ingenia

JUNE 2023 ISSUE 95

INVESTING IN GREEN ENGINEERING
THE UK'S SUCCESSFUL SPACE SECTOR
ENVIRONMENTALLY FRIENDLY DENIM
MAKING MATERIALS WITH FUNGI

Royal Academy of Engineering

www.ingenia.org.uk

INGENIA

Royal Academy of Engineering

Published by the Royal Academy of Engineering
Royal Academy of Engineering
Prince Philip House, 3 Carlton House Terrace
London SW1Y 5DG
Tel: 020 7766 0600 | Website: www.raeng.org.uk
Email: ingenia@raeng.org.uk
Registered charity no. 293074

Editor-in-Chief
Faith Wainwright MBE FREng

Deputy Editor-in-Chief
Professor David Delpy CBE FREng

Senior Editorial and Brand Manager
Gemma Hummerston

Editorial Manager
Florence Downs

Editorial Board
Ginny Clarke CBE FREng, Professor Yulong Ding FREng, Kati Gastrow, Michael Kenward OBE, Doug King FREng, Dr Paul Miller FREng, Dr Anna Ploszajski, Professor Simon Pollard OBE FREng

Director, Communications and Engagement
Jo Trigg

With thanks to
Andy Coulson (proofreader)

Ingenia welcomes proposals and suggestions for articles that aim to stimulate readers from both within and outside the engineering community. The writing style should be clear, authoritative and easy for non-specialists to digest. Prospective authors should submit a one-page outline to the Senior Editorial and Brand Manager, Editorial Manager, the Editor-in-Chief or to any member of the Editorial Board.

The Royal Academy of Engineering acknowledges the assistance given by the authors of articles in this issue of *Ingenia* and of other individuals and organisations who have made contributions. The information contained in this publication has been published in good faith and the opinions expressed are those of the authors, not of the Academy. The Royal Academy of Engineering cannot accept any responsibility for any error or misinterpretation based on this information. The Royal Academy of Engineering does not endorse any product or service advertised in *Ingenia*. Permission to reproduce text or images from *Ingenia* should be sought from the Royal Academy of Engineering in the first instance.

Ingenia online can be found at **www.ingenia.org.uk**

Design
The Design Unit www.thedesignunit.com

Print
Pensord www.pensord.co.uk

Ingenia magazine is mostly recyclable – please remove the cover before placing into household recycling. The inks are vegetable based and the paper produced under Forest Stewardship Council guidelines.

WORLD LAND TRUST www.carbonbalancedpaper.com CB09060725

Ingenia uses Carbon Balanced Paper

Advertising and sponsorship
Rachel Earnshaw
Tel: 020 7766 0720
Email: rachel.earnshaw@raeng.org.uk

Subscriptions
To cancel your subscription or update your personal information details, please contact the *Ingenia* team by sending an email to ingenia@raeng.org.uk

Front cover

Showing how myclium might be used in products of the future.

© Benjamin Leon

ISSN 1472-9768

WELCOME

Engineers push the boundaries of what's possible, scoping out new frontiers in every sector.

In construction, engineers are researching mycelium (page 10) as a biodegradable alternative to fossil-derived materials. Meanwhile, engineers are driving a sustainable approach to fashion by changing the traditional method of blue-dyeing jeans into a process that uses bacteria to consume less water (page 20).

As engineers develop products, being truly inclusive of different needs only comes with a determinedly people-centric approach. Dawn Bonfield OBE FREng highlights the importance of really listening to people when creating engineering solutions, to make them suitable and fair for everyone. An example is Metacarpal (page 34), which is creating a prosthetic hand that aims to encourage wider take-up as aesthetics are improved and differentiated movement of fingers is made possible.

What's really out of this world is how engineers in the UK are contributing to space technologies and exploration missions (page 15). This is a sector not without its public ups and downs, as January's launch exercise in Cornwall showed. However, with other UK spaceports revving up for their own launches, more ups are on the way.

Ingenia is changing. With sustainability in mind, we've removed our laminated cover, reduced the amount of paper used, and switched our packaging to paper. Do let us know what you think at **ingenia@raeng.org.uk** or via Twitter using **#IngeniaMag**. Also, keep an eye out for further digital upgrades in the future, and don't forget that you can subscribe to our e-newsletter via our website.

Faith Wainwright

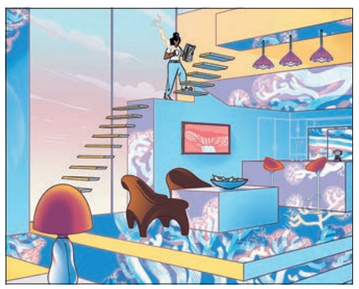
Faith Wainwright MBE FREng
Editor-in-Chief

@RAEngNews #IngeniaMag

CONTENTS

UP FRONT

FEATURES



IN BRIEF

IN BRIEF

STUDENTS 'BUILD A DOME IN A DAY'

A student placing one of the foam bricks onto the bamboo framework

On 14 March, 80 Year 12 students took part in a unique 'Build a dome in a day' engineering workshop in the nave at Holy Sepulchre, Holborn Viaduct – inner London's largest parish church.

Supported and encouraged by trainee engineers, the students built a replica of the famous St Paul's Cathedral Dome, working to the principles of the architect's original concept. The cathedral's triple dome is considered to be a masterpiece of structural engineering, constructed in Portland stone between 1675 and 1710. The entire structure – inner and outer domes, central cone, drum piers, and supports down to foundation level – is estimated to weigh 67,270 tonnes.

After a visit to the cathedral to learn about the dome's construction, the students returned to the nave to construct a 4.5-metre-high replica dome. The students' efforts captured the attention of BBC London, featuring on the evening news. All materials were then recycled, with 2,200 foam bricks donated to the Oxford House community arts space in Bethnal Green, London.

Ada Nwadigo, Queen Elizabeth Prize for Engineering Ambassador and civil engineer at Laing O'Rourke, took part in the build. She said: "Sir Christopher Wren's work has left an indelible mark on London's skyline. His designs incorporated advanced engineering techniques that allowed for the creation of some of the most significant buildings in London, such as St Paul's Cathedral and the Royal Observatory in Greenwich."

London Diocesan Churches supported the event, which also received funding from the Royal Academy of Engineering's *Ingenious* programme (see next page for more). It was led by Chris Wise RDI FREng, Senior Director of Expedition Engineering, and formerly a professor at Imperial College London, Yale and UCL; and Catherine Ramsden, Founding Director of the architectural practice Useful Studio.

The timelapse video of the construction is available to watch at **youtu.be/riV0x1xp2SA**

INGENIOUS PROJECTS FOR THE NEXT GENERATION OF ENGINEERS

Rubbish Robots: Making Robots from Rubbish

In May, the Royal Academy of Engineering announced 16 new *Ingenious* public engagement awards for projects across the UK designed by engineers to engage the public with engineering and inspire the next generation.

The projects focus on topics from climate change, healthcare, diversity and inclusion, and ethical innovation to a ballet-inspired engineering initiative.

'The Mechanics of Life: Movement, Mobility and Me' will bring together engineers at the University of Leeds and creatives at Northern Ballet to engage a diverse audience with the mechanics of movement through dance. The project will culminate in an experience day for high school students where they will co-design an engineering-inspired performance, choreographed and performed by Northern Ballet and digitally captured in film.

Many projects are addressing climate issues, including 'Rubbish Robots: Making Robots from Rubbish', which will inspire students in central Scotland to build new kinds of robots from e-textiles and e-waste. 'Living laboratory: climate action' will introduce students to hydro-environmental engineering with smart sensors.

These are just a few of the 2023/24 Ingenious projects. To find out about more, please visit the Academy's website at **www.raeng.org.uk**

REPORT SHOWS MANCHESTER AND BRISTOL ARE HUBS FOR SPINOUTS

In May, a report published by the Royal Academy of Engineering's Enterprise Hub and Beauhurst showed that Manchester and Bristol have the highest growth in spinout populations, while Edinburgh attracts spinouts from across the UK.

The third annual edition of the *Spotlight on spinouts* report found that a total of 58 spinouts are now hosted in Manchester and 47 in the City of Bristol, rising from 52 and 42 respectively. The City of Edinburgh, with a total of 78 spinouts, continues to attract companies spun out of universities from other locations in the UK, that choose to operate and grow their businesses within the city because of its strong research institutions, funding ties, and access to top talent.

The data compiled in *Spotlight on spinouts* analyses: which universities are successfully generating spinouts; their geographic spread and IP policies; the top spinout sectors, investors and investees; survival rates and growth trajectories; Innovate UK grants; and spinout leadership composition including gender, age, and nationality.

Minister for Science at the new Department for Science, Innovation and Technology George Freeman MP said: "From Glasgow's satellite city to Warwick robotics, South Wales semi-conductors and Solent MarineTech, the UK is home to many high growth R&D clusters. This report shows that with the right backing, we can make a success of spinning out businesses in every part of the country."

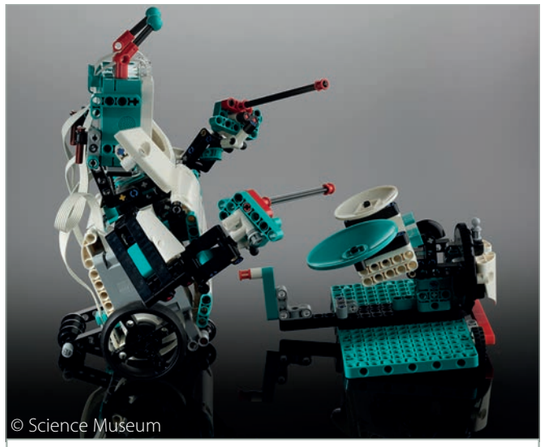
IN BRIEF

GET INVOLVED IN ENGINEERING

© London Transport Museum

THE BIG BUILD

16 to 18 June 2023
London Transport Museum Depot, Acton
Discover the story of the Underground at London Transport Museum's Acton Depot. The working museum is home to many amazing objects from London's transport history, and the open days will include talks, tours, vehicle displays, and family activities. Children aged eight and over can have a go at coding electric toy trains, and visitors have the chance to see demonstrations of heritage train signalling equipment, learn about the evolution of the Tube network over its 160-year history, and ride a miniature railway. Tickets must be booked in advance at **ltmuseum.co.uk/whats-on/depot-open-days-big-build**


© Science Museum

ENGINEERS

From 23 June 2023
Science Museum, London
From 23 June, the Science Museum's new Engineers gallery will be open. The gallery is dedicated to world-changing engineering innovations and the diverse and fascinating range of people behind them, supported by the Queen Elizabeth Prize for Engineering Innovation. Its four sections – Bodies, Lives, Connections, and Creating – will host stories from more than 60 engineers working in a broad range of industries, such as farming, fashion, robotics, and medicine, shining a light on their lives, motivations, thought processes, and what they do day to day.
www.sciencemuseum.org.uk


© IET

ENGINEERING OPEN HOUSE WEEK

12 to 18 June 2023
Nationwide
At Engineering Open House Week, families, schools and children can explore STEM-inspired events across the UK. The hosts include well-known and local organisations, businesses and STEM projects, demonstrating technologies, energy systems, buildings, and much more. Locations include Canterbury Christ Church University in Kent, The National Museum of Computing in Milton Keynes, Make UK in Birmingham, and Bangor University in North Wales. To discover other locations, visit **www.engineer-a-better-world.org/engineering-open-house-week**

NETWORK, VISIT, INSPIRED

18 July 2023
Cambridge and online
Stemettes and The PA Foundation are holding a day of STEAM learning, project work and discussions for Key Stage 3 and 4 students. They will be able to network with industry role models and take part in a group project to help them build their communication and presentation skills, as well as learn about a future career in STEM. To find out more and register, visit **stemettes.org/events**

THE SECRET SUPERPOWERS OF THE SEABED

23 June 2023
Royal Institution, London
Join Professor Susan Gourvenec FREng, Professor of Offshore Geotechnical Engineering and Deputy Director of the Southampton Marine & Maritime Institute, for this talk about the seabed superpowers that engineers can tap into to support infrastructure, as well as the latest emerging technologies that will enable us to design and build offshore wind farms at a scale, pace and accuracy. For tickets, visit **rigb.org/whats-on/secret-superpowers-seabed**

THE GREAT EXHIBITION ROAD FESTIVAL

17 to 18 June 2023
South Kensington, London
This weekend of free events for all ages focuses on science and the arts, with experiences from organisations including Imperial College London, the Science Museum and the Royal Commission for the Exhibition of 1851. The programme of workshops, talks and shows includes robot building, creating artificial cells, designing an earthquake-resistant structure, bedtime stories for very young engineers, and more. To find out what's happening, visit **greatexhibitionroadfestival.co.uk**

ENGINEERING IDEAS EXHIBITIONS

Until 11 July
Nationwide
Each year, Primary Engineer's Leaders Award asks school students and young people up to 19 years old: "If you were an engineer, what would you do?". You can find out their innovative ideas and answers at one of 22 regional awards and public exhibitions across the UK. To attend one of the events or register for next year's competition and teaching resources, visit **www.leadersaward.com**

BIG BANG FAIR

21 to 23 June 2023
Birmingham NEC
The Big Bang Fair provides schools with a wealth of interactive activities and STEM inspiration, students can access careers advice and meet with scientists and engineers. Visit **www.thebigbang.org.uk/the-big-bang-fair** to sign up.

HOW I GOT HERE

HOW I GOT HERE

Q&A

LAURA TUCK
DESIGN ENGINEER

© Katende Adirl

The Washing Machine Project team road testing a prototype in Uganda © Katende Adirl

After a stint designing products now sold worldwide for Dyson, design engineer Laura Tuck has been working to empower women worldwide at several startups.

WHY DID YOU BECOME INTERESTED IN SCIENCE AND ENGINEERING?

I was drawn to engineering because of a love of both maths and design at school. I would often be found sneaking off to the design classroom at school to take something apart or build something new, and would spend my evenings doing maths puzzles. I had a teacher that put me forward for an engineering scholarship and I learned that engineering was the perfect combination of these skillsets.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I got to where I am now through an initially very academic pathway. After A levels in maths, physics and design, I studied manufacturing engineering at the University of Cambridge. After graduating, I wanted to develop my design skills, so I joined Dyson as a design engineer, working on multiple products that are now sold worldwide. Through my time there, I found a passion for the problems that have been traditionally overlooked. For me, that meant tackling the technology gaps that exist for women worldwide. This led me to a range of inspiring startups, including Elvie (a wireless and wearable discreet breast pump), Peequal (a sustainable 'squat' urinal) and The Washing Machine Project. Through these, I've developed breast pumps that give women the freedom to feed their baby without being tied to the home, women's urinals that give equal access to toilet facilities, and manual washing machines that have the potential to save time for the billions of people worldwide who still hand wash clothes.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

My biggest achievement to date has been the design, development and distribution of The Washing Machine Project's manual washing machine, which is designed specifically for use in refugee camps and other areas where electricity and running water are not available. I recently got the opportunity to distribute some of these machines to communities in Uganda, seeing first-hand the impact they will have on the lives of the women and children currently spending hours each day hand washing clothes.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

My favourite thing about being an engineer is the opportunity to create something new and innovative. As an engineer, I get to use my creativity and technical expertise to solve problems and develop solutions that have never been seen before. It's a challenging and exciting field that offers endless opportunities for growth and development.

WHAT DOES A TYPICAL DAY INVOLVE FOR YOU?

A typical day for me involves a mix of designing, testing and collaborating with colleagues and partners around the world. Whether coming up with whole new concepts, building prototypes to take around the world, travelling to visit communities where our products are being used, or working with manufacturers to scale our concepts, every day is different and full of exciting challenges.

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

My advice would be to keep an open mind and look for opportunities to learn from people with diverse backgrounds and perspectives. Don't be afraid to ask questions, seek out mentorship, and push yourself out of your comfort zone. And most importantly, always stay curious and passionate about using your skills to make a positive impact in the world.

WHAT'S NEXT FOR YOU?

As for what's next for me, my focus is on taking The Washing Machine Project's latest innovation to as many people as possible. Finding a mechanical solution is only part of the answer; we also need to get it out into the world and continue learning to have a positive impact on as many people as possible. I'm excited to continue pushing the boundaries of what's possible and to explore new ways to use engineering to create a better world.

QUICK-FIRE FACTS

Age: **28**

Qualifications: **BA and MEng, manufacturing engineering**

Biggest engineering inspiration: **Mary Beatrice Davidson Kenner – the inventor of an adjustable sanitary belt with an inbuilt pocket for pads. (Sanitary belts predated adhesive pads and were used until the 1970s.)**

Most-used technology: **headphones**

Three words that describe you: **curious, analytical, determined**

OPINION

OPINION

BUILDING A GREENER FUTURE

Engineers have their work cut out to decarbonise all sectors. Will Arnold, the Head of Climate Action at the Institute of Structural Engineers (IStructE), says a mindset change is imperative. Revolutionary ideas will be key for the future of how we create, maintain and power our buildings – with fresh minds and diverse teams at the forefront.

Will Arnold

The future of humanity is endangered by the dual threat of climate breakdown and biodiversity loss across the globe. Weather systems are changing, leading to more extreme floods and droughts, threatening people's safety, homes, and food supplies. Nature loss continues to reach new highs, endangering fragile ecosystems on which humans rely on to live.

This breakdown is happening primarily because of how we make stuff, create energy, grow food, and provide transportation. All four of these industries have engineers at their heart, and so we must transform them if we're going to better protect nature and return our climate to the sweet spot that enables humanity to thrive.

I work in the building industry, and our main impacts on the climate and biodiversity emergency come from two things:

1. Heating and powering our buildings, to keep us at a comfortable temperature and allow us to turn on the lights/TV/kettle.
2. Using construction materials (concrete, steel, bricks, glass, and so on) to create and maintain our buildings.

Both create carbon emissions – through generating power at power stations for (1), and through burning fuels to make the materials in (2). Additionally, our use of materials threatens wildlife all over the world. The materials used to make the steel frames in a UK shopping centre could have been made using iron and coal from places as far away as Brazil or China, threatening nature wherever they were dug out of the ground.

So, to engineer buildings that will secure the future of humanity, we need to tackle (1) by reducing the energy used by our buildings and ensuring that it is fully renewable. To tackle (2), we need to stop demolishing existing buildings, upcycling them instead, and then invent new manufacturing methods to create zero-carbon materials that we can use where we really need to build something new. Approaches to both of these are laid out in the UK Green Building Council's roadmap to net zero. So that's all sorted then, right? Wrong.

WE NEED A REVOLUTION

The problem is that most of our plans are based on improvements in efficiency. We aim to use less power and less material. But there are two problems with this.

Firstly, it's just not quick enough. If you look at how rapidly the world needs to decrease carbon emissions and nature loss, you see that we're not talking about small gains year-on-year. If you look at the latest IPCC report, you realise that not only do we need to slash emissions year-on-year (something which we're not even close to doing yet), but eventually we have to get past net zero and through to a carbon-negative world, where we start to repair the damage done to our climate. We need something really transformative to happen if we're going to pick up the pace.

Secondly, whenever we've found an improvement in efficiency in the past, studies show that we've actually increased consumption as a result. When the chainsaw was invented, lumberjacks didn't start to work two-day weeks, rather, they cut down more trees. This so-called 'Jevons Paradox' has led many to conclude that efficiency policies are not helpful.

So instead of efficiency increases, we need breakthroughs, game-changers, and transformations.

When Dick Fosbury invented the Fosbury Flop approach to the high-jump in the 1960s, he didn't simply make high-jumping more efficient, he revolutionised the sport. Today, every competitive high jumper uses the Fosbury Flop method. We need Fosbury Flop thinking for our homes and buildings, our construction materials and methods, and the ways we think about power generation and consumption. This is what the IStructE argues for with much of the thinking behind *Design For Zero*, its flagship book on eliminating materials-based emissions.

DIVERSE AND CREATIVE TEAMWORK

Today, engineering teams around the world are looking for new minds and new ideas. We need enthusiasm, intelligence and imagination. We need people who are mathematically talented, others who are wonderfully creative, and others who are skilled communicators. We need those who love to solve problems, and others driven by a desire to see people all over the world live a comfortable, enjoyable life. We need people from different backgrounds and cultures, with different interests and opinions. Where teams have this diversity, they thrive.

The most successful engineering teams are doing truly revolutionary things. I'm lucky enough to be a judge for The Structural Awards, which celebrate the world's most amazing engineering achievements in construction each year. This year saw two incredible projects given the grand title of 'Supreme Award for Structural Engineering Excellence'.

The first, 'Hylo', is a building where the engineers showed it was possible to upcycle an existing 16-storey tower-block in central London, adding a whopping 13 new storeys to the top of it and doubling its floor area. This halved the emissions and material used, compared with constructing a new building.

The second, 'The Arc', is a bamboo gymnasium for The Green School in Bali. Its awe-inspiring roof was built entirely from locally sourced 14-metre-tall bamboo arches. Its structural typology takes inspiration from how the human ribcage is stabilised, resulting in a unique shape and an unprecedentedly low carbon footprint. Both buildings had diverse, creative, talented and passionate teams of engineers at their heart – and have set the bar higher for what we should aim to achieve.

BECOMING AN ENGINEER OF THE FUTURE

Many engineering courses and apprenticeships now put climate and sustainability at their heart, aiming to produce young engineers who understand the challenges facing humanity even better than their future employers do. Some are even moving away from the 'do less harm' ethos of sustainable design and towards the exciting world of 'do more good' that comes from regenerative approaches. These are true revolutions in the way that we engineer the world.

This means that when it comes to climate, new engineers entering the industry are often the most informed members of any given design team. The more senior members of those teams are looking to the next generation to bring their views and ideas for new ways of doing all of this.

The UK has always been well-known in having its Fosbury Flop engineering moments and pioneering radical ideas to solve the world's biggest problems. The climate and biodiversity crisis is perhaps the biggest problem of all, and we need to lead by example in developing the most extraordinary solutions to it.

BIOGRAPHY

Will Arnold is a Fellow and staff member of The Institution of Structural Engineers (IStructE), responsible for embedding sustainability action into all aspects of the institution's work. He is responsible for driving the update of minimum standards for institution members, developing supporting guidance, and leading collaboration with wider industry. Will was the lead author of *Part Z* (an industry proposal for embodied carbon regulation in the UK) and is helping to deliver both the UK Net Zero Carbon Buildings Standard and the Built Environment Carbon Database. In recognition of his work instigating change in the field of structural sustainability, Will holds the IStructE President's Award and the Memcom Outstanding Achievement Award.

BUILDING WITH FUNGI

BUILDING WITH FUNGI

Mycelium is often touted as a wonder material, with mushroom-based replacements to leather, plastic packaging and meat all on the rise in recent years. Sonia Klug explores the outlook for mycelium in the built environment, from insulation to its role in so-called 'living construction'.

Illustration for *Ingenia* by Benjamin Leon

Did you know?

- A cubic inch of soil can contain so many mycelium filaments that, lined up end-to-end, they would reach almost 13 kilometres
- These vast and complex networks can live for centuries, stretch over kilometres, and are even rumoured to help trees to communicate with each other
- Engineers are working on mycelium materials that could regrow and repair themselves, which could one day lead to self-healing leather or even building structures

Over the past two decades, scientists have experimented with growing mycelia – the networks of hair-like threads that sustain all fungi – to create new materials. And our mycelial appetite is mushrooming, with startups the world over securing millions in funding for their low-carbon, biodegradable (and sometimes edible) products. Now, scientists and engineers are turning to mycelia to help shape the buildings around us.

While mycelium is no replacement for concrete or steel, it does have potential for internal and non-load-bearing materials, from stud walls to doors and insulation. Since many construction materials are derived from petroleum, mycelium could be a good alternative.

Some companies and researchers are taking the concept even further, with early prototypes of temporary buildings made from mycelium bricks. Others propose living mycelial structures that can grow and shift with time. But what many mycelia-material proponents have in common is a belief in the need for a mentality shift in the way we construct and experience the buildings around us.

The Living and Arup's Hy-Fi Tower, built in a courtyard at the Museum of Modern Art, New York, from compostable bricks manufactured by Ecovative © Arup

FLEXIBLE FUNGI

Unlike photosynthesising plants, fungi get energy from digesting organic matter such as cellulose and lignin. They can convert this into mycelium and fruiting bodies, such as mushrooms. Depending on the type of fungi, the medium they grow in, the CO_2 content, temperature, and air humidity, mycelium can form materials with completely different qualities: rigid, foam-like, flexible, dense, loose, strong, or easily torn.

For example, mycelium can be grown as a 'skin' or layer on the surface of a liquid containing starch, sugars, yeasts, and other nutrients. Fermenting solid substrates is another approach to grow mycelium materials. Vegan leather grown this way by US-based Bolt Threads has already been used in Stella McCartney bags and Lululemon yoga mats. Mycelium vegan meat, which can resemble steak or bacon, involves a similar approach.

Mycelium can also grow in a dry layer of agricultural by-products, such as shredded corn husks, sawdust or straw. As the fungi part-digest the plant matter, they bind the remaining waste fibres in a rigid but lightweight composite structure. This can result in a material akin to polystyrene that can be used as packaging. In the UK, The Magical Mushroom Company

Fungal mycelium growing on an agar-based nutritious substrate gel © Mogu

has produced and sold over half a million pieces of packaging made this way, using an approach developed by US-based Ecovative. After use, mycelium packaging can be torn into smaller pieces and composted with garden waste, turning to soil in about 45 days.

BUILDING WITH MYCELIUM

While mycelium-based construction materials are still a nascent area, enough progress has been made for many a headline speculating about compostable future homes made of living fungus. But these are not wholly unfounded ideas.

The materials and foresight teams at Arup have been researching biomaterials such as mycelium in the built environment for over a decade. Back in 2014, they provided structural engineering for an eye-catching temporary structure made from mycelium composite bricks. This art exhibit, the Hy-Fi Tower, was installed in a courtyard at New York's Museum of Modern Art (MoMA).

Arup's engineers worked closely with New York-based architecture practice The Living to come up with a design. After testing the composite material's strength, they calculated that the bricks (made using Ecovative's approach) could be used in a structure up to 12 metres high. Aiming for a structure capable of withstanding 65 mph winds, their design featured a wide base and round towers.

This striking project numbers in the few that have used mycelium for external, load-bearing bricks. "There are still significant barriers for mycelium, including technical understanding, particularly in terms of longevity in exposed environments and structural applications," says Florence Wu, a biomaterials specialist on the Arup team who has been involved in several recent mycelium-based projects, including an award-winning initiative to restore wetlands with floating mycelium islands.

Wu also worked on acoustic insulation tiles, conceived by Italian company Mogu. Mogu's foam-like, sound-absorbing tiles are designed to reduce noise and echo in internal spaces such as offices. The company worked with Arup to determine the product's technical specifications.

"In nature, fungi are formidable decomposers and recyclers, responsible for transforming dead organic matter," explains Mogu's co-founder, designer and engineer Maurizio Montalti.

"In our case, they hold the potential to process low-value materials, such as agro-industrial waste, and turn those into high-value materials and products."

GROWING THE DATA ON MYCELIUM

Testing was an integral part of product development. Mogu worked closely with the Arup team for this, gathering data on sound absorption, fire safety, compressive strength, humidity resistance, and performance after installation.

"We often had to go back to the drawing board when the result wasn't in the accepted range or couldn't be reproduced," says Montalti. "There were many iterations. We shared the data with Arup, to… eventually [establish] a process that would consistently deliver a high-performing product."

"We assessed and analysed their data in relation to building standards," adds Wu. "Having robust testing and data that shows performance and compliance is crucial to gain the trust of the public, to inform engineers and builders, and enable policymakers to legislate, paving the way for wider adoption."

Despite the consumer appetite for materials with a lower environmental impact, as Wu points out, lack of data is a major barrier to biomaterials being more widely adopted. For instance, many mycelium products have limited data on durability. And without evidence that they fulfil specifications – either stipulated by building regulations, or performance required by a client – they are unlikely be used.

However, Wu is positive that longevity will not impede mycelium adoption. "There is the perception that mycelium doesn't perform well in terms of longevity," she says. "[But in] retail outfits, most internal finishes, such as acoustic walls, change on average every 7 to 10 years, particularly in high turnover places such as London. So maybe this actually suits those applications."

There is more manufacturers and researchers working with mycelium must do to better understand and tailor its properties. For instance, the amount of water it absorbs is important for indoor use, especially in humid climates. One mycelium expert has compared it to a sponge, noting it should be sealed with water repellent (which could compromise its sustainability credentials). Others report that mycelium composites, densely grown on the right substrate, have more suitable water absorption properties than clay bricks, mortar and glass fibre.

Either way, more R&D and case studies will clarify what is possible. The Living's latest project will test mycelium as insulation, sandwiched between millimetre-thick sheets of a fibreglass shell, for the walls of prefab affordable housing units in California.

HOW TO GROW A TILE

Growing a tile. (Left) The mycelium begins to grow on the substrate. (Centre) A denser mat of mycelium. (Right) The tiles before and after growth © Mogu

Maurizio Montalti explains the production process of Mogu's acoustic WAVE panels. "The challenge was not just to create a tile but also a protocol that would yield the same outcome every time. It's a lot more complex than a chemical reaction because there are so many variables when dealing with biological processes," he says.

Selecting the strain

There are a mindboggling number of different fungi species (estimates range from 2.2 million to 5 million), while individual species can have many hundreds of strains. The Mogu team looked at 250 strains before settling on one that would support the development of an optimal product.

The substrate

The substrate on which the mycelium grows is a blend of residues from the textile and agricultural industries. Cotton that's too impure to be used for fabric is blended with hemp fibres, hydrated and sterilised to eliminate microorganisms that could interfere with the fungus's growth.

Incubation

The substrate is then mixed with fungal spores and used to fill special bags equipped with a filter that allows for gas exchange. The bags are stored at the optimal temperature for growth – about 25˚C and incubated for a few weeks. As the mycelium grows, it turns the bags into dense white blocks.

Growth

Once the growing medium is fully colonised, the cultures are robust enough to be processed in the factory. The blocks are shredded and the fibres poured into moulds the desired shape of the tiles. These are placed on shelves in an incubation room with controlled temperature, humidity and CO_2 concentration of air, similar to a vertical farming system. Now, the mycelium grows back very quickly, solidifying in the shape of the mould.

Sterilising

The semifinished tiles are then dried in a desiccator at about 70˚C to stop the biological activity of the fungus, turning it into an inert material.

Finishing

The tiles are finally treated with nontoxic substances to tailor technical properties such as fire resistance, depending on the space they are intended for. They can also be coloured with water-based paints.

The Hub for Biotechnology in the Built Environment's knitted mycelium structure, 'grown' from local waste materials at the Farrell Centre in Newcastle © Jill Tate

Cost is also an obstacle, with many mycelium products considered high end and niche. If projects such as The Living's are successful, they could raise mycelium's profile and in turn, demand for it, bringing down prices.

LIVING BUILDINGS

Dr Meng Zhang, an associate professor in microbial biotechnology at the University of Northumbria, believes that mycelium products can go even further in construction – but depends on close collaboration between engineers, architects and biologists. She says this cross-pollination is critical if these emerging biomaterials are to fulfil their potential.

"R&D goes hand-in-hand with large production processes," she explains. "[Understanding] the biology of mycelia is essential. Engineers and scientists… must continuously monitor substrates and growing conditions."

Working to capitalise on such partnerships, Dr Zhang and her colleagues secured £8 million in funding from Research England to establish the world's first Hub for Biotechnology in the Built Environment. This initiative from the universities of Newcastle and Northumbria involves bioscientists, architects, designers, anthropologists, and engineers. The hub envisions a future in which living buildings reduce pollution, metabolise their own waste, and generate energy.

Dr Zhang is the biological lead for the hub's Living Construction research group. Rather than seeing materials as end products, it is working towards materials that form part of an ongoing biological process.

Dr Elise Elsacker, a former group member who is now a research fellow at the Vrije Universiteit Brussel, has demonstrated results to this effect. Her work shows that with the appropriate treatment, mycelia can regrow after goods have been created. "That would enable products that could regenerate, such as self-healing leather. For example, if you have a cut in the leather surface, you could add a nutrient that regrows the broken leather," says Dr Zhang.

While self-healing mycelium leather is in its early stage, Dr Jane Scott, a textile designer, and her colleagues at the hub, grew mycelium onto a wool, paper waste and sawdust matrix to form an arched, cave-like structure for the launch of the University of Newcastle's Farrell Centre for architecture and cities in April. The mycelium can be regrown if cracks appear, while the entire structure is compostable at end of life.

The Living Construction group is also exploring how mycelium insulation could be grown in cavity walls, and 'welding' materials with long mycelium filaments as an alternative to cement. While at a very early stage, this would have vast potential, given that 5% of global CO_2 emissions stem from the cement industry.

Montalti, too, sees promise in bio-fabrication – the ability to use cultured organisms to "create technical products that specifically address a need sustainably," he says. "Fungi can, for example, produce chitin within their cell walls, the same hard material making up the exoskeleton of shrimps."

Dr Zhang believes that mycelium products could fundamentally change the construction industry and be an important step towards a circular economy. "Living materials hold huge potential to construct in a new way. Living cells could transform how we build."

BIOGRAPHIES

Florence Wu joined Arup's materials consulting team in 2019 after graduating from Imperial College London with a master's in materials science and engineering. Her work has focused on biomaterials, in particular mycelium.

Maurizio Montalti is Founder of Amsterdam-based design-research studio Officina Corpuscoli and Co-Founder of Mogu. Mogu produces mycelium acoustic insulation and flooring tiles, as well as other biologically obtained materials, mostly for the (green) building industry and fashion.

Dr Meng Zhang is a biodesign specialist and associate professor in the Department of Applied Science at Northumbria University. Within the Hub for Biotechnology and the Built Environment, she is one of the biological experts on many interdisciplinary research projects and co-leads the Living Construction theme.

© NASA/Alberto Bertolin

LIFT-OFF FOR SPACE IN THE UK

The UK has a solid foundation in space technology, from our space telecommunications and electronics know-how, to engineering planetary rovers for exploration missions. Now, its ambitions are growing, with satellite launches from UK soil almost on the horizon. Stuart Nathan digs into the past, present and future of the UK's space sector.

According to the UK Space Agency, our thriving space industry generates an annual income of £17.5 billion and employs 48,800 people.

The majority of this industry is centred around satellite telecommunications, including television broadcasting via satellite and GNSS (global navigation satellite system) services. Space manufacturing and operations are smaller segments, but still worth over £3.7 billion combined. The former includes making satellites, launch vehicles, and other components and instruments. Counted among the latter are operating satellites and launch services.

While still a fledgling area, much has been made of the potential for satellite launches from UK spaceports in recent years. This is because UK satellites must currently be sent long distances for launch – not ideal for

LIFT-OFF FOR SPACE IN THE UK

Did you know?

- Space isn't just a gateway to the Moon, Mars and beyond. Having consistent access to space will also enable us to monitor climate change and protect critical national infrastructure, from ambulance networks to the electricity grid and banking systems
- In November 2022, the UK government committed £1.84 billion to new space programmes, including Earth observation and climate programmes
- There are already three spaceports in the UK, with more anticipated in locations such as Argyll and Snowdonia

complex and sensitive equipment. They also compete for spots in busy launch schedules at spaceports abroad, against other national and commercial customers.

Three spaceports have been established in the UK so far – in Cornwall, Sutherland and the Shetland Isles – and more are in the works. The spaceports, mostly in remote locations for safety reasons, are an important addition to the UK's large and growing space sector.

Once these are up and running, UK satellites will have much greater flexibility to get to space when needed. While the first attempted satellite launch from UK soil in Cornwall in January 2023 failed, more are scheduled. SaxaVord Spaceport at Unst in Shetland says its first launch is planned for the end of 2023. Meanwhile, the Civil Aviation Authority has granted over 340 licences to companies in the UK space sector since July 2021.

All this suggests the future is bright for the UK's space industry. So, how did we get to this point?

A HISTORY IN SPACE

"We are really good at telecommunications," states Sarah Macken, Vice President for UK sales at Airbus Aerospace and Defence, the UK's biggest spacecraft manufacturer, at its site in Stevenage. "It's a really deep history that has evolved over 50 years. We got into that market very early on and have managed to maintain a position. We've done that by co-investing with government and through the ARTES programme [advanced research in telecommunications systems – the European Space Agency's R&D programme for commercial telecommunication products and services]."

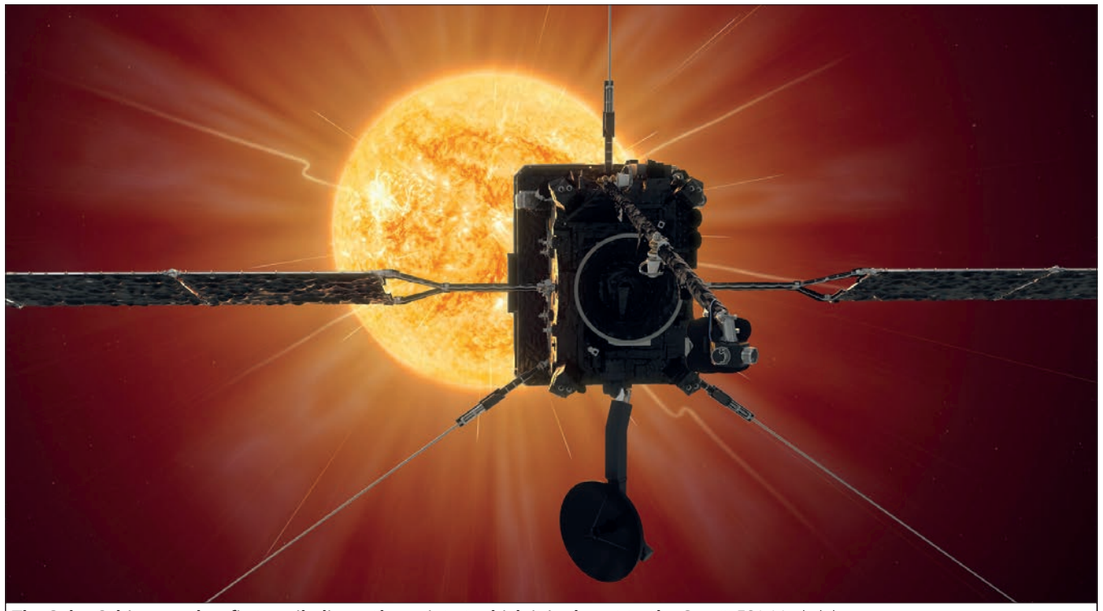
Macken believes that one of the UK's most important specialisms in satellite manufacture is signal processing. Signal processing circuitry is embedded all around the satellite and includes subsystems that boost the signal and transport it around the satellite. "We've been at the forefront of developing that from the analogue into the digital era. [Digital signal handling] allows a lot more flexibility in how satellites are operated. Today, satellites can be reprogrammed and moved to a new location. In the analogue days, you would put it up there and that was it. That is no longer the case. The UK was successful at the start of that trend, and it is still there today."

According to Macken, while people often associate electronics manufacturing with East Asia, commercial electronics and programming are in fact big UK successes – particularly for the space sector. "We supply about 25% of the world's satellite communications products, which is a huge proportion," she says, referring to electronic components from whole satellites all the way down to individual subsystems such as those for signal processing mentioned previously.

EXPLORING NEW WORLDS

The UK has also played a significant role in space science missions. Macken says that 2020's Solar Orbiter mission was a particular highlight. This European Space Agency (ESA) satellite was launched to take images of the Sun closer than any other spacecraft. "It was led by the UK: we did the design; we came up with a solution to the problem of how you operate so close to the Sun." The data it collects advances our knowledge of the Sun, as well as feeding into climate models.

Further afield, the ExoMars mission is Europe's attempt to uncover whether life has ever existed on Mars. It's set to launch in 2028 after many delays, including one caused by the invasion of Ukraine. The UK led the development of the ExoMars Rover, named Rosalind Franklin.



The Solar Orbiter reaches first perihelion – the point at which it is closest to the Sun © ESA Medialab

"Our experience on that project will lead into the lunar economy, where we are seeing growing interest," says Macken. "At the most recent ESA ministerial meeting, a new programme was funded to develop lunar communications and navigations in a project called Moonlight, which is really exciting."

This is linked to NASA's Artemis programme, of which ESA is a key partner. That programme aims to return people to the Moon by the end of the decade and will hinge on reliable and autonomous lunar communications and navigation services.

The Moonlight project aims to send three or four satellites into lunar orbit by space tug. This transfers spaceborne cargo from one orbit to another orbit with different energy characteristics. The tug will deploy satellites one by one, to form a constellation of lunar satellites. Engineers have optimised the constellation's orbits to cover the lunar south pole.

This area is the focus of upcoming missions for two reasons. Firstly, certain regions of the south pole have year-round sunlight. This is important for solar-powered equipment, as days and nights in other lunar areas can be two weeks long. The presence of polar ice is also a huge plus, as water is key for long-term exploration. Moonlight's plan is to provide sufficient satellite communications capacity for future missions, alongside accurate real-time positioning for lunar missions.

Airbus also built a rover at its Stevenage site for NASA and ESA's joint Mars sample return mission. Scheduled for the 2030s, this was designed to collect samples of Martian soil and rock cached by NASA's Perseverance rover, which landed on Mars in 2021. However, in July 2022, the agencies abandoned the fetch rover concept in favour of using two small helicopters. Despite this setback, Airbus has been testing its fetch rover in a quarry near London and hopes that it may be used on a future lunar mission.

Abbie Hutty, a systems engineer who worked on the fetch rover at Airbus, now works for Japanese space company iSpace in Luxembourg. Like her former employer, she has switched her attention from Mars to the Moon. The UK's record in developing rovers helped to make Hutty an attractive proposition for iSpace. "The UK is the only European country that has led rover projects in recent years. If you're looking at surface operations, we have a lot of competence that other countries cannot compete with. That meant that I had a very competitive skillset."

BUILDING PARTNERSHIPS

The UK is also home to smaller companies involved in space. Over 100 space organisations with more than 1,400 employees are based at the Harwell Campus just outside Oxford. Countless startups sit alongside hubs of larger players such as Airbus, Lockheed Martin, the UK Space Agency, and ESA. For example, Astroscale is developing services to remove hazardous space debris, while Oxford Space Systems manufactures satellite hardware.

Leicester is also a space hub, thanks to the UK National Space Centre. This museum and educational resource is twinned with a space research programme, in partnership with University of Leicester.

"The University of Leicester has had a continuous research programme starting with rockets, graduating to satellites and expanding into planetary science and Earth observation," explains Martin Barstow, professor of astrophysics and space science at the university and Director of Strategic Partnerships at Space Park Leicester (SPL).

LIFT-OFF FOR SPACE IN THE UK

"Launch sites near the Equator use the rotation of the Earth to boost launch velocity, and you can reach Equatorial orbits with ease," Archer explains. "If you launch from higher latitudes, you don't get that boost, but it does allow you access to orbits that are difficult to reach if you launch from the Equator"

The intention with SPL, he explains, was to bring academic and industrial partners together under one roof with laboratories and a large ISO-6 rated cleanroom. "For small companies, often one of the big challenges is investing in expensive infrastructure, which they might only need on an intermittent basis," he adds. "Our shared facilities help them avoid that challenge."

Currently, 25 companies use SPL's facilities. "A lot of our activities include building things to fly in space, particularly instruments for space research, planetary exploration, astrophysics, Earth observation, and that's essentially our heritage," Barstow says. "Equally, we have a similar volume of people who are into the use of data from those instruments, the downstream and spin-off activities that move out into industry."

He explains that space-developed technologies can also become very valuable to areas like medicine or agriculture. One example of this is Earth observation. In such missions, satellites gather data about the planet's physical, chemical and biological systems via remote sensing technologies, which is then used to monitor and assess changes in Earth's natural and built environments (see box 'Solving problems on Earth with a bird's eye view'; also 'The evolution of Earth observation', *Ingenia* 77).

LIFTING OFF

According to Matt Archer, Director of Commercial Spaceflight at the UK Space Agency, spaceports will also become an important part of the UK's space industry ('The final frontier', *Ingenia* 82). Spaceport Cornwall will only host horizontal launches — those from adapted conventional aircraft such as Cosmic Girl, the Boeing 747 used by Virgin Orbit. This is because the safety case for horizontal launch is essentially the same as an airport, as the launch itself doesn't happen on the ground. More of a risk surrounds the propellants used for launch when it takes place from the ground, as in vertical launches.

However, two sites equipped for vertical launch aim to begin operations in Scotland in 2023. One is in Sutherland on the A'Moine peninsula; the other is even further north at Lamba Ness on the island of Unst in the Shetlands.

Orbex will operate the Sutherland site. The Scottish company is developing a small commercial launch vehicle that is designed to be reusable. It has a 3D-printed engine, with its main structures and tanks composed from advanced carbon fibre and graphene composites.

Meanwhile, the spaceport on Shetland's isle of Unst, SaxaVord, will host launches from a variety of commercial operations. It has already announced partnerships with German launch operations provider Rocket Factory Augsburg and US firm ABL Space Systems, while Lockheed Martin is to build a satellite tracking and communications station.

Missions from UK spaceports are likely to be different from those launched from more familiar established launch locations, such as NASA's Cape Canaveral or the ESA's Kourou site in French Guiana. "Launch sites near the Equator use the rotation of the Earth to boost launch velocity, and you can reach Equatorial orbits with ease," Archer explains. "If you launch from higher latitudes, you don't get that boost, but it does allow you access to orbits that are difficult to reach if you launch from the Equator. Our advantage is in reaching polar and sun-synchronous orbits, which are actually very useful for telecommunications satellites and Earth observation missions."

Virgin Orbit's carrier aircraft Cosmic Girl ready for lift off at Spaceport Cornwall © Spaceport Cornwall

Sun-synchronous orbits travel over both poles regularly, often multiple times per day. They allow satellites to take pictures of the same part of the Earth on the same part of each day. "You might want to take a bunch of Earth observation images of the UK during the day at a particular time," Archer adds. "You'd use a sun-synchronous orbit for that. The Scottish spaceports will specialise in those sort of launches, while Cornwall will be able to handle a wider range of orbits because the aircraft can fly to different latitudes to release its launcher."

Looking further ahead still, in the same way that NASA has shown how large missions can capture the imagination, so could the idea of putting large arrays of photovoltaic panels in orbit to send energy down in microwave-form to the Earth. This approach, space-based solar power, could help us to decarbonise the energy supply. It may provide huge opportunities for the UK space industry in the coming decade and beyond.

Such grandiose plans are, of course, for the future. But the fact remains that the UK is a major player in space. Without input from UK industry, much of the world's vital communications infrastructure would not exist, and the industries that depend on it, including media and finance, would suffer. In fact, a 2022 report from industry consultancy Technopolis on behalf of the UK Space Agency found that every pound invested in the UK space industry generates a return for the UK economy of £11.80. There aren't many industries that can boast such a multiplier.

SOLVING PROBLEMS ON EARTH WITH A BIRD'S EYE VIEW

Earth observation is used for many things, but perhaps its most important application is protecting our planet. Copernicus, operated by the EU, is the world's largest Earth observation programme, and its Climate Change Service provides important data on climate change, from monitoring glaciers to collecting data on droughts.

Looking to a smaller scale, UK startup Rezatec, also based at Harwell Campus, have helped water utilities identify pollution sources. Its approach uses machine learning techniques to analyse satellite images, looking at things such as the types of crops, land topography, and the hydrology (the way water is distributed on land).

For example, to analyse the types of crops over a land area, their engineers fed vast volumes of data into its crop ID model, training it to recognise the 'signature' of specific crops with over 97% accuracy. This was used to estimate fertiliser application and fed into a model to map risk to water sources from particular crop fields.

Read more in *Ingenia* 77.

CLEANING UP IN SPACE

With the ever-increasing array of satellites launched into orbit, what about the concerns about the Earth's orbits becoming congested with 'space junk'?

Thankfully, work is underway to tackle this problem. The groundwork was laid in 2019, by a consortium led by the University of Surrey, with several partners including Airbus. Its RemoveDEBRIS spacecraft (In Brief, *Ingenia* 77) involved a vision-based navigation system that validated debris-tracking techniques in orbit with cameras and LIDAR, along with a net and harpoon to actually capture space junk. Successful testing took place in 2019.

Meanwhile, Harwell Campus-based startup Astroscale recently announced that its debris removal service is on track to remove two defunct satellites by 2026 using a robotic capture system.

Stuart Nathan thanks Sarah Macken, Vice President for UK sales at Airbus Aerospace and Defence; Abbie Hutty, Lead Systems Engineer, iSpace; Martin Barstow, professor of astrophysics and space science at the University of Leicester and Director of Strategic Partnerships at Space Park Leicester; and Matt Archer, Director of Commercial Spaceflight at the UK Space Agency.

TURNING JEANS GREEN

© Fanette Guilloud/Death to Stock

TURNING JEANS GREEN

Did you know?

- Denim's characteristic appearance comes from weaving together indigo 'warp' (up-and-down) threads into undyed 'weft' (left-and-right) threads. The warp yarns are predominant on the face, which is why the outside is bluer and the inside is paler coloured
- Most denim is made on an automated loom where projectiles carrying the threads are fired back and forth
- Instead of chemically synthesised indigo, synthetic biologists have developed an approach to dye fabrics using bacteria fermented in large tanks, like those used for brewing beer

Peek in the wardrobe of most people in the UK and you'd be hard-pressed not to spot at least one trusty pair of jeans. Leonie Mercedes looks into the textile engineering behind this wardrobe staple – and how new technologies are attempting to lessen their well-documented environmental burden.

It's been 150 years since Levi Strauss filed a patent for riveted work trousers, the robust workwear worn by California's gold rush miners that would become the blue jeans we know and love today. Back then, jeans were made to last, and they were much simpler to make.

Fast forward to the 21st century, and our jeans have become a go-to garment for virtually any occasion. The array of colours, textures and embellishments we now expect from denims has made them more complex to make, harder to recycle, and they don't last as long, condemning them to landfill sooner.

Jeans are also an incredibly resource-hungry product, for several reasons. Firstly, they're made of cotton, a notoriously thirsty crop that is often grown in water-stressed areas with harmful pesticides. Secondly, there's the distinctive indigo hue and worn-in look we expect from denim. This is achieved by a series of dyeing and finishing methods that use dangerous chemicals – sometimes including carcinogenic azo dyes and heavy metals – and vast quantities of water.

This all takes a significant toll on people and the planet. What measures are being taken to make this wardrobe staple more sustainable?

THE KEY INGREDIENT: COTTON

Cotton is the standard fibre for making denim, although other plant-based fibres, including viscose, lyocell, modal, and hemp (known collectively as cellulosic fibres) can also be used.

About 25 million tonnes of cotton are grown each year, with China, the US and India being the top producers worldwide.

Depending on where it's cultivated, it takes thousands of litres of water to produce a kilogram of cotton. In Uzbekistan, cotton farming has consumed so much water that the Aral Sea, once one of the world's four largest lakes, has almost dried up.

Cotton yarns – each pair of jeans requires about 1.5 square metres of woven fabric
© ORTA

TURNING JEANS GREEN

The rope dyeing process, where yarns are bundled before going through the dye bath © ORTA

Most cotton is grown with fertilisers and pesticides, which can pollute local water supplies. Pesticides can be particularly hazardous to human health. In 2022, a report compiled by environmental groups estimated that each year, 385 million people globally experience unintentional poisoning by pesticides, resulting in 11,000 deaths.

To reduce these impacts of cotton production, many jeans manufacturers are turning to organic and recycled cotton. Unfortunately, because of limited availability, neither material is a panacea. Instead, some brands are using deadstock (leftover) fabrics, or turning to fast-growing hemp and nettle fibres – usually at high-end prices.

HOW TO MAKE A PAIR OF JEANS

Once the textile fibres are in hand, there are many steps that go into making a pair of jeans, including spinning, dyeing, weaving, washing, and finishing.

After the cotton is cleaned and combed, its fibres are spun into yarns. Spinning consumes a lot of electricity – to run the machines, as well as maintain the optimal temperature and humidity. Ventilation systems and local suction systems at each machine keep the air clean, as errant cotton fibres settling in the wrong places, along with dust, can create impurities in the fabric.

The yarns are then dyed either individually, as a sheet (known as slasher dyeing) or bundled into ropes (rope dyeing). Successive dips into a series of dye baths, or boxes, deepens the colour to the right shade of indigo. The yarns might be dyed again after they have been woven into a textile, and once again after the fabric has been made into a garment.

Indigo is the traditional dye used in denim manufacture, although the majority of denim makers use synthetic indigo. As indigo is not water-soluble, it must be chemically altered (reduced) before it can bond to the cellulose fibres. This is often done by adding the bleach sodium hydrosulphite. However, scientists have developed other cleaner, less water-intensive methods for doing the job, including electrochemical reduction.

Reduced indigo, called leucoindigo, is pale yellow. After their dye bath, the yarns are oxidised – exposed to air – again, so that the indigo can return to its insoluble form and its blue colour.

Dyeing is a part of the manufacturing process that often does the most environmental harm. It uses vast quantities of water, as denim yarns are cleaned, dipped in up to 13 dye baths (thousands of litres each), and then rinsed. And the resulting wastewater – contaminated by the chemicals that fix the dye to the fabric, unbonded residual dye and cotton fibres – has to go somewhere. It many cases, it is dumped into local waterways, turning rivers black and making local people sick, from Savar in Bangladesh to Kathmandu.

However, Dr Mark Sumner, a lecturer in sustainable fashion at the University of Leeds School of Design, says that many responsible retailers and brands are working with suppliers that have effective effluent treatment plants, where the chemicals and solids are extracted from the effluent before it is discharged. He notes, however, that "treatment plants use lots of water and energy. There's a financial and environmental cost associated with that."

Nevertheless, there are several innovative approaches that have been developed to reduce the impact of dyeing denim (see 'More environmentally friendly dyes').

Denim is made on industrial looms, where the white (or ecru, meaning undyed) weft (left-to-right) yarns are woven into the indigo warp (up-and-down) yarns. When the fabric is ready, it goes to the garment manufacturers, who cut it, sew it, and add accessories such as buttons and rivets.

In the next step, the jeans are washed and finished to create a 'worn-in' style. This transforms them from a dark, stiff pair of trousers into pieces with mass-market appeal, with what looks like a bit of a history.

For instance, to fade the indigo, jeans are often stonewashed, in a laundry machine with pumice stones. This also softens the fabric, so they're more comfortable to wear. However, like so many other stages of denim production, stonewashing consumes a lot of water and produces effluent contaminated with residual dye.

There is another undesired effect: "As well as removing the colour that's been put in through these long dyeing processes, you're also reducing the lifetime of the product," Sumner says.

Eco-conscious denim makers are turning to less water-intensive methods of bleaching that do not damage

Denim mill ORTA, based in Turkey, produces the equivalent of more than 20 million pairs of jeans a year © ORTA

the garment. These include enzyme washing, where cellulase enzymes break down the dyes and soften the denim; and ozone washing, where ozone is added to the wash to fade the fabric without producing the polluting effluent.

Finishing also covers the final touches jeans go through before hitting the rails. Well-worn jeans bear a set of characteristic markings that suggest a life well lived, including the 'whiskers' near the front pockets. These markings are often made using potassium permanganate, a strong oxidising agent that can burn the skin and damage the eyes. Lasering offers a water- and chemical-free method of creating these features, and according to online denim guide Denimhunters, gives more consistent results than potassium permanganate.

MAKING FASHION CIRCULAR

Evidently, a lot of work is under way to make jeans manufacturing less of an environmental burden.

But reducing a garment's environmental impact requires consideration of its entire lifecycle – not just production. This is the thinking behind a circular economy, where resource management and production methods are transformed to eliminate pollution and waste. With this in mind, the Ellen MacArthur Foundation has created a set of recommendations to help manufacturers and brands reduce the waste and pollution associated with making jeans, and make garments easier to recycle.

The foundation's Jeans Redesign bases its guidelines on three focus areas, which are that "jeans are designed to be used more, made to be made again, and made from safe and recycled or renewable inputs".

Testing garments for durability is a key recommendation, with one minimum requirement being that jeans should survive at least 30 washes.

MORE ENVIRONMENTALLY FRIENDLY DYES

Sulfur dyes are widely used as a less water-intensive alternative to indigo. These dyes have a better affinity for cotton, requiring fewer dye baths and offering improved colour fastness (resistance to fading or transfer). One such dye is the Advanced Denim system developed by Archroma. It uses a single dyeing box and another box containing a sugar-based reducing agent to achieve a medium colour intensity, greatly saving on water and energy consumption. The company claims that no wastewater is produced at all.

To avoid the toxic chemicals associated with dyes altogether, some companies, including Norwich-based Colorifix and California-based Tinctorium, are genetically modifying microorganisms to recreate pigments found in nature, such as indigo.

Tinctorium grows genetically modified bacteria that produce a precursor to indigo. It uses an enzyme – instead of a chemical agent – to reduce the pigment to leucoindigo. As indigo produced in this way has the same chemical structure as naturally occurring and synthetic indigo, it can be used in conventional dyeing machines.

Colorifix, meanwhile, has developed an entire array of bacteria-based dyes. It first uses digital gene databases to identify the DNA linked to pigments found in nature, whether from a plant, animal, insect, or microbe. Then, it programs this code into microbes so that they produce the pigment. The microbes (and as a result, the pigment) can then be grown in fermentation tanks – similar to brewing beer. The company says its dyeing process reduces water consumption by 49% compared with conventional approaches, and requires no extra dyeing chemicals, as the cells themselves are used to deposit the pigment into fibres. According to an interview with CEO, Dr Orr Yarkoni in *SynBioBeta*, the company has even piloted fermentation and dyeing using saltwater, to save stretched freshwater resources.

Foam dyeing is another alternative method of dyeing that requires less water. Colour is transferred through a foam, so there is no need for successive dye baths. Jeans brand Wrangler uses a foam dyeing process developed by Texas Tech University in its Indigood™ range.

'Emotional' durability is also an important factor – that is, that garments remain "relevant and desirable" to the wearer.

One of the minimum requirements of recyclability is that garments are made of at least 98% cellulose-based fibres in the total textile composition, while another is that any components in the garment, such as fastenings, are easy to remove.

Sebla Önder, sustainability specialist for the Turkey-based denim manufacturer Orta Anadolu, says that from a sustainability point of view, when creating denim from scratch, it is best to keep things simple.

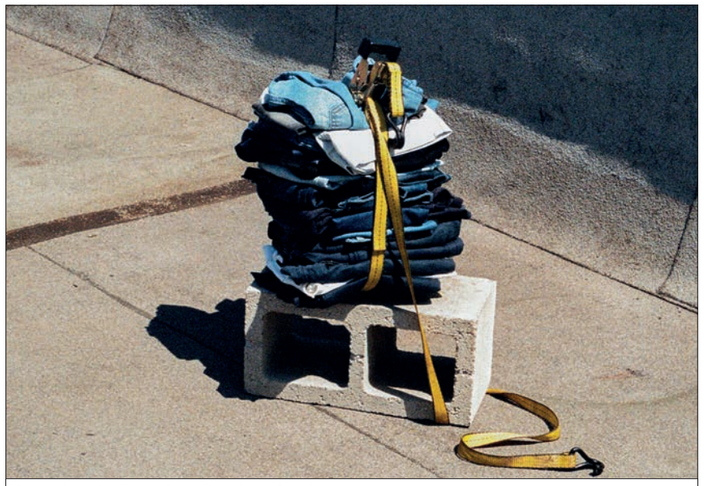
She recommends making jeans from 100% cotton, which makes the garment easier to recycle, and sticking to a midshade indigo to reduce the amount of dye required (as fewer dips in the indigo baths are needed). She notes how energy consumption quickly snowballs when extra processes are added to denim production; for example, bringing 2% elastane into the textile composition requires not just the extra step of adding the elastane but also the step of heating the textile to fix it. Here, just one extra ingredient requires two extra processes.

With all this in mind, how can you make better choices as a consumer? When in the market for any new garment, Sumner recommends thinking first about whether you actually like it, and then how often you think you're going to wear it – not necessarily how long you think you'll have it. "Keeping it in your wardrobe and not wearing it is probably the worst thing you can do with any garment," he says.

He adds that we should also think about aftercare, taking steps to preserve the life of the piece such as by washing only when we really need to, and avoiding tumble drying.

As scientific and engineering innovations continue to transform a centuries-old industry, making it fitter for the future, it is worth remembering that our choices as consumers can still have an impact.

HOW TO SPOT GREENWASHING



© Mackenzie Freemire / Death to Stock

Sustainability has become increasingly important to the average consumer, and more of us are taking practical steps to shop responsibly – brilliant news for everyone and the planet.

The not-so-brilliant news is that brands that cannot demonstrate their eco credentials will still market themselves as environmentally friendly, in a practice known as greenwashing.

As consumers, we must look past the labels saying 'sustainable', 'recycled', or 'responsible', and instead find out what the brands are actually doing. Many garments have a long supply chain and there's no way of conveying all relevant information about how a piece was made on a label.

"If you want to be more sustainable in terms of your fashion choices, you have to do a bit of research," says Sumner. He recommends checking brand websites for corporate statements about their position on sustainability. "If they are saying nothing about their sustainability agenda, or what they're doing, we have to assume they're doing nothing," he says.

BIOGRAPHIES

Dr Mark Sumner is a lecturer in sustainable fashion at the University of Leeds. He has a diverse research portfolio that includes textile and fashion sustainability, microplastics, modern slavery, and consumer behaviour. Mark developed his textiles and sustainability expertise by working for the UK's largest clothing retailer for over 15 years, where he was involved in supply chain management, textile innovations and sustainability. He has made major contributions to several UK and International sustainability initiatives including Sustainable Clothing Action Plan 2020, Textiles 2030 and ZDHC. Mark also contributed to the House of Commons Environmental Audit Committee report on fast fashion.

Sebla Önder is Sustainability Chief at ORTA. With a background in the chemicals sector and sustainability consultancy, she has worked in multiple industries, from textiles to construction. Sebla is a chemical engineer who graduated from Yeditepe University in Istanbul, Turkey, and holds a master's degree in sustainable energy engineering and policy from Carleton University in Ottawa, Canada.

ACCOUNTING FOR NET ZERO

© Var Pap/Pixabay

As we strive to achieve net zero and eliminate CO_2 emissions, attention has turned to how to account for investment in green tech and show that 'green finance' lives up to its label. Adrian Barnes and Professor Simon Pollard OBE FREng explain the relationship between engineering innovation, 'due diligence' for analysing risks and returns on investment, and the growing number of factors that influence decisions on responsible and sustainable investment.

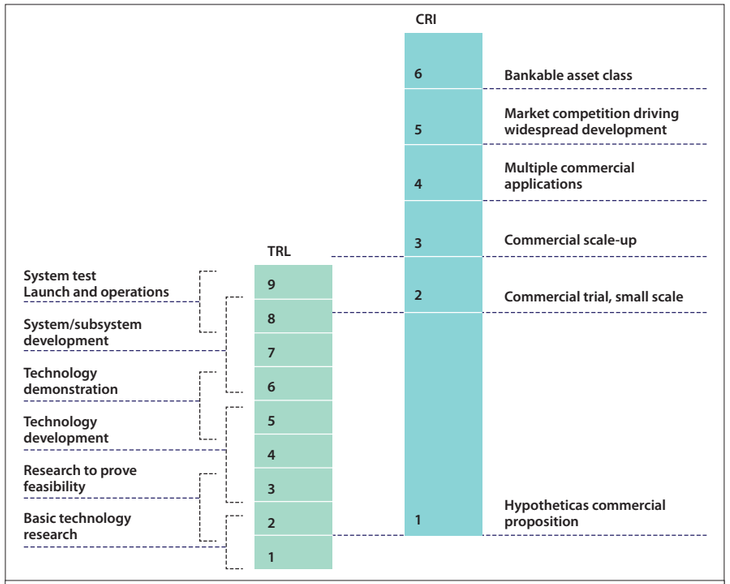
Over the past decade, financial markets have warmed to the concept of 'green investment' – investment that has a stated positive environmental contribution. Investment in 'clean tech' is now a mainstream activity, especially for established technologies such as wind energy and solar photovoltaic power generation. This growing enthusiasm for green finance has led to new ways for investors to ensure that the ventures that they back really are sustainable technologies that can contribute to the quest for 'net zero'. The investment profession has its own well-developed terminology and approach to managing risk and opportunity. While these approaches cover commercial and technical considerations, the rise of green investment means that there is increasing overlap with environmental, social and governance (ESG) factors.

ACCOUNTING FOR NET ZERO

The growth of green investment has seen widespread use of the terms 'responsible investment' and 'sustainable investment'. In practice, each label has a distinct focus that becomes important as we look to finance net zero engineering and to make the UK an internationally attractive investment hub for net zero technologies and services.

Mission Zero, the government's Independent Review of Net Zero, published in January 2023, recognises the UK as a world-class supplier of environmental goods and services, including clean tech and green finance. It also points out that the UK is well placed to take advantage of the comparative advantages it has over other advanced economies. It acknowledges this sector's key role in paving the way to sustainable economic growth in the UK.

Taking energy supply as an example, policy on the energy sector's transition to net zero is driven by the need to balance sustainability, energy security and reliability, and affordability. Achieving this balance requires the sustainability, engineering and finance professional communities to collaborate. These communities have much to learn about each other's ways of working and the factors that determine good decision-making. The UK has also recently upgraded its Green Finance Strategy, which aims to drive investment in green tech to deliver the country's energy security, net zero and environmental objectives (See 'Supporting green investment').



Ways to analyse the commercial potential of new ideas include the assessment of technology readiness levels (TRL) and commercial readiness index (CRI) (adapted from the Australian Renewable Energy Agency's report Commercial Readiness Index for Renewable Energy Sectors)

Investors will support a new technology where they believe that there will be a return on investment. The investment sector uses the terms bankability or *'investability'* to demonstrate willingness to finance a technology after considering risks and returns. Investors need to understand how a new technology is likely to perform in both engineering and financial terms. Investors have differing expectations of risk-taking and of the magnitude and timing of the financial returns they expect.

Before they back any venture, investors will want some idea of a technology's readiness for investment. One way to demonstrate this is through processes such as the assessment of technology readiness levels (TRLs). Developed by NASA in the 1970s, TRLs offer a nine-level framework for classifying technologies (see figure above). Using frameworks like these, potential funders – including publicly funded technology incubators, grant funding bodies, venture capital or 'angel' investors, or fully commercial equity investors and lenders – can then define their willingness to invest in technologies at different stages of commercial viability.

Through TV programmes such as *Dragon's Den* we have become familiar with scrutinising new business ideas and the claims made for them. When looking at technologies beyond the fundamentals of proof of concept, intellectual property and market demand, investors may call upon support from engineering specialists for more detailed due diligence.

SUPPORTING GREEN INVESTMENT

The government is developing mechanisms to support green investment, with the aim of making the UK an internationally attractive investment hub for net zero technologies and services, as well as a 'net zero aligned' finance centre.

A range of actions address international and national obligations. These include:

- aligning financial institutions with net zero ambitions
- updating national green finance strategy to signal UK leadership
- encouraging private sector investment
- support for emerging markets.

To build confidence in the delivery of auditable and sustainable outcomes, much of the effort is on transparent disclosure and financial reporting to accepted and newly developed standards.

This can include engineering input on:

- fundamentals of engineering design
- configuration of unit processes and their individual and combined performance
- project management aspects
- the environmental and technical suitability of proposed site
- safety
- securing regulatory permits
- technology performance in the early stages of implementation
- the acquisition and analysis of reliability data when technologies are in service.

Investors assess these factors as the basis for a robust evaluation of a 'risk-adjusted return on investment'. Assessments may extend beyond the feasibility of a pilot or near-industrial scale trial, to a full-scale application. Assessments may also involve considering supply chain risks; for example, for bespoke engineering components provided by only one or two suppliers globally; or subassemblies with specific warranties; or the examination of financial models that detail how profits are generated. Then there are maintenance agreements to ensure long-term reliability. Investors may also seek opinions on a company's organisation, its governance, and its commercial and technical abilities. Where investors use other people's money for the investment – say from pension funds or through banks – the investor has a 'fiduciary duty' to act in the best interests of the beneficiary. It must then align the investment to the beneficiaries' appetite for risk. Without due diligence, there could be misalignment between these interests and an investment manager could run the risk of regulatory action.

These factors underline the complexity of financing new technologies that claim to contribute to net zero. Independent technical appraisal has become critical in assessing engineering innovations such as anaerobic digestion technologies (see 'Anaerobic digestion'), biogas, hydrogen, and energy storage. The issue is complicated by the rapid arrival of many new commercial players with competing technology claims. Investors need greater confidence, and, because of an uncertainty in technical success, may look to share risk in earlier investment stages.

Additionally, investors look to reduce how long it takes to pay back debt, or to schedule pay back more frequently as a contingency against suboptimal technology performance. They can also insist on building up reserves to pay for periodic maintenance. There have also been suggestions that the bankability of climate change projects and technologies should align to national policies, investment fund priorities and should secure local community support. The 'hydrogen economy' could face such challenges as it takes off. R&D projects may need initial public investment to demonstrate technical viability and stakeholder confidence before attracting private

ANAEROBIC DIGESTION

A biogas production plant © Gerald Krieseler/Pixabay

Anaerobic digestion (AD) technology produces bioenergy from organic wastes that would have historically gone to landfill or been spread on land. AD uses natural processes within engineered containers where microorganisms convert waste material from plants or animals into useful products in the absence of air.

The biogas produced is typically a mixture of 60% methane and 40% carbon dioxide by volume. Biogas can provide heat, electrical power or a biomethane as a transport fuel. AD first attracted investors because of its potential to offer long-term municipal green waste contracts combined with the possibility of supplying energy to the grid.

The bankability of investment in AD has focused on features such as set-up costs, availability of technical expertise, project management, the feedstock flows to and from waste catchment, the time taken to ramp up to full-scale operation and hence security over revenues, and the engineering performance of the technology in its various forms.

Responsible investment, as a more general term, involves comprehensive and prudent management of ESG considerations to deliver long-term economic returns. It minimises harm to stakeholders and the environment, and transparently discloses environmental and social impacts and outcomes of the investment.

Sustainable investment includes the above and goes further by pursuing specific sustainability goals, actively investing to drive a transition to long-term ESG sustainability.

MILESTONES		Nonbinding indicative offer/exclusivity ↓	Acquisition/debt financial close (FC) ↓	Sale/re-financing FC ↓
Transaction stage	**Origination**	**Structuring**	**Ownership/ debt repayment**	**Divestment/ re-financing**
ESG tools	Project screening Red flag review	Due diligence (DD) Transaction documentation – covenants/conditions precedent/shareholder agreements	Transition planning (such as environmental and social action plan)/conditions afterwards Stewardship/active ownership Regular disclosures and reporting Owner's engineer oversight Board meetings Lender's environmental and sustainability consultant	Vendor/borrower DD Buyer/lender DD Sustainable asset labelling/ certification schemes

Investors and lenders can use various tools to identify and manage ESG issues at various decision points through the investment lifecycle

finance at later stages. Such approaches to due diligence have been applied for decades. However, the changing nature of investment means that investors place increased importance on ESG issues and claims about sustainable development.

Investors will take different approaches, depending on which of the two markets they invest in: public markets (listed stock exchanges, government bonds, or public commodities) or private markets (property, infrastructure, or private equity venture capital). They will most likely consider the countries where the investment happens and the countries' regulations, as well as their own ability to control the companies they invest in, for example by taking >50% controlling equity stakes versus a minority investment or through lending.

Engineering technologies that can drive a low-carbon transition offer specific outcomes for carbon reduction and related goals. While this aligns them to sustainable investment goals, unless sustainable outcomes can be backed up with reliable evidence, unsupported claims, or 'greenwash' could cast doubts on the credibility of the green finance market. Investors need evidence to validate claims of 'sustainability' before a technology is eligible for investment from pools of capital earmarked for green investment.

Green financing for projects that contribute to our net zero ambitions is gathering pace, alongside a developing tapestry of regulations, reporting standards and guidance for investors. As this continues, there will be a growing demand for in-depth technology appraisals. Furthermore, the range and complexity of issues that investors and lenders now have to address on investments in clean tech is increasing as a result of higher expectations from shareholders, pension fund beneficiaries, bank depositors, and other sources of capital. Then there is the development of more demanding regulation and rising expectations from society at large. To meet these demands for technical advice, the finance sector will increasingly draw on engineers and sustainability professionals. In turn, engineers will need to understand the issues that face the world of finance.

GLOSSARY

Asset: in financial terms, anything that holds current or future value for a business; asset classes being, for example, specific classes of clean technologies.

Emerging markets: new market opportunities often characterised by disruptive novelty, fast growth and an uncertainty in returns.

Green finance: a loan or investment, whether from public or private sources, used to support environmentally sustainable activity.

Net zero engineering: engineering approaches to securing a balance between the amount of greenhouse gases produced and the amount removed from the atmosphere.

Risk premium, or default risk premium: often, an extra amount of interest paid to an investor by the borrower as compensation, say, for the uncertainty in technology performance and thereby pay back of the investment.

BIOGRAPHIES

Adrian Barnes joined the UK Green Investment Bank in 2013 from a background in environmental consultancy. A key figure in the UK green finance sector with Macquarie Asset Management's Green Investment Group, Adrian contributes to emerging ISO standards on green finance, and on harmonising greenhouse gas assessments between financial institutions.

Professor Simon Pollard OBE FREng is a Pro-Vice-Chancellor at Cranfield University and an environmental engineer specialising in risk management. He is a frequent commentor on the green economy and a Non-Executive Director of the Institute of Environmental Management and Assessment.

AIMING FOR INCLUSIVE OUTCOMES

Dawn Bonfield MBE FREng has had a diverse career in engineering. After starting her career in composite materials, she's done much to promote the role of women in engineering and is now focusing on the critical skills that future engineers will need to address our most pressing issues around sustainable development. She talked to Michael Kenward OBE about her plans for delivering these skills and the challenge she is about to take on as President of the Commonwealth Engineers Council.

© Photography by Pablo Herrera Pérez. Image courtesy of the British Science Association

When Dawn Bonfield MBE FREng started working as a materials engineer, women faced a glass ceiling that was all but shatterproof. Today, thanks in part to her work, there is a wider recognition throughout the engineering profession that diversity is important. Bonfield has become a driving force in ensuring that engineering organisations pay more than just lip service to the idea of diversity and inclusion. This includes not only ensuring that the profession is representative, but crucially that engineers produce solutions that are accessible, inclusive, free of bias, and have the needs of all people at their heart.

At school, Bonfield was interested in science, especially materials. And unlike many other people her age at the time, she was familiar with the work of engineers, as her father was a design engineer, working for Pilkington, the glassmaker. Thanks to these connections, she gained her first work experience during school holidays working at Pilkington's insulation factory at Cwmbran in South Wales. She then attended pre-degree summer schools in materials science at Cambridge, the University of Manchester Institute of Science and Technology (UMIST), and Bath, which influenced her choice of university course.

Bonfield studied materials science at the University of Bath and made use of the links that the university's materials department had with French car company Citroën, working in the company's labs in Paris where she researched the production of ceramic-coated piston heads to increase the engine's fuel efficiency. After a year in Paris, she returned to work at British Aerospace and the company's Sowerby Research Centre in Bristol where she researched thermoplastic and metal matrix composites for aerospace applications.

Bonfield then moved to British Aerospace's Stevenage site, now MBDA. It was around this time, in the late 1990s, that events, including the birth of three children, brought home the challenges that, at the time, faced women who took time out to bring up a family.

TRANSFERABLE SKILLS

It isn't that long ago, but at the turn of the century, few businesses had successful processes for retaining talented women with valuable engineering experience. But Bonfield wasn't one to sit and do nothing. She qualified as a childminder, becoming an active leader in the National Childbirth Trust (NCT). "It was great for developing different types of skills and different viewpoints," she says. And it gave her invaluable insights when she moved back into engineering. "Women gain a host of transferrable skills when they are taking career breaks and negotiating the challenges of having young children. These skills enhance their careers and should be seen as beneficial for the workplace. So, our challenge is to ensure a way to retain the skills of women so that they can successfully navigate their way back to the workplace, and where we see this as beneficial to their career path, rather than a step backwards as if often the case – if they return at all, that is."

Bonfield used her experience and insights when she went to work for the Women's Engineering Society (WES), which was set up in 1919 "to support women in engineering" ('A century celebrating women engineers', *Ingenia* 79). She became a WES council member in 2011 and was President between 2014 and 2015. While there she founded National Women in Engineering Day to celebrate WES's 95th anniversary in 2014; now International Women in Engineering Day (INWED), it will mark its 10th anniversary in 2024. Bonfield became CEO of WES in 2015 and oversaw the organisation's transition from a volunteer-led to a professionally staffed charity.

MAGNIFICENT WOMEN WITH ELECTRIC DREAMS

Dawn Bonfield's espousal of women in engineering doesn't stop with today's engineers and those training to join them. She also documents the history of women in engineering.

When she joined WES as its first paid CEO since Caroline Haslett, she became intrigued by her predecessor's history as the first director of both WES and the Electrical Association for Women (EAW), which was a spinout from WES that formed in 1924. "From there I became interested in the other fabulous women in engineering whose stories don't get told."

One outlet for Bonfield's interest is her website Magnificent Women in Engineering, "dedicated to the magnificent women in engineering from the past 100 years". This uses the inspiring history of women engineers to encourage the next generation. It also records and celebrates the achievements and hidden histories of these women, for example through the iconic 'blue plaques' to commemorate their lives.

In 2019, Magnificent Women published the Top 100 Historical Women in Engineering List. The first entry in the timeline notes that the University of Cambridge accepted women in 1869 but did not allow them to be awarded degrees until 1948.

A later entry notes that in 1898, Hertha Ayrton becomes first member of what is now the Institution for Engineering and Technology, the first woman to be elected to a professional engineering institution.

Bonfield's current project is called Electric Dreams: A Festival of Womanpower. This marks the centenary of the founding of EAW through a year-long celebration of history, heritage, outreach, and campaigning, in the same way that EAW campaigned for the safe use of electricity in the home to serve the needs of women.

www.magnificentwomen.co.uk

Dawn Bonfield at COP 27, which she attended as a representative of the World Federation of Engineering Organizations. While there, she spoke at two panel sessions on the impact of climate change on women and why engineering solutions needed to know this and how they can take it into account

Bonfield continues her work on the importance of gender in engineering today through her work with the World Federation of Engineering Organizations (WFEO) where she is UK representative and Deputy Chair of the Women in Engineering Committee. She leads a project that looks at how engineering is serving women globally. "Women and men can have very different experiences in different parts of the world, because of their societal or religious roles, cultural norms, and their access to education and independence," Bonfield explains. "As engineers we need to be aware of this, as we are literally building the world around us, and it needs to serve the women and other minoritised groups just as much as it serves the majority."

ENGINEERING FOR EVERYONE

Bonfield's thinking today has evolved beyond the challenges of diversity and inclusion in the profession. She now talks in terms of "inclusive engineering outcomes", which she defines as "the process of ensuring that engineering products and services are accessible and inclusive of all users, and are as free as possible from discrimination and bias, throughout their lifecycle". Bonfield has had the opportunity to pass on her thinking to future generations of engineers as a Royal Academy of Engineering Visiting Professor of Inclusive Engineering at Aston University. "My role at Aston is concerned with creating future engineers who understand the need to eliminate bias and discrimination in engineering products and services, ensuring that solutions are appropriate, ethical, accessible, sustainable, responsible, and work to ensure that nobody is left behind. This will be crucial as we address the challenges of sustainable development and climate change and ensure that our future solutions hear the voices, and use the talents, of everybody."

Bonfield gives a concrete example of diversity in action, drawn from her attendance at COP – the UN's climate change conferences. "When you go to COP and listen to women and indigenous people talking about how their lives are affected by climate change, it is really clear that we have not taken their needs and considerations into account in the past, and how crucial it is to do this effectively when creating our engineering solutions of the future."

Bonfield's work at Aston now includes teaching on a professional engineering MSc and degree apprenticeship. An online course for professionals who are already working

as engineers and want to become professionally registered, it encompasses all the areas of professional development that underpin inclusive engineering, such as ethics, sustainability, and global responsibility. As a part of the course, engineers have to draw on their own experiences for examples of where critical thinking has been an important component, where ethics has come into their work, and their role as leaders to ensure sustainable development.

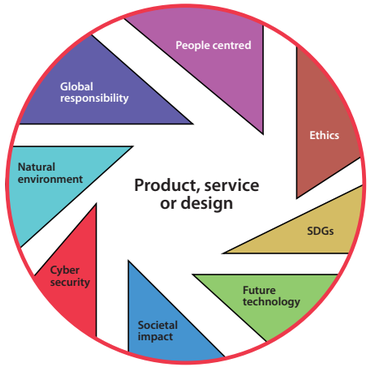
Bonfield's work also encompasses the wider field of education. She has been involved in the development of the new engineering design and development T level, which is in its first year of delivery. "These new qualifications are important in creating diverse pathways into the engineering profession for all young people, and we really do need vocational skills as well as people with engineering degrees" Her view is that the education system should enable multiple pathways so all students have access to engineering careers and thinks that a single-science A level exam could be a winner. "Put the best bits of every science subject into that A level, including sustainability and climate change, and it could be the one A level that almost everybody wants to take."

THINKING INCLUSIVELY

Bonfield can reel off a long list of examples where engineers need to think about inclusivity in their work. One particularly newsworthy area is artificial intelligence (AI). The role of AI in driving what we see online is infamous. She points to how large language learning models can exacerbate bias and stereotype, through the use of "historical datasets that do not reflect the world as we see it today. These systems are notoriously difficult to change. Another area where we need to think about inclusivity is in the choices we make in selecting engineering materials. Historically we have made these choices based on the physical properties of materials, and often don't appreciate the working conditions of the people who have produced them, or the potential impact of their disposal on certain communities. Visibility of the unintended consequences of our engineering choices for people and our planet is all part of inclusive engineering thinking."

Bonfield adds: "These inequalities are much harder to see, and this is where we need more sophisticated frameworks to understand the risks". One seemingly simple tool that Bonfield deploys is an Inclusive Engineering Framework, a diagram that allows engineers to make "systems decisions". Beyond her teaching at Aston, Bonfield deploys this concept in her consulting business, Towards Vision.

Inclusive engineering framework



PROMOTING PROFESSIONALISM

Another part of Bonfield's work in education is in her role as Royal Society Entrepreneur in Residence at King's College London. For her, there is more to entrepreneurship than the usual image of creators of new businesses. "The whole conversation within engineering education has come of age because entrepreneurship and engineering skills are so closely aligned." Engineers may not see themselves as entrepreneurs, but companies want people to have that entrepreneurial mindset. "It goes alongside the move towards systems thinking and systems engineering, being able to see complex problems from a range of perspectives. It all points in the same direction."

Underlying the institution's approach to engineering education, she says, is that "engineering is a profession, not just a subject. We're trying to create engineering students who think like engineers; who understand the scope and importance of their work in developing a net zero future that is equitable and inclusive to all; and who have the confidence and competence to lead the changes required."

Supporting the development of professionalism is also in Bonfield's sights in another role that she is about to take on: President of the Commonwealth Engineers Council (CEC). Established in 1947, this network of engineering institutions is somewhere for engineers to share knowledge and solutions. She sees her time at the CEC as "a fantastic opportunity to work more closely with our Commonwealth partners bringing real collaboration, visibility of problems, and potential partnerships to reality". Some Commonwealth countries lack the professional institutions needed to support their own engineers. One aim is to work together with engineers and professionals in these countries to find ways of addressing what are increasingly global problems. "Some of them identify influencing government as one of the most important things that they could do as engineers." Topics such as climate change and sustainable development really need informed input. Ten of the 20 most vulnerable countries to climate change in the world are Commonwealth members, she explains. "We have direct access and opportunity to supporting one another with engineering solutions to climate change."

For all the challenges facing the engineering profession, Bonfield is positive about the future. "You hear people talk about diversity and inclusion all the time in every sector, which was absolutely not the case five or ten years ago. Culture has changed. Inclusion, and inclusive thinking, is now mainstream thinking, and this will stand us in good stead for the important work ahead."

BRIDGES TO THE PAST


© Shutterstock

Dawn Bonfield doesn't hesitate when asked about her favourite bit of engineering. "Bridges" she says. That explains the collection of postcards of historic bridges around the UK on the wall of her office in King's College London, which is a five-minute walk from Waterloo Bridge, a particular favourite.

It isn't just the local bridge's engineering that appeals to Bonfield: its construction was a key moment for the history of women in engineering. Designed by Sir Giles Gilbert Scott, it was built during the Second World War by many women engineers, "and for that reason it is sometimes referred to as The Ladies' Bridge".

Bonfield is working on another project that also taps into the history of Waterloo Bridge, which has four empty plinths at the ends. The original idea was to commission sculptures for the plinths but the plan never got beyond the draft stage.

One proposal came from artist and sculptor Barbara Hepworth. Bonfield now hopes to use Hepworth's scale models as templates for schools to 3D print their own artworks.

QUICK Q&A

What are you most proud of?
Two things: the way that inclusive engineering outcomes are now becoming mainstream concepts in engineering, and secondly the success of International Women in Engineering Day.

What's your advice to budding engineers?
If you don't already see yourself represented in engineering, then that's exactly why you are needed. We need more people to bring their unique experiences to the profession because we are building the future world in which we'll live.

Best part of the job now?
The variety. No two days are the same. I love the breadth of my engineering involvement and the interesting areas and organisations I work in.

Do you have a favourite tool/tech gadget?
I like Amy Johnson's (abridged) thoughts: "In engineering there are many jobs beyond a man's strength. At first, if a job was beyond my strength I would fetch a man engineer, and if he couldn't do it he'd fetch a tool. I soon learned that it saved time to fetch the tool right away."

Which engineering achievement couldn't you do without?
The wheel.

Overlooked engineering successes?
Engineering skills are key to addressing climate change and the Sustainable Development Goals. We often fail to mention this when explaining the profession to young people. If we were better at articulating this, I think we would see more people wanting to join the profession.

Who influenced your engineering career?
The person who influences me, supports me, and endlessly encourages me is my amazing husband, Peter Bonfield – another materials science graduate, who I met at the University of Bath, and who has been my husband for 30 years.

CAREER TIMELINE AND DISTINCTIONS

Studied materials science at the University of Bath, **1983–1987**. Materials researcher, Peugeot Citroën, Paris, **1987–1988**. Materials engineer, BAE Systems, **1988–1993**. Materials engineer, MBDA, **1993–1998**. Conference producer, Institute of Materials, Minerals and Mining, **2004–2011**. Leader, **2011–2014**; President, **2014–2015**; CEO, Women's Engineering Society, **2015–2016**. Appointed a Member of the Order of the British Empire, **2016**. Visiting Professor of inclusive engineering, Aston University, **2017–present**. Director, Towards Vision, **2017–present**. Royal Society Entrepreneur in Residence, **2021–present**. Fellow, Royal Academy of Engineering, **2022**.

INNOVATION WATCH

MAKING PROSTHETICS WITHOUT COMPROMISE

Prosthetics for upper limb differences often involve a choice between something user-friendly and affordable, or aesthetically pleasing. University of Strathclyde-based startup Metacarpal is trying to bring all three elements together with a new body-powered prosthetic hand.

Fergal with Metacarpal's 3D-printed prototype © Becky Duncan

More often than not, the upper limb prosthetics that appear on the news are straight out of *Iron Man*: complex, powerful and loaded with hardware. Yet despite the impressive technological advances in the field, some studies suggest that less than half of people with upper limb differences use prosthetics at all.

You might think it's the prohibitive expense. Many high-tech myoelectric devices, able to sense the muscles' electrical impulses, cost upwards of £30,000. At least, that's what Fergal Mackie, CEO of University of Strathclyde-based startup Metacarpal, assumed at first.

Speaking to experts at the university's prosthetics department, Fergal and his co-founder discovered that people were indeed trying to make such devices cheaper and therefore more accessible. But they realised that wasn't the only issue with these devices.

IMPERFECT SOLUTIONS

"The problems are really centred around the way they're controlled," says Fergal, explaining that the myoelectric arms tend to struggle with fine motor functions – for instance, picking up very small objects.

Being stacked with batteries and motors also makes them weighty devices. Many people, including children and a lot of women, find them too heavy to wear all day, every day.

Enter the split hook. Invented in 1912, the split hook is one of the most popular upper limb prosthetics. It consists of two hooks that can open and close thanks to a mechanism controlled by the user's shoulder.

The mechanism is much like a bike's brake. Pulling the brake lever pulls the cable, closing the brake pads on the wheel. On the split hook, a cable coming out of the hook goes around the user's back to a shoulder harness on the opposite shoulder. Pulling this closes the hook's grip.

"The split hook is arguably more functional, and still more popular, than myoelectric hands," says Fergal. "And definitely for harder tasks, you would want the split hook rather than a myoelectric hand."

However, the split hook only provides a pincer-like grip – not so good for things like cooking utensils, "where you need a good, solid grasp". And prosthetics are not just functional objects – they carry a psychological significance as well. "A lot of people [who] are recommended the hook would say, 'no, no, I'm not wearing that thing'," Fergal says.

Researchers have redesigned the split hook, including making hand models to cover it. But according to Metacarpal, no one has created a body-powered prosthetic with the aesthetic features of the myoelectric hands. "That's one of the things that bionic hands have done really well," says Fergal, referring to how some prosthetics users like the way bionic hands proudly exclaim their artificial nature.

EVOLVING THE SPLIT HOOK

So, the co-founders of Metacarpal set out to make a more accessible and functional upper limb prosthetic, which also had some of the aesthetic appeal of the more technologically sophisticated devices.

The initial design was centred on the intuitive body-powered mechanism of the split hook – but replacing the hook with a new terminal device, capable of different grips.

Metacarpal is perfecting its design bit by bit. "The first thing we looked at was the fingers, then the wrist, then the bits that go inside the palm to make it work. So now, you're creating this whole palm to bring those together – and the thumb was a separate piece of its own as well," says Fergal.

To demonstrate the function and value of the idea, the founders created a prototype using their own 3D printer. They sought out feedback from their target audience to inform its development. "There's a really helpful guy in Glasgow called Rico. He'd do stuff around his house that you would do every day – washing dishes, making a coffee, things like that – to test the device and see where it's helpful and where it's not," says Fergal.

Beyond the prototype, they knew that it would need a combination of different materials and parts to get it working as functionally and as efficiently as they wanted. Now, with a workshop and access to more sophisticated tools, the team is exploring sheet cut metal, laser cutting, photoetching, and punching, for the bulk of the hand, and intend to use industrial-grade 3D printing for the parts that resemble the shape of the hand.

"We're trying to make it as strong as possible. You can imagine [when] you can't feel the device, it's going to take a bit more wear than your natural fingers," says Fergal. "There's one major complaint that we always hear about the myoelectric hands and that's that they just break all the time."

And without all the batteries and motors needed for a myoelectric hand, the team has a lot more weight to play with before the prosthetic starts to become too heavy.

However, creating different grips with the same body-powered mechanism as the hook is no mean feat. "You've got five fingers, but they're all pulled from one cable," Fergal explains. Upon meeting an object, such as a ball, all the fingers would stop at the same time. "But if I was to grab a ball, all my fingers would adapt around the ball."

To address this, Metacarpal is testing a differential mechanism – meaning all the fingers can be pulled from one input, but their ultimate position can vary. But even testing out ideas is tough. "It's pretty difficult to insert them into the model without just designing the hand around the system," Fergal says. He's confident in their ideas for mechanisms but says they will need to develop their testing rig so that it can measurably simulate how it might interact with objects.

PROSTHETICS WITHOUT COMPROMISE

Now, the team is fundraising for a seed round closing in December 2023, and hope this will get the product to market. "We just want it to be the most functional prosthetic hand available, that doesn't compromise the way it looks," says Fergal.

And after that? "I think it's all things in body-driven prosthetics. That isn't to say that we might not incorporate electronics, but the control of them is always going to be driven by the user's body. The harness is the first way we can do that, but we're going to do a lot of research into other methods. And I think that's something that we could really improve."

EYES ON THE INNOVATORS

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

Animal-free: cellular agriculture startup **Multus Media** is a partner in a new £24 million initiative to cut carbon in food production

Riverlane has raised £15 million in Series B funding, to develop a self-correcting operating system for quantum computers, which are prone to errors

Fighting antibiotics resistance: **MetalloBio** were named the overall winners at the North East, Yorkshire and the Humber StartUp Awards 2023!

Supporting athletes: injury rehabilitators **Movetru** were featured as one of Innovate UK's Women in Innovation Success Stories

It's field trials time for flood preventors **Manhole Metrics**: the team is working with Yorkshire Water to provide proactive responses to flooding

HOW DOES THAT WORK?

AEROSOLS

From your deodorant spray to your breath, airborne pollen, exhaust fumes, and volcanic ash, aerosols are everywhere. These nano- and micro-scale particles can be liquid or solid, and are suspended in a gas (normally air). Putting environmental aerosols aside, this article will explore the kind sprayable from a can.

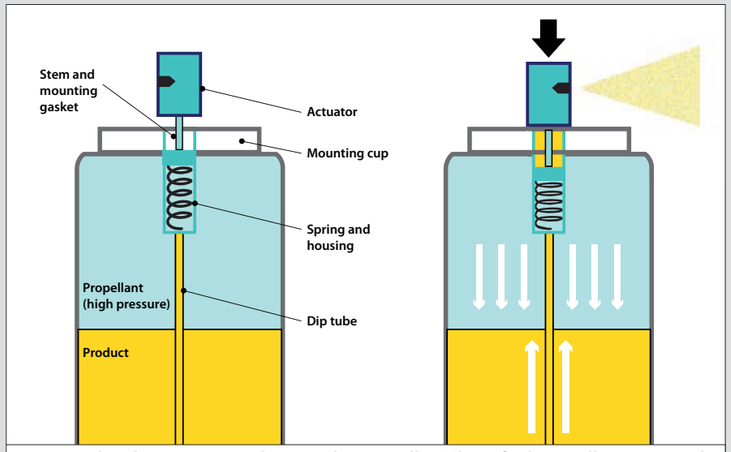
The Norwegian engineer Erik Rotheim was the first to patent an aerosol in a spray can in the late 1920s. However, it wasn't until the Second World War that they rose to widespread use. US scientists developed a disposable canister that could apply controlled doses of an insecticide (DDT) for soldiers in the Pacific to fend off mosquitoes carrying malaria. (Unfortunately, DDT was later found to have harmful effects on wildlife and people – and wouldn't be the last aerosol-related chemical to do so.)

So how does such a can turn a liquid into aerosol particles? The same principles applied in the 1941 patent govern today's aerosol cans. Essentially, the can contains two different fluids: a pressurised fluid (the propellant) and the product (such as deodorant or spray paint). While a valve to the outside is closed, the propellant pushes upwards on a gasket and keeps the can hermetically sealed.

The valve is topped by an actuator – a button you can press when you're ready to spray the aerosol. This actuator joins onto a tube that extends to the bottom of the can, like a straw in a drink. A spring connects the two, pushing upwards to keep the valve closed when the actuator is not being pressed.

Pressing down on the actuator pushes against the spring and opens the valve. This creates a large difference in pressure between the high-pressure interior of the can and the low-pressure external environment.

What happens next depends on the type of propellant in the can. For compressed gases, the drop in pressure causes the propellant to expand, forcing product into the dip tube.



An aerosol with a compressed gas as the propellant (liquefied propellants mix with the product rather than being separated into two phases, as shown) © Adapted from Christian Cavallo, LLC

For liquefied propellants, it's slightly more complicated. First, the drop in pressure causes some of the propellant to evaporate into a layer of gas at the top of the can. This then pushes the liquid product (along with some of the remaining liquid propellant) into the dip tube. At the top of the dip tube, a narrow inlet funnels the liquid to the atomiser's tiny hole, where it is ejected as a fine spray.

The way that the valve and nozzle are designed is hugely important. Some valves are more suitable for liquids (such as hairspray), some are better for powders (such as dry shampoo). Some are better for cans that are normally turned upside down to use, such as whipped cream. Meanwhile, the nozzle design determines spray shape, size of aerosol particles, and more. Creating a flat, fan-shaped plume is simple, and just requires a V-shaped notch to guide the aerosol particles as they exit the hole. Meanwhile, a helix structure protruding from the hole produces a cone-shaped plume.

While the resource and energy requirements of manufacturing aluminium aerosol cans have a significant environmental impact, aerosols are at the centre of one environmental success story.

Originally, gases called chlorofluorocarbons (CFCs) were used as propellants, but scientists realised in the 1980s that they were degrading the ozone layer. Production of CFCs begun to halt from the 1990s, and now, 99% of them have been phased out. Today, liquefied gases such as butane, propane or isobutane (often, a mixture of all three) are commonly found in aerosol cans instead.

Thanks to this unified global effort, UN scientists predict that the thinning of the ozone layer will be healed by 2050 (which equates to avoiding an extra 0.5–1°C of warming).


CREATE
NEW
WORLDS
THIS IS
ENGI
NEER
ING
MEET FELICIA. VR VISIONARY. AS A CHILD, SHE LOVED GAMING CONSOLES AND COMIC BOOKS. NOW, SHE WORKS FOR FACEBOOK, USING CUTTING-EDGE VIRTUAL REALITY AND AUGMENTED REALITY TECHNOLOGY TO CREATE NEW WAYS FOR PEOPLE TO CONNECT.
SEARCH 'THIS IS ENGINEERING'