonstrator, in terms of numbers involved – nearly two million – was WEAVR. WEAVR is the name of the esports consortium led by ESL Gaming, the world's largest esports company. ESL organises and produces video competitions worldwide and these used to culminate in big stadium events with thousands of esport supporters present. The original AotF idea was to make the event audiences feel more involved with the gamers playing in front of them. With COVID-19 came lockdowns and a rethink.

ESL Gaming organises international pro circuit tournament competitions that used to end up in large stadiums such as this one in Birmingham in 2019. Now, with WEAVR technology, viewers can access matches virtually from home with tailored commentaries and VR input © ESL Gaming/Helena Kristiansson

A screengrab of the WEAVR Twitch Extension during the grand finals between Alliance and Team Secret at ESL One Birmingham Online in June 2020 © WEAVR

Esports were in a good position with regards to live events: they could technically continue, as all games could be played remotely, the problem was with production as broadcast crews and commentators usually work side by side. Large arenas couldn't be played in, so the production teams switched to software-based components allowing the crews to do everything – like playing replays – remotely.

Dr Florian Block is Reader in Digital Creativity at the University of York and the R&D Director of WEAVR. He says: "Even before COVID-19 struck we didn't want to just replicate the physical stadium experience, we wanted to take it up a notch when freed of physical constraints for those not attending an event in person. Not to just compensate, but to fully explore how immersive tech can generate audience engagement. So what we've created are things like a VR space, a virtual VIP lounge where spectators wearing VR headsets watch the game on big monitors, move around and play with flaming swords in super-high pixel resolution."

Perhaps one of the strongest innovations is WEAVR's data artificial intelligence (AI). Its new technology consumes huge numbers of historical data points from esports competitions. It then tailors the information to the individual viewer and can provide targeted commentary for that person. It can tell which player a viewer is interested in, it understands their level of understanding about the game and then provides custom-made commentary.

Dr Block adds: "The secret sauce is the way that we slice the data and the way we train machine learning and AI models to understand the data and construct really interesting output. So there's an algorithmic contribution and then the way that the model is applied to generate stories. We have found ways of identifying extraordinary moments in game play that we know have a high relevance for fans."

The resulting viewing numbers are impressive. During 2020, WEAVR reached 1.8 million unique fans. That number includes people using interactive overlay on broadcasts, using the mobile app and VR – all additional engagements that weren't there before. The results have been so strong that the companies involved are now looking to fully commercialise their innovations.

THEATRE DEMONSTRATOR

The *In Performance* demonstrator consortium consisted of 15 organisations headed by the Royal Shakespeare Company (RSC). The RSC was going to use devices such as mobile phones, extended reality headsets and streams into live performance environments and, to some extent, the home. When COVID-19 restrictions came into being in March 2020, all theatre productions stopped and the RSC had to start over. All it was left with, from its months of preparations for an in-person event, was the symphonic score recorded by the Philharmonia Orchestra, completed days before lockdown.

The RSC team decided to stage a 25-minute livestreamed performance titled *Dream* taking inspiration from Shakespeare's *A Midsummer Night's Dream*. It would use live motion – capture fed through Unreal Engine, a game engine developed by software engineers at Epic Games – to film and form avatars for Puck and other sprites. The platform is used by film production companies as well as video games developers and enables the making of realistic 3D graphics. The RSC also used it to create the graphics for and control a motion capture character of Ariel in a 2016 production of the *The Tempest* ('The technology behind *The Tempest*', *Ingenia* 71).

Steve Keeley, from RSC Digital, was one of the Unreal Engine operators that fed in audio and lighting cues for *Dream* at the University of Portsmouth's motion capture studio © RSC

The RSC consortium created a virtual set that tracks, with a camera's motion, around actors and objects and rendered everything in real time to a large LED screen. This would then be broadcast live to thousands of subscribers across the world on tablet, desktop and mobile.

The RSC consortium used the University of Portsmouth as its virtual venue. The university is part of the Joint Academic Network (Janet) that provides a secure, fast fibre-optic backbone to the UK's research and education community. Its bandwidth could keep a dedicated stream going out to audiences worldwide.

Alex Counsell is the Technical Director for the Centre of Creative and Immersive eXtended Reality at the university and worked on *Dream*. He says: "We had five actors in motion capture suits covered in 67 markers each. I had 48 Vicon Vantage 16 megapixel cameras on the studio floor that created and streamed a digital skeleton for each actor across the network. Using Unreal Engine as our display tool we could create digital animation, communicate with other internal networks controlling the lighting as well as the QLab audio system. All of this information was projected onto our giant LED video wall that would draw the story world and broadcast in real time to the viewer."

Alex and the other team members had duplicate systems in place so that each audience-critical piece of equipment would have a fail-safe in place. However, if the motion capture system stopped then it was game over: they couldn't have another machine running in parallel to that. If the software crashed, as it did in the technical run-throughs, then a holding screen would be put up while they rebooted.

After months of preparation, the RSC broadcast 10 successful 25-minute performances of *Dream* in March 2021 with no stoppages and no holding screen. It was a formidable technological achievement to be able to stream seamlessly across mobile phones, personal computers and tablets. There is inevitably a digital inequality in potential viewers' systems and the live streaming had to work across all platforms.

Two of the notable interactive elements were with the audience and the actors. The event was live streamed

DINOSAURS AND ROBOTS APPS

In the field of *Visitor Experience*, the demonstrator chosen was a collaboration led by the immersive content studio Factory 42, bringing together the National History Museum and the Science Museum. This demonstrator was perhaps the most affected by the closure of venues. It had intended to combine mixed–reality technology and immersive theatre with visitor experiences in museums and shopping centres, bringing dinosaurs and robots to life while allowing audiences to interact with them.

My Dino Mission is a free skills-based AR app for 7- to 10-year-olds that helps a stranded dinosaur get back to its own time period millions of years ago. Developing users' STEM skills, children can recognise dinosaur species, what they eat and need to survive. Youngsters can even take photos of themselves interacting with their dinosaur in their home or back garden.

My Robot Mission is a free skill-building app for 10- to 12-year-olds that sets challenges to create robots in simulated AR environments. Their robots have to function in deserts or snowy mountains and help tackle future world problems, all within the backdrop of their own home.

for free but people could pay to have an interactive ticket. This would split the person's screen into two and the new interface would allow a mouse or finger on a touchpad to drag back an illuminated firefly and fire it into the 3D space occupied by *Dream's* Puck and fellow sprites. Puck, played by EM Williams, and the others would then follow the brightest path placed before them.

Another interactive groundbreaker used a Gestrument through Unreal Engine in a livestreamed performance of motion capture. Alex explains: "The Gestrument is like a Theremin where you use gestures to play music, but with no device. Each actor could control their individual signature instrument with movement of their hand and a simple pinch gesture could turn the instrument on or off to allow them to use it only when needed. Puck had a harp sound, and there was a flute, a piano and others. Pinching index and thumb switched the Gestrument on, then we followed the distance from their hips. Below hips meant the prerecorded music went down an octave or two, and the strength of the gestures would alter the attack and timbre. It could never go out of key but it gave each actor agency over their own instrument."

WHAT'S NEXT?

Sarah Ellis, RSC's Director of Digital Development, said: "As we come out of this pandemic we need to look not only at what we lost but at what we found. How do we bring those audiences that can't come to Stratford-upon-Avon but want to be with us? The jeopardy of live is big but we reached tens of thousands of people in over 70 countries with *Dream*. Now we have to look at the R&D developed and see what can be built on and how we could commercialise the elements that have been the most popular. We've shown that real-time tech works live and will influence how we create new production processes. It will enable a new creative vision that will connect with an audience at home."

The esports demonstrator has also shown the possibility of working differently. The statistics surrounding esports are large, very large. It is estimated that global esports revenues will grow to £800 million in 2021, a year-on-year growth of 14.5% from 2020 figures. Trade researchers estimate that the global games livestreaming audience will reach more than 720 million people in 2021, up 10% from 2020.

Dr Block thinks that WEAVR's potential goes further than esports. "So the key innovation here is that we are going away from the one-for-all coverage that traditional sports have," he says. "That just won't engage the audiences of the future. Teenagers want to consume what they want, when they want. They snack information and the consumption patterns are radically changing. The tailored AI-driven concentration can really address the appetite of the new audience and you will see that that will carry over into traditional sports and even into how mainstream entertainment is consumed. That's the new future."

WALLACE AND GROMIT

The *Moving Image* demonstrator teamed up the animation studio Aardman, with Fictioneers, a consortium of creative UK companies, with research support from the University of South Wales. In January 2021, the demonstrator launched the free app *The Big Fix Up* starring Wallace and Gromit in their first new adventure for a decade.

Wallace and Gromit have set up their latest business venture, Spick and Spanners, and the game player becomes an employee helping fix up the interactive city of Bristol (Aardman's home city). The app allocates tasks and guides the user via AR gameplay, computer-generated animations, in-character phone calls, extended reality portals, and comic strips.

Lead characters are voiced by Ben Whitehead, Miriam Margolyes OBE and Jim Carter OBE. They assign tasks to the user (who starts the game as a Bright Spark Apprentice) while Wallace and Gromit's fictional contraptions, such as rockets, end up landing in players' kitchens or bathrooms. The pair are inventors and help the user think in that way too.

BIOGRAPHIES

Dominic Joyeux spoke to:

Matt Sansam, UKRI's Head of Delivery for Audience of the Future.

Dr Florian Block, Reader in Digital Creativity at the University of York.

Alex Counsell, Technical Director for the Centre of Creative and Immersive eXtended Reality at the University of Portsmouth.

Sarah Ellis, RSC's Director of Digital Development.

SILVER MEDALS

The Royal Academy of Engineering Silver Medal was established in 1994 to recognise an outstanding personal contribution to British engineering that has resulted in successful market exploitation.

DR SITHAMPARANATHAN SABESAN
CEO, PERVASID LTD

PervasID is the result of Dr Sabesan's groundbreaking work as a PhD student at the University of Cambridge. His work in the area of battery-free radio frequency identification (RFID) tag tracking has been internationally recognised and has resulted in four patents. As founder and CEO, Dr Sabesan successfully grew PervasID from its inception to become a global enterprise.

RFID systems use electromagnetic fields to automatically identify and wirelessly track tags that are attached to assets. They conventionally suffer from 'dead spots' where tags are not detected well within the range of the reader. PervasID overcomes this problem and achieves near 100% accuracy in detecting battery-free tags to less than one metre over wide areas. In commercial trials against all other competitors, PervasID achieved more than 99% tag detection accuracy over a 20-metre distance compared with 80% achieved over 2-metre to 3-metre distance using conventional approaches.

Dr Sabesan's customers include the largest aircraft manufacturers, Stanley Black & Decker, blue chip retailers, and NHS hospitals including Guy's and St Thomas' in London. Stanley Black & Decker also use the tags to track supplies from their tool cabinets used by aircraft manufacturers. Each cabinet contains over 1,000 tools, and it can result in serious safety incidents if any are left inside an aircraft. It is estimated that foreign object debris (FOD) costs the aviation industry $13 billion per year in direct and indirect costs, including flight delays, plane changes and fuel inefficiencies. In healthcare, PervasID solutions are being deployed in NHS hospitals for tracking surgical instruments to enhance decontamination and sterilisation processes and for tracking hospital assets to ensure that mission critical medical devices are available at the right place and time, for robust and efficient care. The need for this level of traceability of medical devices has been particularly evident in the COVID-19 pandemic. The solution is predicted to save billions for NHS hospitals and will save lives.

Dr Sabesan won a Royal Academy of Engineering Engineers Trust Young Engineer of the Year award, the Sir George Macfarlane Medal 2016 for excellence in the early stage of his career, an Engineering Enterprise Fellowship and most recently in 2021 has been awarded a Queen's Award for Enterprise: Innovation.

DR ANDREW LYNN
CEO, FLUIDIC ANALYTICS

Dr Andrew Lynn is a materials engineer, inventor and entrepreneur. He has founded four engineering companies based around his innovations, and brought several technologies to market, including a regenerative medical implant for cartilage and bone repair.

In his current role as CEO of Fluidic Analytics, Dr Lynn has been responsible for leading the company's progression from a promising idea, through product development, to producing research and diagnostic products for characterising protein interactions. Two of these products have been launched commercially and one has made fundamental contributions to breakthroughs in the understanding of the mechanisms of action of drugs for Alzheimer's Disease. The products have also enabled a 40-patient clinical study to be conducted at University Hospital Zurich into how antibodies protect the body against COVID-19. The clinical study was featured on BBC News in October 2020.

In addition to the impact it has made in medicine, Fluidic Analytics has created 96 full-time jobs, filed or licensed 19 patents and attracted £35 million in investment.

Dr Lynn's work has resulted in over 20 peer-reviewed publications and eight international patent families. He has been recognised with an ACES Academic Enterprise Award and a spot in MIT Technology Review magazine's prestigious list of the world's top innovators under 35. Chondromimetic, an orthopaedic implant that Dr Lynn developed during his PhD, was a finalist for the MacRobert Award 2009.

DR TOM CARTER
CTO, ULTRALEAP

Dr Tom Carter invented a technology that uses ultrasound to create tactile sensations on bare hands. Sound waves from a collection of small ultrasonic speakers are focused onto the user's hands, causing the skin to vibrate and elicit the sensation of touch.

His groundbreaking technology enables entirely new user interfaces and experiences, making interaction with virtual objects and applications possible. The technology can be used in any market where a user interacts with a device or appliance. It's recently been used to demonstrate automotive safety with Groupe PSA and the DS Aero Sport Lounge Concept Car, and for immersive entertainment with LEGO, where participants could feel and build with virtual LEGO bricks in mid-air.

Dr Carter was inspired by the commercial viability of gesture recognition as a new way to interact with machines during his undergraduate degree at the University of Bristol. He wanted to find a way to add the sense of touch so that users could feel the virtual objects that they were interacting with, without having to wear gloves or hold controllers.

The core innovation behind Dr Carter's mid-air haptic solution is based on complex patented algorithms that carefully control ultrasound, projecting tactile sensations directly onto a user's hands. He founded Ultrahaptics Limited in November 2013.

In May 2019, Ultrahaptics acquired world-leading hand-tracking company Leap Motion. It subsequently rebranded to Ultraleap, where Dr Carter remains CTO and continues to lead the company in all technology advancements. Dr Carter won the Colin Campbell Mitchell award with his two co-inventors in 2016.

AN OUTSIDER WHO CHANGED THE SYSTEM

Dr Agnes Kaposi FREng © Jay Kaposi

As a Jewish Holocaust survivor, political refugee and woman in engineering, Dr Agnes Kaposi FREng has every reason to call herself an outsider. But it didn't stop her from becoming the third woman ever to be elected as a Royal Academy of Engineering Fellow in recognition of her role in changing technical education and defining the field of systems engineering. She told Michael Kenward OBE her remarkable story.

Had it not been for the Hungarian Communist Party, Dr Agnes Kaposi FREng might have followed her interest in physics and maths and achieved her ambition to become a meteorologist. After the Second World War, the Communist party controlled everyone's lives in Hungary and brushed aside her requests to study physics, telling her to study electrical engineering instead. Dr Kaposi warmed to the subject and ended up with a career that, after a troubled early life, led to her becoming one of the first women to be elected to the Royal Academy of Engineering.

In the event, she says she feels grateful to the "faceless Communist bureaucrats". Meteorology might have been fun but so was engineering, and it proved to be a rewarding career.

Life was difficult enough in post-war Communist Hungary, but by then Dr Kaposi was used to hardship, having survived Germany's invasion of her native country, and the Nazi Holocaust of the Second Word War. It would take a book to describe how she went from Holocaust survivor to being one of the UK's leading engineers. Prompted by questions from her granddaughter, Dr Kaposi has written that book, *Yellow Star – Red Star*, a richly illustrated autobiography and a fascinating account of Hungary's mid-20th century history and politics. Dr Kaposi recruited a distinguished historian, Dr László Csősz, senior archivist of the National Archives in Hungary, to provide a historical narrative and to "fact check" her recollections.

In the title of the book, 'Yellow Star' refers to Dr Kaposi's Jewish childhood before and during the Second World War. Hungary's antisemitism, and some of the country's numerous anti-Jewish laws, predated the rise of Hitler. Dr Kaposi recalls how those laws affected her family, although as a child, she barely knew that they were Jewish – they hadn't been actively religious, and her parents had no affiliation to any synagogue. She was more aware of her parents' socialist leanings than their religion.

Dr Kaposi describes 1939 as a "memorable year". It would have been for any six-year-old due to start school just days after the start of the Second World War. Anti-Jewish laws caused unemployment and poverty and antisemitic propaganda even penetrated the classroom, but the real impact of Nazism came when the German army occupied Allied Hungary in March 1944. Within weeks, Hungary's Jews were compelled to wear the yellow star as a means of identification and were crowded into ghettoes in preparation for mass deportation to Auschwitz. Half of Dr Kaposi's family perished, as did more than half of Hungary's Jews. She and some of her family survived: theirs was the only Auschwitz-bound train diverted to Austria where they worked and starved in labour camps as farmers, factory workers and manual labourers.

Liberation by the Soviet army brought its own traumas. It took a month for surviving members of the emaciated family to cover the 150-mile journey, mostly on foot, from their camp near Vienna to a ruined Budapest. They never regained their home or their possessions, but they found an empty flat in a nearby town where all the local Jews had been murdered.

Dr Kaposi relates: "I got back from the camp on 1 May 1945 and on 2 May, hungry, without hair, without proper clothing, without a book, a pencil or a pen, I was at school. This is the way that I was brought up, the way my father trained me. Education was top priority. If I got home with 95% of the marks, I needed to account for what had been amiss."

UNIVERSITY ENGINEER

No surprise then, that Dr Kaposi excelled at school and in 1951 went on to university. For a brief period immediately after the war,

Agnes Kaposi as a six-year-old in September 1939, due to start school

Hungary was a multi-party parliamentary democracy, but by 1949 the country became a one-party state, the 'Red Star' era described in Dr Kaposi's autobiography. Communist tyranny deprived people of choice. Her boyfriend John loved gadgets, was a master of tools and machines, and was the "complete engineer", graduating just before Dr Kaposi started university. Dr Kaposi had no interest in tools, machines and gadgets, but the Hungarian Communist Party sent her to study engineering in Budapest. She only just managed to escape from another future: thanks to subterfuge by a concerned teacher, she narrowly avoided spending four years studying in the Soviet Union.

After marrying at the end of Dr Kaposi's first year at university, she and John graduated from the same electrical/electronic engineering course: John with a 'good enough' degree and Dr Kaposi with top honours. Yet, he would jokingly tease his wife throughout their 60-year marriage that she would never become an engineer.

The Technical University of Budapest was a revered institution. Dr Kaposi did well, but was an outsider from the start, "at sea" as she puts it. Why did they introduce different specialisms of engineering independently of each other, rather than teach fundamental principles of engineering and then apply those to different branches of the subject? She explains her thinking with an example. The course covered vibration in mechanical structures and other fields, such as acoustics. Bridges don't look much like loudspeakers but the two have a lot in common. "The frequencies and amplitudes of vibration were different, but those are just parameters; the equations were the same," she explains. "I couldn't understand why we were learning the same equations several times over." She plucked up the courage to ask her professors, but they told her to just get on with it. As an 18-year-old she did what she was told but later in life she decided to investigate the challenge she had thrown at her professors. Maybe she could tackle problems reasoning from the general to the particular. This approach helped her make the change from vacuum-tube-based electronics to transistor circuits, from analogue to digital communications, from switching theory learned in telephony to its use in computing. It also kickstarted her development of a discipline that came to be known as systems engineering.

As an undergraduate Dr Kaposi was lucky to be given an exciting degree project, supervised by Dr Béla Julesz, celebrated visual neuroscientist and experimental psychologist. The project was theoretically demanding and practically important: devising the nationwide transmitter/receiver network for a hybrid communication system to provide TV/telephone services for the whole country. The experience would come in useful later when Dr Kaposi arrived in the UK.

On graduating in May 1956, the Communist party commanded Agnes to take up the post of junior development engineer in EMG, a company that designed and manufactured electronic instruments for the Communist bloc. Sampling oscilloscopes were advanced instruments and working on their design was exciting, but Dr Kaposi's career at EMG was short: in six months her whole life was to change.

A NEW START

October 1956 brought Hungary's failed uprising against Communist rule. The chaos following offered an opportunity for Dr Kaposi and John to leave. They were keen to find freedom, have a normal life and start a family. So, they joined 180,000 others who fled Hungary and left the country illegally. In yet another journey of cross-country treks and uncertain train rides that would make a good film, the pair travelled across Europe. Their intended destination was Britain, but at the Paris stage of their journey the British Embassy turned them down on the grounds that they were only offering asylum to those still in Austria. After more than 150 job applications, the couple finally received offers from Pye in Cambridge where John, a radar technologist, designed circuits for the new colour television, while Dr Kaposi had a chance to continue her undergraduate work on multichannel television networks.

Their next move was to Ericsson Telephones in Nottingham where they each took charge of the design of a subsystem of the first electronic telephone exchange to be introduced in the UK and throughout the Commonwealth. Computers were the next step, and Dr Kaposi and John moved to the R&D Laboratories of ICL, among the first generation of computer engineers. However, the British computer industry was shrinking and there were frustrations.

A MOVE TO ACADEMIA

In 1964 Dr Kaposi left ICL but maintained contact with industrial research through the rest of her career. Her first significant post was as a senior lecturer at Kingston Polytechnic – now Kingston University. Once again, she was an outsider. "I knew nothing about the British education system," she says. "I had never been to a British school and didn't know the difference between university and polytechnic." Although she did know about computing, which had yet to be covered in engineering courses. Kingston was a good place to try new ideas. With her research experience and her PhD completed, Dr Kaposi wanted to devise a course to meet the increasing demand for IT skills. Her master's degree course was innovative in content, mode of delivery and student population. It was an immediate success: scientists, engineers and mathematicians in senior and mid-career posts in industry, business and government queued up to join, seeking to bring the benefits of this new technology to their jobs. "Even now, I am proud of that course," she recalls.

CHANGE-MAKER

The success of the Kingston course persuaded Dr Kaposi that she could take on the bigger challenge of running her own department. Her next move was to South Bank Polytechnic – now London South Bank University – as Head of Department of Electrical and Electronic Engineering. This had once been a centre of excellence of electrification and power engineering, supported by the Electricity Board and the power industry, but demand for these subjects had dwindled, industrial support was no longer forthcoming, and staff almost outnumbered students. Dr Kaposi was in a good position to rescue such a department, but here again, she was an outsider. Her

WOMEN IN ENGINEERING

The role of women in engineering has been a constant issue for Dr Kaposi throughout her career. Comparing the position of women in Communist and western countries was the subject of her 1972 Churchill Fellowship, taking Hungary as an example of one, the US and the UK as the other. She found that under pressure of the Communist Party, a larger percentage of women studied engineering at university in Hungary than in the UK or in the US, but there was almost equal paucity of women engineers in senior positions in the east and west. Her findings date back half a century, but she suspects that even today, women engineers as senior decision-makers might still be outsiders.

staff, middle-aged and all male, told her that she had fallen victim to the passing fashion of computers, which were "here today and gone tomorrow". They said it was nothing short of 'vandalism' making room for computers by removing some of the underused bulky power engineering equipment from laboratories. Perhaps upset that they hadn't got the top job, some made it clear that they disliked having a woman in charge. "The woman's place is in the kitchen," is how Dr Kaposi recalls a lunchtime comment by a member of staff. That attitude seems less surprising when you learn that this was a few years before the *International Journal of Electrical Engineering Education* conducted a national survey showing that just 15 women, out of a total of around 1,600 academics, taught degree-level electrical and electronic engineering. Dr Kaposi was the only woman to head a department.

Dr Kaposi is, she says, "very proud" of her part in getting the British Computer Society to become a recognised as a professional engineering institution. "They applied and my colleagues were saying 'they are not engineers, they don't know any physics'." By then, she was well known in the engineering world, but still had to enlist the support of eminent names that the engineering community could not ignore © Jay Kaposi

Dr Kaposi learned that it would take two years to navigate the purchasing bureaucracy before she could buy the first computer for her department. She contacted the local Chamber of Commerce. "Do your businesses need some computing skills?" she asked. Receiving an enthusiastic answer, she invited potential participants to pay upfront for short courses. She employed postgraduate students from Imperial College London as teaching staff. Computers arrived, a first step towards the review and modernisation of the curriculum.

Just then, engineering institutions introduced course accreditation. The intention was only to accredit full-time courses. Gaining the support of her staff, Dr Kaposi challenged the accreditors, refusing to submit South Bank's full-time course for accreditation unless the part-time course was also considered. She argued that the part-timers were superb students: "It was a privilege to teach them because they were dedicated to learning and they benefited staff by bringing in insight of current industrial practice." Professor Ewart Farvis of Edinburgh, IEE's senior accreditor, understood the argument; he had himself started his career as an apprentice. With his support, South Bank's Electrical and Electronic Engineering department gained equal recognition of its full-time and part-time courses. This was a turning point for the department. Student numbers started to rise, new, younger staff could be recruited, and course review could be devised and implemented. A surprising additional result was that IEE's accreditation committee invited Dr Kaposi to join it as the only woman and the only polytechnic head.

Word about the courses at South Bank spread. The Manpower Services Commission heard about the department's computing-oriented course curriculum and saw this as a possible answer to a current problem of graduate unemployment. It offered funding and sponsorship and, in response, Dr Kaposi devised several courses: routes to industrial jobs for unemployed graduates. "At first, only holders of a first- or second-class degree in science or engineering qualified for entry into our master's course, but to aid graduates with good degrees in other disciplines, we offered an industrially sponsored preparatory conversion course in mathematics and laboratory work." Dr Kaposi believes that, with its 200 postgraduate students, her department was running one of the largest graduate schools in the country.

Funded by the Manpower Services Commission and with special dispensation from the European Community, the department also offered a one-year intensive course for unemployed women graduates, leading to a Higher National Certificate (HNC) qualification. To convince employers of their equal value to industry, these women took the same qualifying examinations as the men on the department's well-established HNC course. "We served the local and the wider community, giving a chance to men and women to reach their full potential. I speak about this with socialist pride."

A decade on from Dr Kaposi's arrival at South Bank, the department was thriving, student numbers were well above 1,000, the undergraduate and postgraduate curriculums were up to date, and there was a flourishing research school, funded by industry, the Research Council and the European Commission. The old guard had moved into line or had retired, and the young staff were more than able to provide the energy and initiative to augur a safe future. Dr Kaposi felt that the time had come for her to move on.

SYSTEM OF SYSTEMS

Throughout her academic career, Dr Kaposi worked as a researcher and industrial consultant. Her research work extended from computer-aided design and software engineering to methodological foundations for systems engineering, captured in two of her books: *Systems, Models and Measures* and *Systems for All*, written in collaboration with one of her PhD students. Interest in her research created demand for consultancy services. While still at Kingston, her clients included Plessey Radar, which then went on to sponsor Dr Kaposi's PhD; Imperial Tobacco; and Rank Xerox, for whom she designed small special-purpose computers, embedded in the company's machinery for years. Other clients needed support for a series of projects, such as the Admiralty Surface Weapons Establishment and AT&T Europe in Stuttgart, Antwerp and Paris. Three sabbatical months at BT's Systems Research Division at Martlesham led to several years of consultancy engagement with branches of BT.

After leaving South Bank, Dr Kaposi set up a full-time consultancy business in partnership with John and a resident IT specialist from Imperial College London. Using the methodological handle of systems engineering and drawing on their network of industrial and academic contacts, they created bespoke teams to tackle various projects for a wide range of clients, such as Siemens in Brazil and Germany, two international banks, and quality certification agencies in two European countries. They also acted as advisors on staff development and curriculum review to several universities in the UK and Europe. With undimmed socialist convictions, Dr Kaposi remarks with some regret that full-time consultancy was far more lucrative than an academic career. The business thrived for over a decade, until John became too ill to work and passed away.

That was when Dr Kaposi finally gave in to her family's demands to record her life story. Even here, she took an engineer's approach. "I knew the difference between remembering something and knowing something about it, or knowing it properly and having the authority to write it down for publication. There was a lot of research to be done." Her book *Yellow Star – Red Star* took 10 years to write. She visited libraries, museums and historical sites, searched through books and documents, looked for advice from fellow Holocaust survivors, and sought support from historians. It was the director of London's Wiener Library who suggested the historian Dr Csősz as a collaborator. This settled the format of the book: narrative of a witness, authenticated by the voice of a historian.

Nowadays, Dr Kaposi is a busy educator with engagements reaching two years ahead. Her approach to history is the framework for her presentations. Her main concern is that people have failed to learn the lessons of the past, so intolerance increases, violence persists, injustices sharpen, and minorities continue to struggle under tyranny. The need to learn from the Holocaust has become more pressing as the number of survivors dwindles. Dr Kaposi agrees that there is a need for the second and third generation to tell the story of the Holocaust, but she has reservations about this, and explains her concerns with an engineering parallel. "An engineer would know that, from source of information to recipient, there is the danger of cumulative distortion and interference."

Dr Kaposi with her autobiography, *Yellow Star – Red Star*, an account of her life in Hungary before and during the Second World War and under Communist rule, as well as her subsequent journey to the UK © Jay Kaposi

CAREER TIMELINE AND DISTINCTIONS

Born, **1932**. Studied electrical/electronic engineering at the Technical University of Budapest, **1951–1956**. Junior development engineer, EMG Budapest, **1956**. Development engineer, Pye Ltd, **1957**. Senior R&D engineer, Ericsson Telephones, **1958–1961**. Principal R&D engineer, International Computers Limited, **1962–1965**. Senior Lecturer/Principal Lecturer, Kingston Polytechnic (now Kingston University), **1966–1976**. Head of Department, Electrical/Electronic Engineering, South Bank Polytechnic (now London South Bank University), **1977–1987**. Churchill Fellow, Women in Engineering, **1972.** Partner, Kaposi Associates, and Director, Kaposi Associates Ltd, **1988–2009**. Fellow, Royal Academy of Engineering, **1992**. Published autobiography, *Yellow Star – Red Star*, **2020**.

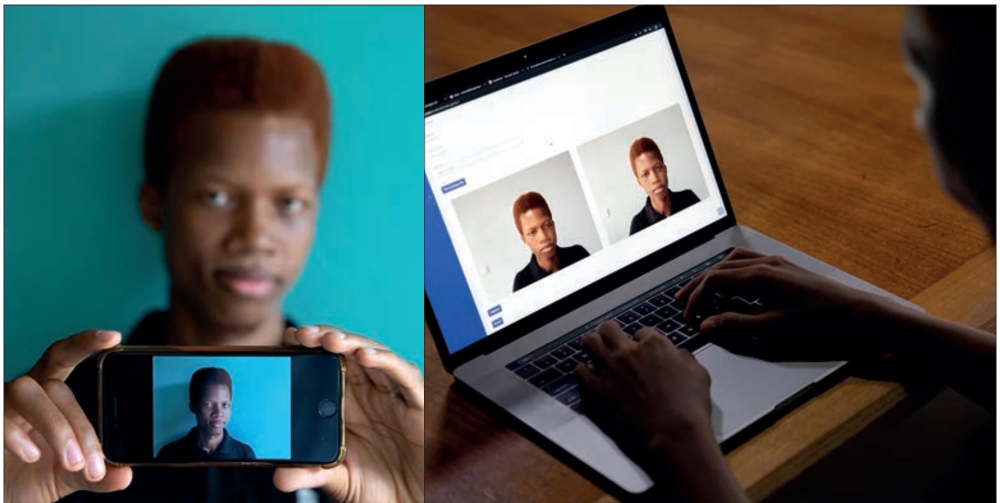
REMOTE AND SECURE ID VERIFICATION

Charlette N'Guessan is an Ivorian tech entrepreneur who is passionate about solving local challenges with technology. She used her software engineering background to launch BACE API, a digital identity verification system currently being used in financial services in West Africa.

In 2017, Charlette moved to Ghana to attend a one-year training programme for tech entrepreneurs and met her BACE API Co-Founders Samuel Sowah Mensah, Arinze Christopher Ugwu and Jean Cedric Attiembonon. They carried out market research with banks and fintech companies and found that many were struggling and overspending to meet regulatory requirements for customer security. They also discovered that online identity fraud was a big problem.

As a team of software engineers and data scientists, they decided to address these challenges by building BACE API. The digital identity verification system uses robust live detection, facial recognition and artificial intelligence (AI) technologies to verify people's identities remotely and in real time. Its verification process is simple, fast and secure – it asks a user to submit a photo of their ID, take a selfie and then complete a 'liveness test', which involves a user completing multiple video tests to ensure they are actually the person they say they are. It can be integrated into existing apps and systems and is aimed at financial institutions and other industries that rely on identity verification to provide services. The software uses a phone or computer's built-in camera and does not need any special hardware.

While facial recognition technology is used widely, BACE API is unique in its different use cases, its focus on the African market and its 'liveness test'. The company built up its presence in the African market by contributing to the conversation and research about avoiding bias and discrimination in tech solutions. According to the World Bank's Identification for Development (ID4D) programme, more than 40% of people without ID globally live in Africa. BACE aims to create unique digital identities for any African citizen through its biometrics technologies.



BACE API software uses facial recognition and artificial intelligence to verify identities

The technology can be used in industries such as finance, telecoms, e-learning and events platforms, customer onboarding, access control, and identity validation. It is currently used by multiple fintech startups based in West Africa, but the company hopes to expand to east and southern Africa in the next few years. The innovation won the Africa Prize for Engineering Innovation in 2020, which helped the company to secure its first paying customers and provided worldwide coverage.

During the COVID-19 pandemic, the technology has allowed companies to authenticate and onboard new customers without having to meet them in person. While there were initially challenges in local adoption of the technology, the impact of COVID-19 has helped to speed up the process as customers can now see the value of the technology.

The next step for BACE API is to expand into new countries, add additional features to its product and contribute to helping to better regulate the financial industries. The company also hopes to expand into transport, for example airport check-ins, and healthcare by allowing hospitals to manage patient records using secure digital platforms.

HOW DOES THAT WORK?

COMPOSTABLE PLASTICS

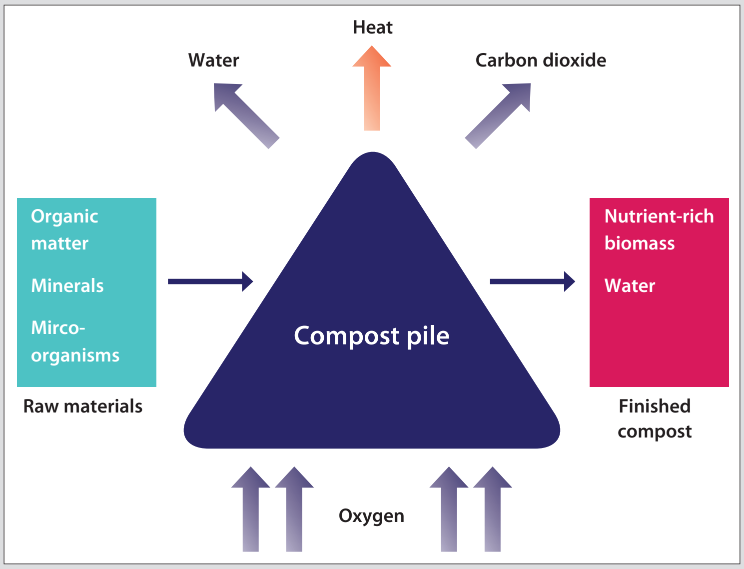
As society increasingly turns to greener alternatives to single-use plastics, consumers are buying those that are touted as biodegradable and can be broken down by microbes. A number of these are compostable, which means that they can be turned – alongside food and other organic waste – into compost.

In 2018, WRAP launched the UK Plastics Pact to tackle the problem of plastic waste. One goal was to make all plastic packaging recyclable, reusable or compostable, and eliminate all unnecessary single-use packaging by 2025. This prompted an explosion of plastic products labelled 'compostable', particularly in areas where products can't usually be recycled because of contamination, such as single-use nappies, wet wipes and ready-meal trays.

Wider awareness of plastic waste has ignited a strong public demand for more sustainable plastic products. Research from UCL's Plastic Waste Innovation Hub found that 84% of households taking part in its citizen science survey reported that they were more likely to choose products marked as 'biodegradable' or 'compostable'.

However, the UK currently doesn't have any systems for collecting, sorting or processing compostable plastics en masse. According to *Recycling Waste World*, many existing industrial composting facilities won't accept 'compostable' plastics as they are contamination risks. Products are unregulated and consumers report being confused about how to properly dispose of them.

Compostable plastics are a subset of biodegradable plastics



– polymer materials designed to biodegrade in certain composting environments, either a home composter or, more commonly, industrial composting facilities. Around half of the biodegradable plastics in the market are made from starch-blends with polyesters such as polylactic acid and polycaprolactone.

Their breakdown by microbes can be aerobic (in the presence of oxygen) or anaerobic (in the absence of oxygen) to become biomass (nutrient-rich organic matter that can be used to fertilise and improve soil), water and carbon dioxide (for aerobic composting) or methane (for anaerobic conditions). Most products labelled 'compostable' aren't suitable for home composting but need processing in industrial plants.

These plants closely control the temperature, presence of specific microbes, and amount of water, UV light and gases present to ensure the plastics compost as completely as possible. The problem with home composting units or plastics composting in the wider environment is that these variables are not at all controlled. These unknowns, together with the size, shape, surface area, and thickness of the plastic objects themselves, can all affect the time taken for the material to compost, if it does at all.

Compostable plastics don't have to completely disappear to gain the title. European standards for compostable packaging require that the material breaks down under industrial-scale composting conditions within 12 weeks, leaving no more than 10% of the original material in pieces bigger than two millimetres, and doing no harm to the soil itself in terms of the presence of toxic elements or affecting the pH, saltiness and presence of minerals like nitrogen, phosphorus, magnesium, and potassium.

In other words, 'compostable' coffee cups, wet wipes or teabags that end up in a home composting bin – or worse out in the wider environment – may still be there in months or years to come, or will have disintegrated into microplastics, which can wreak their own havoc on soils and ecosystems.

Without better guidance, regulation and infrastructure, compostable plastics risk making the environmental problem with plastics worse.

BIOGRAPHY

Dr Anna Ploszajski is an award-winning materials scientist, writer, presenter, podcaster, performer, trainer, and storyteller. She is a materials generalist, equally fascinated by merino wool as stainless steel, through all the wonderful metals, plastics, ceramics, glasses, and natural substances that make up our material world.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