ingenia

JUNE 2018 ISSUE 75

LANDMINE DETECTION
DISCOVERING GRAPHENE
INNOVATIVE PLASTIC RECYCLING
3D-PRINTED DENTAL IMPLANTS

ROYAL ACADEMY OF ENGINEERING

ROYAL ACADEMY OF **ENGINEERING**

Sponsors

The Royal Academy of Engineering acknowledges the generous support of the following organisations for *Ingenia*:
- Arup
- BAE Systems

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: editor@ingenia.org.uk

Registered charity no. 293074

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 Managing Editor, the Editor-in-Chief or to any member of the Editorial Board.

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

Design
The Design Unit www.thedesignunit.com

Print
Manor Printing Services www.manorprinting.co.uk

Ingenia magazine is recyclable. The cover is treated with a recyclable laminate, the inks are vegetable oil based and the paper produced under Forest Stewardship Council guidelines.

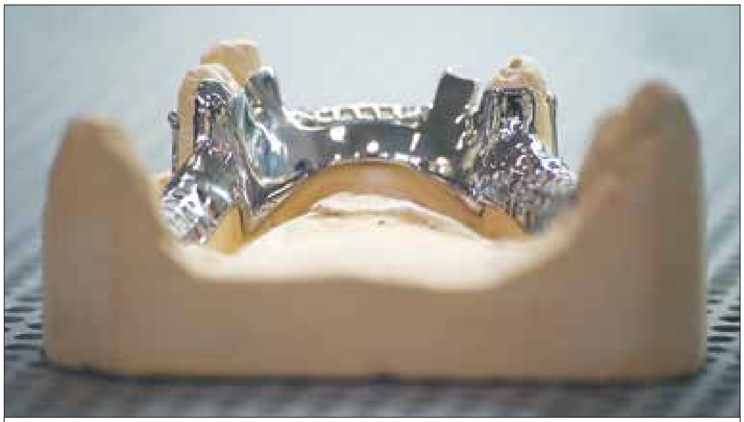
Advertising and sponsorship
Gemma Hummerston
Tel: 020 7766 0679 Email: gemma.hummerston@raeng.org.uk

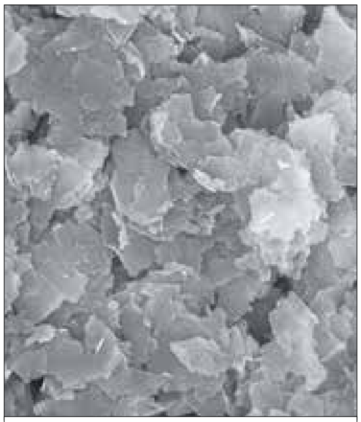
Subscriptions
To cancel your subscription or update your personal information details, please contact the *Ingenia* team by sending an email to ingenia@raeng.org.uk

Front cover
3D-printed dental implants. Image courtesy of Renishaw

ISSN 1472-9768

Royal Academy of Engineering promotes excellence in the science, art and practice of engineering.





CONTENTS

@RAEngNews #IngeniaMag

This QR code links to www.ingenia.org.uk containing a searchable archive of all *Ingenia* articles

THIS IS ENGINEERING
FASHION SPACE BIG STUFF ENTERTAINMENT SPORT
FOLLOW WHAT YOU LOVE INTO ENGINEERING
THISISENGINEERING.ORG.UK
THIS IS ENGINEERING

EDITORIAL

CULTURE CHANGE IN BUILDING SAFETY

Dr Scott Steedman

In time, we will see the tragedy of the Grenfell Tower fire as just as significant a turning point for the construction sector as the Piper Alpha disaster was for the offshore industry 30 years ago. Back then, the Cullen Inquiry triggered widespread changes in operating practices and regulations, notably through the introduction of the 1992 Offshore Installations (Safety Case) Regulations. This required owners and operators of rigs and other installations to submit a safety case that gave full details of how they would manage health and safety on offshore installations.

Published on 17 May, *Building a Safer Future: Independent Review of Building Regulations and Fire Safety* by Dame Judith Hackitt DBE FREng has similarly recommended an enhanced regulatory framework, especially for high-risk or high-rise mixed-use buildings. As part of this new framework, the report recommends that a new regulatory body should oversee the safety of people for the entire life-cycle of a building, throughout design, construction and operation. This radical proposal will prompt a rethink by government and the construction industry of the often complex web of responsibilities for safety in building construction and use.

Two further recommendations in the Hackitt Review will be essential for this proposal to be implemented effectively. Firstly, any new system of through-life safety management will require the industry to embrace digital record-keeping throughout, from the building products to construction, through handover to operation and maintenance. This will be costly to implement but will bring long-term benefits through improved safety and operational efficiency. With notable exceptions, the sector has been slow to adopt common standards for creating and managing information throughout the life-cycle of a construction project. This process is key to giving owners and operators the information they need to manage their buildings.

Secondly, the Hackitt Review highlights the question of how engineers demonstrate and maintain professional competence. No system of life-safety management can function without a robust, comprehensive and coherent qualification framework that covers all the disciplines that work on such buildings. In future, regulation may require the use of suitable, qualified professionals who can demonstrate that their skills are up to date. The roster of professions could be long, and is likely to include as a minimum not only the fire engineers and engineers designing, installing and maintaining fire safety systems and other safety-critical systems, but also fire risk assessors, fire safety enforcing officers and building control inspectors.

The question then is how to balance the role of regulation with the role of industry. Dame Judith's advice is that there has to be cultural change across the sector. Her central recommendation is that the regulatory regime for high-rise buildings urgently requires overhauling. This must deliver clarity over what is required under the law (and is the responsibility of government to police) and what is guidance for engineers.

The challenge is how to stimulate everyone involved in building and managing high-risk buildings 'to do the right thing' and to realise that the responsibility for safety rests with them and them alone. Regulation can provide only the most basic of safety nets. In the end, industry has to aspire to deliver higher quality outputs.

James Brokenshire MP, Secretary of State for Housing, Communities and Local Government, is in no doubt. As he said on 17 May after the publication of the Hackitt Review: "Let me be clear: the cladding believed to be on Grenfell Tower was unlawful under existing building regulations."

More regulation is not necessarily the answer, certainly not in the short term. The immediate problem is how to ensure existing regulations and supporting technical statutory guidance are clear and complied with.

Public trust matters. Implementing the recommendations in the Hackitt Review will add to the cost of construction and use of high-risk and high-rise mixed-use buildings, but by bringing clarity to the question of who owns the safety risk throughout the life of the building, it will also help the professionals involved to understand their role and responsibilities.

Dame Judith's review argues that the industry should approach the safety case for such buildings as it does for high-risk industrial facilities. This sounds like common sense, but it is a radical step for a construction industry that is struggling to throw off its traditional image. Reform of the regulatory system is inevitable and long overdue. Now we need to engage the engineering profession behind the culture change that is so clearly needed if safety is to be at the forefront in the construction and management of high-risk buildings.

Dr Scott Steedman CBE FREng
Editor-in-Chief

IN BRIEF

WORLD'S MOST POWERFUL WIND TURBINE

The Pacific Orca, pictured, is thought to be the world's largest wind farm installation vessel. It transported the turbine from Sweden and installed it in Aberdeen Bay © TVP Film and Multimedia Ltd

In April, the world's most powerful single wind turbine was installed in Scottish waters.

It is the first of 11 that Swedish power company Vattenfall has deployed at its new European Offshore Wind Deployment Centre (EOWDC) in Aberdeen Bay. The facility can now produce the equivalent of more than 70% of Aberdeen's domestic electricity demand and annually displace 134,128 tonnes of CO_2.

It is also one of two turbines that has extra internal power modes to generate more clean energy. The two turbines have each increased from 8.4 MW (megawatts) to 8.8 MW; it is the first time the offshore wind industry has used an 8.8 MW model commercially.

The new turbines are 191 metres high, with blades that are 80 metres long. The 164-metre rotor has a circumference larger than the London Eye. It is estimated that just one rotation of the blades can power the average UK home for a day.

Gunnar Groebler, Vattenfall's Head of Business Area Wind, said: "The turbines for the EOWDC, Scotland's largest offshore wind test and demonstration facility, help secure Vattenfall's vision to be fossil fuel free within one generation. The EOWDC … leads the industry drive towards generating clean and competitive wind energy power – one that will reinforce Scotland's global energy status."

FUNDING TO ADVANCE EMERGING TECHNOLOGIES ANNOUNCED

The Royal Academy of Engineering is providing long-term support to 10 engineering global visionaries to develop areas of emerging technology. The Chairs in Emerging Technologies will focus on developing technologies that have the potential to bring significant economic and societal benefits to the UK.

Supported by the UK government's National Productivity Investment Fund, the chairs will each receive £1.3 million of funding over the 10-year programme. The projects include the development of bioelectronic therapies for damaged central nervous systems, the rapid advancement of new battery technologies, and improved safety in robotics and artificial intelligence. The areas of emerging technology covered reflect the UK's wider technology goals, based on government-identified priority areas of innovation for the UK, such as healthcare, robotics, clean energy, driverless vehicles, materials of the future, and space technologies.

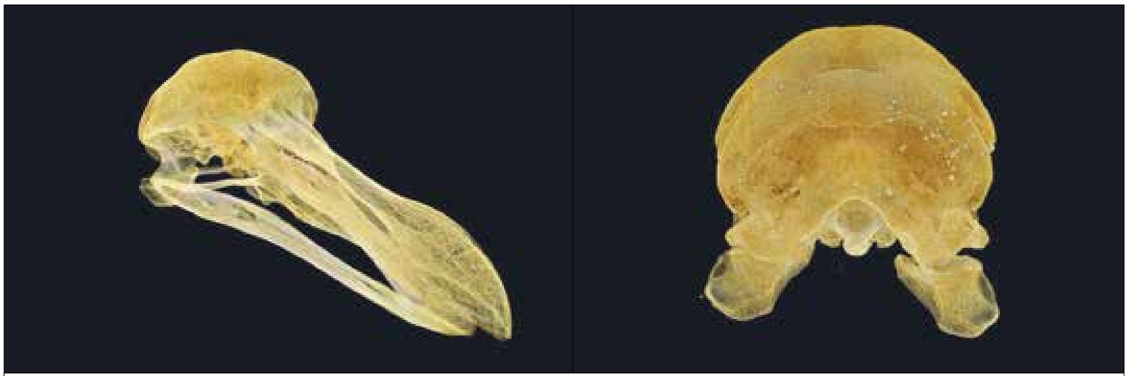
Academy President Professor Dame Ann Dowling OM DBE FREng FRS said: "Emerging technologies offer enormous opportunities for the UK, both economically and socially, but often their potential is not widely recognised until it is championed by a visionary individual … The UK has a rich history of championing disruptive technologies – from the development of the steam engine to the invention of optical-fibre communications. Early-stage technologies offer enormous potential for the UK to continue this legacy and it's vital that we invest in both the technology, and the people behind it, to remain competitive in the global marketplace."

To find out more about the chairs and their research, please visit **www.raeng.org.uk/emerging-technologies**

NEW DISCOVERIES ABOUT DODO'S DEATH

Forensic engineering has revealed that the famous Oxford dodo, housed at the Oxford University Museum of Natural History, died after being shot in the back of the head. It was thought that the dodo, the world's best-preserved specimen of the bird, had died of natural causes after a life in London as a curiosity.

The dodo's remains were transferred to the Warwick Manufacturing Group (WMG) laboratory at the University of Warwick. The WMG team used forensic CT scanning to create a three-dimensional replica of the dodo's skull and discovered mysterious particles. Further analysis showed that these were lead shot pellets, which hunters typically used to shoot wildfowl during the 17th century. The research showed that the dodo was shot in the back of the head and neck.



The CT scan of the dodo's skull shows the shot pellets in white © WMG, University of Warwick

Professor Mark Williams, leader of the Product Evaluation Technologies and Metrology Research Group at WMG, said: "When we were first asked to scan the dodo, we were hoping to study its anatomy and shed some new light on how it existed. Although the results were initially shocking, it was exciting to be able to reveal such an important part of the story in the life of the world's most famous extinct bird."

The bird's skull and foot have been held at the museum for more than 300 years. It is the only soft-tissue specimen of the species in the world and has been essential to discoveries about the bird. It also inspired Lewis Carroll when he wrote *Alice's Adventures in Wonderland*.

PUBLIC ENGAGEMENT WITH ENGINEERING

Participants at a 2017 *Ingenious* project in Thanet, Kent, that helped the local community to learn about the offshore wind farm near their homes © Discovery Planet

The Royal Academy of Engineering has announced 20 projects that have been awarded funding under its *Ingenious* public engagement programme, including hands-on workshops, student radio shows, and science communication training.

The latest round of projects are set to take place across the UK and will provide new opportunities for members of the public to meet engineers and learn about the exciting, creative work that they undertake. The programme offers grants of up to £30,000 and this year, the panel was particularly interested in projects that focused on engaging underserved communities in the most deprived areas across the UK.

Panel chair Professor Mark Miodownik MBE FREng said: "The government has designated 2018 the Year of Engineering and our funded projects this year will contribute to this celebration of engineering … With an annual demand of around 124,000 engineering graduates every year, the profession desperately needs to engage with diverse communities to bring in new talent."

Projects include TechTown Makerspace at Barnsley Library, an interactive making space equipped with 3D printers, robotics and coding areas, and Mars Safari in Kent, which will see 800 Girl Guides work with engineers and STEM ambassadors to build their own Mars Rovers and take them on a safari to explore the surface of Mars.

The *Ingenious* awards scheme is supported by the Department for Business, Energy and Industrial Strategy. It has funded more than 200 projects, providing opportunities for over 5,000 engineers to take part in public engagement activities that have reached more than 2.5 million members of the public.

To find out more about the projects, please visit **www.raeng.org.uk/ingenious-2018**

SPACE PARTNERSHIP AIMS TO REACH FAR SIDE OF THE MOON

Two UK space companies have partnered with a US organisation to develop innovations that will support operations on and around the Moon.

Surrey Satellite Technology Ltd (SSTL), Goonhilly Earth Station (GES) and Astrobotic announced the collaboration at the 34th Space Symposium in Colorado Springs. They aim to deploy in-space communication services to reach the far side of the Moon, which is thought to be a good place for radio transmitters because it is shielded from radio transmissions from Earth.

Lunar logistics company Astrobotic will begin to deliver regular uncrewed payload flights to the Moon in 2020. Many of the companies, governments, universities, and other non-profit organisations operating payloads on the company's Peregrine Lander will need sophisticated communication relay services to reach previously prohibitive destinations on the Moon. SSTL plans to service those needs with data relay services, which GES will receive and transmit back to payload customers on Earth.

At the symposium, SSTL and GES also announced an agreement with the European Space Agency to develop a European lunar telecommunications and navigation infrastructure, including the delivery of payloads and nanosats to lunar orbit. The organisations are aiming to take a low-risk, phased approach to implementing a sustainable, long-term commercial service, which will support lunar scientific and economic development.

The partnerships between the space organisations aim to make space exploration easier © SSTL

JOIN IN WITH THE YEAR OF ENGINEERING

2018. THE YEAR OF ENGINEERING

15 JUNE
WONDER WOMEN IN TECH: DIVERSITY AND INCLUSION IN STEAM INDUSTRIES

Taking place at Here East in east London, Wonder Women in Tech's one-day conference will include guest speakers, breakouts, panel discussions and career development workshops for women in tech and diversity in STEAM (science, technology, engineering, arts and maths).

https://engineerhere.co.uk

21 TO 29 JUNE
UK ROBOTICS WEEK

This week-long celebration returns for its third year to showcase UK technology in robotics and autonomous systems. Open days, lectures, competitions and events for all ages will take place across country.

www.roboticsweek.uk

UK Robotics Week © Here East

23 JUNE
INTERNATIONAL WOMEN IN ENGINEERING DAY

This international awareness campaign aims to raise the profile and celebrate the achievements of women in engineering across the world, and encourage girls and women to pursue careers in the field. Employers, schools, colleges, engineers, and professional engineering institutions are encouraged to hold events, such as student careers visits at engineering workplaces, talks in schools by women engineers or organising networking events. The theme for 2018 is 'raising the bar'.

www.inwed.org.uk

28 JUNE
IMECHE RAILWAY CHALLENGE

The Institution of Mechanical Engineers (IMechE) asks participants to design and manufacture a miniature railway locomotive, which will be tested live at the competition weekend at Stapleford Miniature Railway in Leicestershire. The teams are made up of university students, as well as apprentices and graduates working in industry across the world.

www.imeche.org/events

IMechE Railway Challenge © IMechE

9 TO 14 JULY
EUROPEAN INTERNATIONAL SUBMARINE RACE

This UK-based competition sees teams of university students design, build and power their own submarines at QinetiQ's Ocean Basin ship model test tank in Gosport ('Racing human-powered submarines', *Ingenia* 72). On 7 July, the Institute of Marine Engineering, Science and Technology (IMarEST) is holding an open day and careers fair at Portsmouth Historic Dockyards where members of the public can meet the teams and see the submarines, as well as take part in STEM activities.

www.subrace.eu

International Women in Engineering Day © Here East

European International Submarine Race open day © IMarEST

To discover more events taking place across the country as part of the Year of Engineering, please visit **www.yearofengineering.gov.uk/inspired**

HOW I GOT HERE

Q&A

OLIVIA SWEENEY
CHEMICAL ENGINEER

Olivia graduated from the University of Edinburgh in July 2017

Olivia Sweeney sources aroma chemicals to create fragrances at cosmetics company Lush. She is working on finding new, more sustainable sources of fragrance ingredients, with an interest in the research and development of chemical production from waste streams.

WHY DID YOU FIRST BECOME INTERESTED IN ENGINEERING?

In truth, it was mainly luck. I had varied dreams, from Formula One mechanic to a film orchestra violinist. I've always been concerned about the environment, but my idea of what engineers did was very limited (fixing engines!).

The state of our planet inspired me to become an engineer. I was sick of reading about climate change, landfill build-up and destruction of habitats, and fed up of feeling so small in such a global problem. I wanted to equip myself to make a tangible change, which led me to an engineering degree. The description of chemical engineering resonated with me and, luckily, my A-level subjects allowed me to study it.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I studied AS levels in music and further maths, and A Levels in English literature, chemistry and maths before studying chemical engineering at the University of Edinburgh. I did a few internships during my five-year degree. I spent a month at the National University of Sciences and Technology in Pakistan simulating the effectiveness of membranes for exhaust gas carbon capture. Through a Saltire Scholarship (from the Scottish government and Scottish Higher Education Institutions), I spent three months at Jabil, an electronics company, looking at how its Scottish site could become energy neutral. This included big changes such as installing wind turbines and in-house solutions that included using rain and internal water.

For my Master's research, I spent nine months in Gothenburg conducting joint research between Chalmers University of Technology and Preem, a petrol corporation, where I studied how catalysts impact the composition of biofuel generated from 'tall oil' (a waste product from the paper and pulp industry).

The theme of these placements was sustainability and helping the environment. I knew that was what I wanted to do, but I had not found the most effective or enjoyable way of doing it. Internships are a brilliant way to find out.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

The one that is freshest in my memory is graduating and getting a job in the same week! It is great when all your work pays off. Graduating is something that I have aimed for since starting secondary school, and to have achieved that goal was an exciting, but scary, prospect. Balancing working, studying and all the extras (which for me was music) was near enough impossible, so to achieve the best outcome was equal parts relief and joy!

My biggest non-academic achievement was managing to run the Edinburgh Half Marathon and climb Ben Nevis in three days. It was a close call, but I pulled it off.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

Right now, my favourite thing is saying that I am an engineer. Now that I've graduated I feel that I have earned it!

Apart from that, I love that no problem phases me. They do initially – even engineers are human – but then I can take a step back, break it down into chunks, and understand how those small parts work. Then I can build them back up again into a functional solution. I'm a chemical engineer so have a certain area of expertise, but you can apply that logic to anything. I really enjoy it when people come to me with a problem at work and I can develop a solution, even if it isn't chemical engineering. The things you learn and discover in the process are worth the fear of being a little out of your depth.

WHAT DOES A TYPICAL DAY AT WORK INVOLVE FOR YOU?

It really depends. A typical day is spent at my computer, working through a combination of emails, spreadsheets and research, with a few meetings thrown in. My research at the moment is focusing on waste streams, both within Lush and collaboratively with external companies, to generate new ingredients.

My overall goal is to keep improving Lush's supply chain in line with our cruelty-free testing and ethical buying policies. I aim to spend a couple of hours a week in our manufacturing facility where our quality control is based. Here, I can talk through any supply, quality or compounding issues and work out short- and long-term solutions. An element of my job also helps the creative team achieve its aims and brings new materials to its attention.

No two days are the same – it is busy, stressful and the autonomy that I have is a little scary for my first proper job, but most importantly, it's exciting.

ARE THERE ANY CUTTING-EDGE TECHNOLOGIES THAT YOU WORK WITH?

On my most exciting days, I am lucky enough to visit companies to learn about new developments in the fragrance industry. I have tried out supercritical CO_2 extraction, as well as microwave-assisted extraction. Last week, I went to Nice to meet a supplier who undertakes extractions for us, such as steam and hydro distillation as well as solvent extraction, and got to see ultrasound extraction. My main area of focus is the industrial production of aroma chemicals via fermentation. Trying to achieve this without animal testing and genetically modified organisms has made it more difficult, but I'm excited about the prospect of using fermentation to generate desired chemicals from waste streams.

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

Just do it! I think that young children have an innate curiosity that lends itself well to engineering; this should be nurtured into adolescence and allowed to flourish. You don't have to be good at maths or interested in cars to be an engineer. If anything, we have enough of those engineers! Take what makes you happy, find out how it works and make it better.

WHAT'S NEXT FOR YOU?

I have a few big projects at work that will make a significant impact on how we source our aroma chemicals, so trying to pull those off is my main focus at the moment. I don't want to be UK-based forever, so planning my career to allow me to move abroad is also on my list.

Apart from that, a friend and I are launching a website for young professional women in STEM. We are still a long way from gender equality and being an active part of the solution is the most positive route to take. We have also discussed launching our own green company later. False green marketing is starting to become a real issue and I am passionate about ensuring that people can truthfully be environmentally conscious, sustainable and maybe even positively impact regeneration.

On a more fun note, I have moved to the coast with work, so I want to make better use of living by the sea and take up a watersport. I cannot decide between paddle boarding, sailing and open-water swimming, so suggestions are welcome while I wait for the sun to warm the English Channel!

To find out more about the fragrances that Olivia works with, visit **www.facebook.com/LushLifeEN/videos/1213173202149323**

QUICK-FIRE FACTS

Age: **24**

Qualifications: **MEng Chemical Engineering (Hons), University of Edinburgh**

Biggest inspiration: **Mae Jemison, chemical engineer, doctor and NASA astronaut**

Most-used technology: **My work phone or my iPad**

Three words that describe you: **Happy determined environmentalist**

OPINION

SHOULD WE TRUST CONNECTED DEVICES?

Domestic applications of the Internet of Things (IoT) can yield myriad benefits, but they also bring risks. Paul Taylor FREng, Partner, Risk Consulting, at KPMG LLP, asks whether these risks should make us question whether we should trust the devices that connect our homes to the internet.

Paul Taylor FREng

The growing market for connected home devices brings with it potential benefits for individuals, society and the economy. Personalised services are emerging that could improve individuals' quality of life, such as those that support assisted living, or help improve energy efficiency or physical security. Smart meters stand to bring benefits both to the energy industry and consumers, as well as the environment. Other benefits for consumers from home devices might include greater convenience, decision-making support and remote control of home services when the individual is not physically present.

The furore around Facebook's mismanagement of personal data brings into the spotlight the commercial and other interests involved in the collection, sharing and processing of personal data, and the associated threats to privacy. As the number of Internet of Things (IoT) devices in people's homes grows, I believe there is potential for aspects of people's lives to be observed to a greater degree. For example, certain devices can collect potentially sensitive audio and video information from microphones or cameras. It is also then possible to infer information about individuals based on when and how a device is being used.

Consumer applications of IoT bring both benefits and risks. Do those risks justify the decision to connect home devices to the internet? What actions should individuals take to mitigate them? As consumers, should we trust these devices? As the reach of the IoT grows, it is vital that home devices are both trusted and dependable for their benefits to be realised.

A recent report by the Royal Academy of Engineering and a consortium of universities – the PETRAS Cybersecurity of the Internet of Things Research Hub – *Internet of Things: realising the potential of a trusted smart world*, raises policy, design and research issues for IoT.

As for social media, many business models for home devices rely on people's willingness to share their personal data. Users may be unaware of, or indifferent to, the default configuration of devices. Consumer devices such as Amazon Echo – a home audio speaker system with a voice-activated virtual assistant called

'Alexa' that can control several smart devices using itself as a home automation system – are set with camera and voice always on. Smart TVs now include voice activation, and are listening to and sharing data. People also trade privacy for services; for example, illegal add-ons to Kodi boxes enable data sharing in return for free access to subscription TV services. Media reports highlight the potential for surveillance with warnings on smart toys and smart toasters. News stories about Alexa's 'creepy laugh', when several of the systems mistakenly operated without users instructing them to, are likely to increase people's perceptions of 'being watched'.

A further report by the Academy, *Cyber safety and resilience: strengthening the digital systems that support the modern economy*, highlights that 'cyber safety' – the ability of connected devices and systems to protect individuals or property from harm during a cyberattack or accidental event – is a key challenge. The ability for an individual to operate a smart device remotely has safety implications if they cannot directly observe what that device is doing; for example, if they are operating an electric heater or oven remotely. A hacker's ability to control a device remotely could also have ramifications, for example if the hacker is able to disable a security alarm or unlock the front door.

Many consumer products are coming to market with little or no attention to the security of the devices, the data they gather, use and transmit, and the privacy and safety risks if security is compromised. For example, a hacker may be able to communicate with a child via a smart toy, or to observe when a home is occupied. Away from the home, the impact of a security breach is not limited to the IoT device and the information it holds alone, but affects the security and resilience of connected infrastructure globally. This was exemplified by the large-scale attack in 2016 launched using the 'Mirai botnet' – a computer virus that targets online consumer devices – that resulted in several high-profile websites, including Twitter, Netflix and Airbnb, being made inaccessible.

The government's report on the security of consumer IoT, *Secure by Design*, recognises that, while clear information for consumers is important, it should not be left to them to securely configure their devices: manufacturers must build strong security into their products by design. A vital role for manufacturers is to ensure that software updates are available throughout the lifetime of a product and are rapidly distributed to consumers when security vulnerabilities are discovered. More broadly, I believe that engineers have a responsibility to consider safety and security in all their work, including IoT. It remains to be seen to what extent manufacturers will adopt the voluntary code of practice put forward by government. In the meantime, advice for consumers on how to protect themselves is emerging. The Information Commissioner's Office has published tips on buying smart toys that include turning off the ability to remotely view footage from web cameras and changing default passwords on devices and routers.

There are both legal and ethical issues around how personal data is used and shared by the companies that collect it. The question of how the EU General Data Protection Regulation, which came into force at the end of May 2018, will work in the world of IoT is still unclear. Practical approaches to privacy and trust require significant technical effort, but are beginning to emerge. Personal data stores allow consumers to control how they share data with organisations, with potential benefits to both. Well-designed human–device interfaces help to mitigate risks. Technologies that allow consumers to protect their privacy, such as allowing them to decide the information they are willing to share with third parties and what third parties can use that information for, are under development but have not yet reached the market.

The advice from consumer groups is clear: 'If you don't trust it, don't buy it'. Suppliers of home devices urgently need to change their practices, but until they do so, it seems that consumers will need to continue to take an active role in protecting their privacy and security if they do decide to connect their home devices.

BIOGRAPHY

Paul Taylor FREng is Partner, Risk Consulting, at KPMG LLP. He has led the delivery of some of the most demanding national security programmes in the UK. He is a member of several government technical advisory committees.

A copy of the Academy reports mentioned can be found at: *Internet of Things: realising the potential of a trusted smart world* **www.raeng.org.uk/internetofthings**
Cyber safety and resilience: strengthening the digital systems that support the modern economy **www.raeng.org.uk/cybersafety**

3D PRINTING WITH A BITE

Multiple metal dental products on a build plate immediately after manufacture. The many 'legs' underneath provide support and help to dissipate heat during manufacture, and also support identification tags, all easily removable © Renishaw

Dentistry is a new frontier for the application of additive manufacturing – or 3D printing. The technology is able to produce components with complex three-dimensional geometry, such as those evident in dental frameworks. Engineer and freelance writer Hugh Ferguson investigates how it was introduced in the traditional, artisan-based industry of dental laboratories.

In the early days of additive manufacturing (AM), dentistry seemed a natural application. The three classes of materials most commonly used in dental appliances – ceramics, metals and plastics – coincide with those most commonly used in AM. This technique is also well-suited to creating bespoke products with complex geometry to high levels of accuracy. However, despite the initial enthusiasm, there was very little uptake.

The reasons lie in the network of dental laboratories that support dentists and their patients, by producing the crowns, copings, bridges, plates and dentures that dentists prescribe. Often small and employing skilled metal workers and ceramists, these laboratories have developed an understanding of the materials and techniques that meet the exacting standards required for dental products, embracing strength, accuracy, feel, appearance and affordability. Dentistry has a reputation for conservatism, an understandable reluctance to adopt new materials or techniques unless and until the benefits are proven.

So, engineers worked with the laboratories, not to supplant their existing methods, but to understand how their traditional techniques worked, and where and how AM could best be introduced to improve them.

COMPUTER-DESIGNED DENTURES

As recently as the mid-2000s, the principal materials in a dental lab were gypsum plaster, carving wax and casting alloys. A flexible, negative mould (impression) of the patient's upper or lower teeth would arrive from the dentist, and would be used to make a 'positive' plaster-cast model. A craftsman would then use this to create the shape of the required crown or coping in wax, which would then be cast in metal using the 'lost wax' method, a casting technique that may be more than 5,000 years old. Around the mid-2000s, dental labs began introducing CAD (computer-aided design) systems to scan their dental models and design crowns or copings in their own facilities, with a centralised milling factory manufacturing the items.

Metal alloys continued to be used, but often the materials of choice became soft-state aluminium oxide (alumina) or zirconium dioxide (zirconia), subsequently sintered to produce a very hard chewing surface. Both ceramics can deliver an aesthetic, tooth-like appearance.

Over the following years, dental milling machines, ceramics and tooling have all improved and dropped in price, making metal-free aesthetic restorations affordable. However, metal alloys are still the predominant materials, with a compelling blend of affordability, suitable mechanical characteristics and evidence in use.

MATERIAL REPLACEMENTS

How could AM enter this well-established and fast-developing industry? The first issue was problems with CAD systems. Early systems usually used a proprietary format only readable with software developed by the original CAD vendor. This made it difficult to transfer data to the manufacturing systems, which were also not good at replicating non-uniform shapes and surfaces. The second issue was that the CAD files can have imperfections, and AM is particularly intolerant of errors in files. The issue of proprietary data files was solved between 2009 and 2010 as CAD programs became more open and could output a universally readable file format (in this case, STL). They also became more capable of replicating complex three-dimensional geometry. The challenge of providing data suitable for AM was addressed by improved software in all stages of the process, and including an 'auto-healing' feature to detect and correct errors.

Could AM replace the milled ceramics for new teeth? Zirconia, for example, is expensive and cannot easily reproduce the translucence of natural teeth (or of dental porcelain). It can also obscure subsequent decay beneath the crown, and – despite its great strength – can be subject to micro-cracking. However, AM technology is not yet sufficiently advanced for practical application for ceramic teeth. Skilled ceramicists still create the finest aesthetic finishes, painting multiple layers of dental porcelain up to 1.5 to 2 millimetres thick over a metal (or zirconia) base and firing it in an oven to produce an excellent bond. This results in a strong and resilient tooth with a porcelain finish that can exactly match the colour and translucency of the patient's existing teeth.

The focus moved to the metal parts. A crown, for example, may be made in metal, with the underside fitting snugly on the remains of the tooth that the dentist has shaped to form a foundation, and the upper part ready for the ceramist to add the porcelain coating. Larger items include bridges and denture frames. Dental labs were already equipped with CAD, which made the adoption of AM easier. An added driver was the shortage of skilled metal-working technicians and the escalating wages of those remaining: converting some of the metalwork to AM made business sense.

To be suitable for dental work, the material must be resistant to corrosion, acceptable by the human body, comfortable in the mouth and affordable. Its mechanical characteristics include a combination of strength, elongation, elasticity and resistance to fatigue. Casting alloys have gone through a long process of natural selection to come up with the right mix of properties. Cobalt chrome and nickel chrome became the most widely used, and labs had invested heavily in compatible porcelains so an unnecessary change was undesirable. The latter became the alloy of choice for low-cost dental frameworks as it is easy to cast; although nickel sensitivity in a minority

WHAT IS ADDITIVE MANUFACTURING?

Additive manufacturing is the creation of three-dimensional objects from a three-dimensional digital model by successively placing thin layers of material on top of one another. It can create objects of almost any shape using a wide variety of materials, particularly polymers, ceramics and metals.

A designer can create digital models directly on a CAD system, or a three-dimensional image of the prototype is captured using a variety of forms of digital photography or light scanning, or (for example, for a human organ) a CT scan (multiple X-rays) or an MRI scan.

Some early applications borrowed technology from the printing industry, including inkjet printer heads, to build up solids using suitable binder materials – hence the term '3D printing'. A low-cost market developed, using mostly thermoplastics extruded through nozzles, to create objects varying from toys and jewellery to electronics packaging and simple architectural models. Most were small-scale, but larger applications included manufacturing formwork panels in the building industry to create exposed concrete finishes with elaborate geometry.

Meanwhile at the industrial end, development focused on the use of an energy source such as a laser or electron beam to fuse polymeric or metallic powders layer by layer (see 'Additive manufacturing and 3D printing' *Ingenia* 55). Initially, this created 'rapid prototypes' of parts quicker and cheaper than conventional methods. The term 'additive manufacturing' (AM) emphasises the contrast to traditional 'subtractive manufacturing', for example carving a natural material, or milling and drilling a casting.

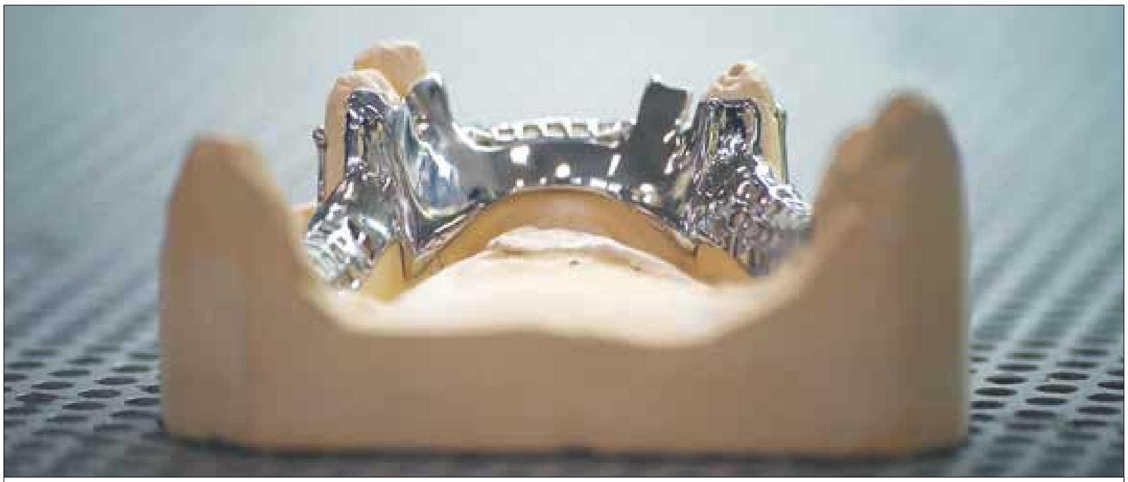
Recent advances in AM include the development of load-bearing lattice structures for orthopaedic implants. By incorporating a lattice, implants can provide a scaffold structure for new bone tissue to grow into, with the spacing and strut thickness of the lattice optimised to match the stiffness of surrounding bone. The lattice, with its 'pseudo-random' internal structure, would be near impossible to manufacture in any other way than AM © Renishaw

Potential advantages include the ability to manufacture on-demand, rather than carry large stocks; to displace expensive machinery and tools such as milling machines; and to make products that would otherwise be too expensive to manufacture.

Some products would be impossible to create by casting or machining. These include products with complex internal channels and pathways, which would otherwise have to be created by assembling multiple parts or intricate lattices and honeycombs that can replicate natural materials, such as bone.

AM can reduce the weight of structures by as much as 40%, which is particularly important in the aerospace and automobile industries where weight reduction is crucial.

However there have also been drawbacks that have slowed AM's introduction, including the high investment cost, early limitations on the conventional CAD software that imposed design and quality drawbacks, constraints on suitable materials, and advances in competing technologies.



Additive manufacturing can capture the complexity of removable partial dentures © Renishaw

of patients has become an issue. Titanium has excellent biocompatibility and is used extensively in the manufacture of dental implants, but dental labs find it very difficult to cast due to its low density and it can be hard to get porcelain to adhere to it.

The metal that best matches the labs' requirements is cobalt chrome (CoCr), using laser powder-bed fusion (LPBF) AM technology. Within an LPBF system, a thin layer of

BONE SUBSTITUTES

Additive manufacturing is also helping with maxillofacial surgery, a specialism of dentistry dealing with the bone and soft tissue around the jaw and face.

A couple of years ago an oral cancer patient at the University Hospital of Wales in Cardiff required surgery to remove the left side of his lower jaw. The surgeon and his team proposed to use bone from the patient's fibula – a bone in the lower leg which carries little load in an adult and is therefore suitable for 'harvesting' for such purposes – to construct a new jaw which could be attached to the remaining healthy bone, and to which new teeth could be added. AM offered a way of maximising accuracy while minimising both risk and time spent in the operating theatre. The team collaborated with Cardiff Metropolitan University's International Centre for Design and Research (PDR) and AM manufacturer Renishaw to deliver the solution.

CT scans produced accurate three-dimensional models of both jaw and fibula. This allowed the team to design the new jaw using two parts of the fibula assembled and attached to remaining bone, with mitred joints to create the shape. AM was used to produce a metal plate to hold the parts together and attach them to the two remaining healthy sections of the jaw.

The next part was a particularly ingenious innovation. After the surgeon had located the best target section of the fibula flap to harvest, a cutting guide was designed to help him remove, with precise control, two sections of bone and vascular connective tissue. The contoured guide, with its complex three-dimensional geometry matched to the CAD model of the bone, fitted the fibula in only one location, removing any possible error. The guide also included holes that precisely located where to drill pilot holes matching the screw holes in the plate, so that the new jaw could be assembled quickly and accurately. Two further cutting-and-drilling guides were produced to precisely fit the ends of the remaining jaw, allowing these too to be accurately cut and drilled. Both the guides and the plate were manufactured using AM, and in both cases the material was titanium.

Removal of the section of fibula, and building and inserting the new jaw were completed in a single operation, with great success. Within weeks the patient was getting married and was delighted with the operation. Some 25 further operations using the same technique have followed.

The AM-produced cutting-and-drilling guide enabling the surgeon to accurately cut and pre-drill sections of fibula for building the new jaw © Renishaw

Two guides enabling the surgeon to cut out the infected middle section of the jaw, and pre-drill holes for the plate connecting to the new jaw © Renishaw

The new jaw, with the two sections of bone from the fibula connected to the remaining jaw either side by an AM-produced titanium plate © Renishaw

AEROGRAFT

Aerograft is a bioactive aerogel sillicate-based material with calcium and phosphate ions. The material is used to improve the stability of implants in several dental and orthopaedic procedures

The Royal Academy of Engineering's Enterprise Hub provides support for budding entrepreneurs in several ways. Its annual Launchpad Competition identifies and supports talented engineering entrepreneurs aged 16 to 25, while its Enterprise Fellowships scheme does the same for the founders and leaders of tomorrow's high-tech companies.

In 2014, Dr Niall Kent, who has a doctorate from dental school, and his colleague Dr Alessia D'Onofrio won the first Launchpad Competition and JC Gammon Award. Their winning innovation is a synthetic bone graft material that can be used to improve the stability of implants in a range of dental and orthopaedics procedures. This provided £15,000 to catalyse growth of their startup company, mentoring from Academy Fellows, and regular meetings with the Award's principal benefactor, investment manager David Gammon HonFREng. Two years later, Niall's co-researcher at UCL, chemical engineer Dr Silo Meoto, received an Enterprise Fellowship to further develop a dental bone graft called Aerograft. These Fellowships provide up to £60,000 in funding plus mentoring, access to the Academy's networks, and training in essential business skills.

The material is a bioactive calcium phosphosilicate, which, in solution, releases calcium and phosphate ions that precipitate to form hydroxylapatite, a mineral found naturally in bones and teeth. It integrates with the existing host bone, encourages natural growth and (in time) naturally disintegrates leaving strong, new bone.

Bone tends to wither unless subject to constant stress, and dental implants need to be embedded on sufficient and strong bone. Bone graft materials are used to regrow bone where insufficient bone is present for an implant fitting. Current bone graft substitutes, such as bovine bone, and synthetic materials, such as ceramic, have limitations. Aerograft offers a higher integration rate (how well the body accepts it) and can also be 'tuned' to produce the different resorption rates (the time taken to be naturally removed by the body).

Aerograft is half way through the extensive (and expensive) tests needed as part of the CE approval process required to sell products in the EU, with encouraging results so far. Negotiations are underway to secure additional funding and partnerships. Meanwhile, a company is being formed with Niall as CEO and Silo as chief technical officer.

CoCr powder is deposited as thin as 20 microns thick, on the machine's build plate and a super-fine laser beam melts an area of the powder corresponding to a 2D slice of the CAD model. The build plate moves down, another layer of powder is added and the process repeats until the component is complete. The unfused powder is then removed and captured for re-use. For efficiency, labs will usually manufacture many items simultaneously, each with its own disposable identity tag.

AM-produced metal parts were originally considered too brittle for larger items such as removable dental frames, which are still used extensively where implants or bridges are either clinically unsuitable or unaffordable. However, the manufacture in an inert, argon atmosphere with less than 0.1% oxygen and a careful post-production heat-treatment process have helped to overcome this process.

The other principle objection is the high initial cost of an AM machine – around £250,000 to £500,000 – which smaller labs can address by collaborating to create the volume to bring cost-per-part down and justify the investment. Quality and accuracy have been found to match established materials and techniques, and in some respects (such as fatigue resistance for dentures) produce substantial improvements.

Furthermore, AM provides better quality assurance and, by reducing faulty products, cuts scrap rates and the need for 're-working'. It also substantially reduces material wastage, can reduce turnaround time for dentists, and can use the time of skilled technicians more efficiently.

MANUFACTURING TEETH

AM is now firmly entrenched in dentistry, working alongside long-established craft-based techniques. This is an example of how beneficial, evolutionary change can be achieved by cross-fertilisation between an established industry and the providers of new technology.

Further adoption of AM is likely to follow. Already 3D-printed plastic models, created with help from a new breed of handheld intraoral scanners operated by dentists, are beginning to replace traditional plaster models. Within five years, AM technology may have advanced sufficiently, and the cost reduced, to allow AM-produced ceramic teeth to replace casting and milling. AM is also making progress in the related fields of maxillofacial surgery and orthopaedic surgery. Its application in printing patient-specific implants, protheses and medical guides could enable surgeons to deliver life-changing procedures that otherwise might not have been possible.

Hugh Ferguson spoke to Ed Littlewood, Marketing Manager of the Medical Dental Product Division, and Alex Harris, Applications Engineer, both from Renishaw, and Dr Silo Meoto from Aerograft to write this article.

MANUFACTURING A DENTAL PROSTHESIS

CREATING THE STUDY MODEL

Dentist

Dentist takes an impression, most commonly in silicone.

Impression posted to dental lab →

Lab

The lab creates a study model by pouring gypsum plaster into the impression. Segmentation of individual teeth helps subsequent activities.

→

A lab scanner digitises the model, often using structured light scanning.

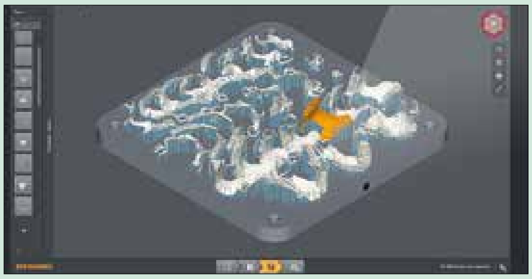
DESIGN AND BUILD PREPARATION

Lab

Digitised data is imported into a dental CAD package where the tooth restoration is designed using the relationships of the adjacent and opposing arrangements of teeth as an aid.

Design data →

Dental manufacturer



The design data is then prepared for build. This is where the build orientation is determined, ID tags and build supports are added to each part and, finally, the parts are nested.

PRODUCTION

Dental manufacturer

The build file is then used to manufacture parts. There could be 200 to 300 parts on one plate.

Framework shipped to lab →

Lab

Finished framework on model.

→

A finished crown with porcelain being applied.

Images courtesy of Renishaw

Humanitarian deminers in Cambodia evaluated a dual-sensor detector, which combines a metal detector and ground-penetrating radar, to search for landmines. The evaluation covered more than 600,000 square metres of land and removed over 5,600 landmines © The HALO Trust

DETECTING LANDMINES FOR A SAFER WORLD

While the use of landmines has reduced over the last 20 years, they are still present in many countries as the result of actions such as civil wars and insurgencies. In times of relative peace, humanitarian demining aims to make the land safe for the returning population. It is a thorough and time-consuming process, and cost-effectiveness is key. Professor Anthony Peyton and David Daniels CBE from the University of Manchester discuss the existing and developing technologies that ensure demining is as efficient as possible.

The indiscriminate use of landmines hit the headlines in 1997, when the media carried photographs of Diana, Princess of Wales, walking through minefields in Angola. Since then, 27 countries have been declared landmine-free, over 51 million stockpiled landmines have been destroyed and the international trade in landmines has ground to a halt. However, more than 60 million people still live with the daily fear of unexploded munitions.

Landmines contaminate some 60 countries, in areas that include jungles, deserts or urban regions. There is no way to know where landmines are: they might be buried or surface-laid, placed by hand or scattered from vehicles or helicopters, in regular or irregular patterns. Furthermore, soil erosion caused by rain can move landmines or cover them. The debris of destroyed buildings in urban environments can also hide devices. Finding landmines is, then, no easy task. Detection equipment needs to work across a wide range of environments, conditions and roles.

Traditionally, humanitarian landmine detectors have used metal detectors that operate at frequencies below 100 kHz. This allows relatively simple and low-cost technology to be used as the basis for detector designs. However, landmine designers have gradually reduced the amount of metal in landmines to make them more difficult to detect. As the metal content in landmines has become smaller, soils that are mineralised (that contain magnetic compounds) cause the detector to generate false alarms and much effort has gone into designs that overcome the effect of soil mineralisation or 'uncooperative' soils.

Landmine fields in Cambodia show the challenging environments that detectors need to operate in

Metallic battlefield debris and shrapnel can also create too many false alarms. For instance, between 1992 and 1998, humanitarian demining in Cambodia excavated over 200 million items, less than 0.3% of which were antipersonnel mines or other explosive devices. Humanitarian deminers need a handheld landmine detector that can reject alarms from small pieces of metal while maintaining the ability to detect minimum-metal landmines.

ENGINEERING CHALLENGE

To overcome these problems, military organisations, universities, industrial research and technology organisations, and private companies have all worked to develop new detectors based on combined metal and radar detectors – so called dual-sensor systems. Using a range of different metal detector frequencies enables differentiation between various types of metal. For example, it can clearly distinguish the metal in a landmine fuse from a coin [see *Distinguishing between metals*]. In a similar way, the ground-penetrating radar (GPR) signature can show how the mine's response to the radar signal differs from the ground and other non-metallic items, such as rocks and roots.

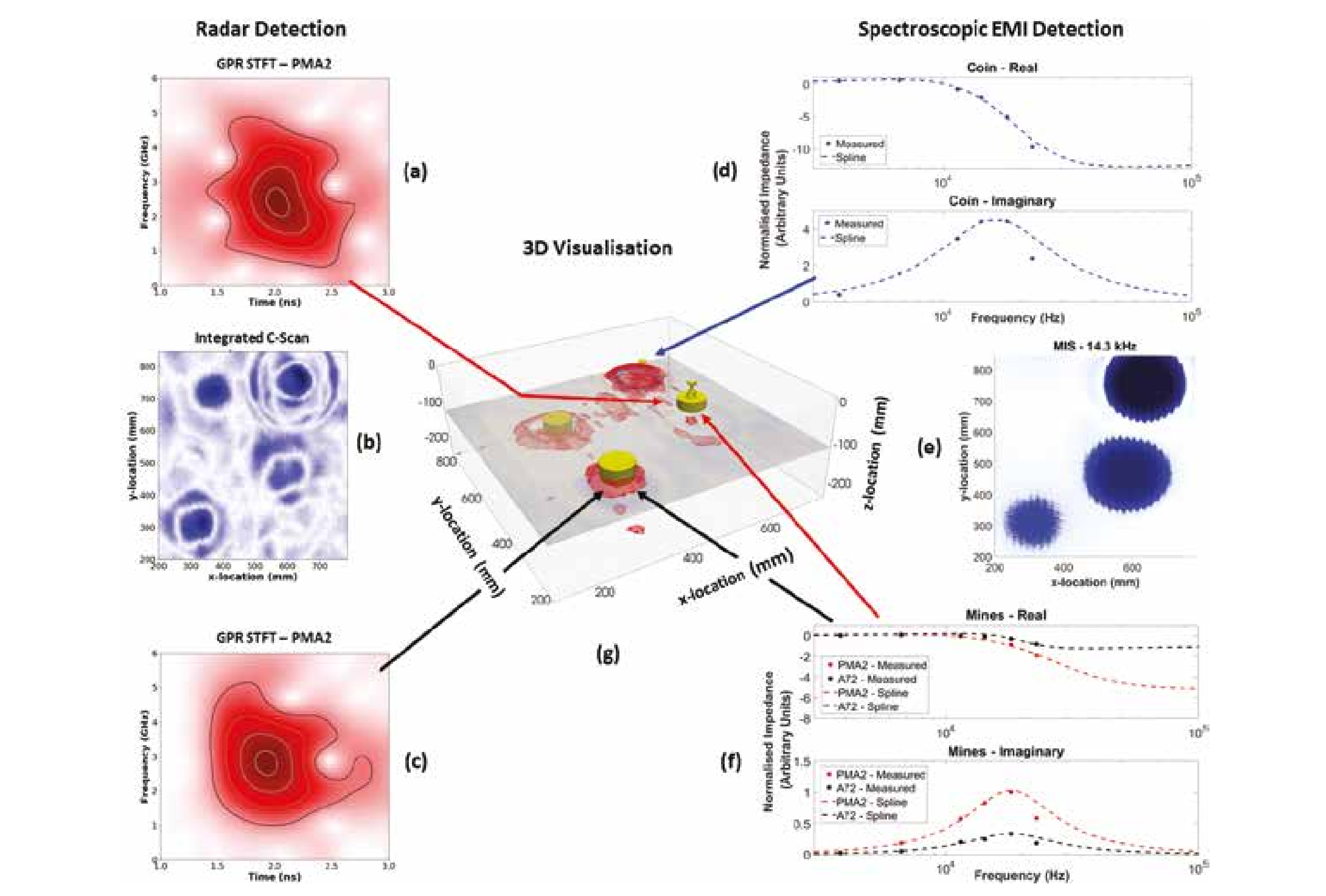
The key to better target recognition lies in understanding and analysing the electromagnetic signatures of landmines over a wide range of frequencies, from those used for both radar, typically a few 100 MHz to several GHz, and metal detection, a few kHz to tens of kHz. A suitable analogy is the vibration of a wine glass when the rim is rubbed. The glass has spectral characteristics that are unique to its size and construction, and will resonate at certain frequencies. While this is an acoustic/vibrational interaction, the same process can be applied electromagnetically.

The relatively small size of worldwide humanitarian demining operations, in terms of the annual sales market for detectors, is a critical aspect that designers and developers have to take into account. While dual-sensor technologies have been developed for military use, they are too expensive for humanitarian demining organisations.

The humanitarian market for metal detectors is estimated to be around $10 million, with an average sales price of $2,500 per unit, and is served by about five main suppliers. Non-governmental organisations in the field of demining have limited budgets to purchase new technology, which sets the bar for the sales price for new detectors. The market is also too small to support the high costs of developing advanced technologies. The engineering challenge is to devise affordable mine detectors that humanitarian organisations can use safely and reliably in the field. One way in which developers of new mine detectors may achieve this is to exploit the inexpensive electronic components developed for consumer products.

Demining demands physical and mental concentration from

DISTINGUISHING BETWEEN METALS



This diagram shows a composite image containing the captured metal detector and ground-penetrating radar (GPR) spectral information over a series of targets in an experimental trial. The images on the left (a to c) show radar data, and the graphs on the right (d to f) multi-frequency metal detector data. The image in the middle (g) shows the position of four target objects with the GPR data information overlaid. The GPR response is represented using red highlights in the figure, and it is possible to see that these highlights correspond with the known object locations.

The plot shown in (b) is an integrated image of the full GPR depth data. In this image, the radar data from the different depths where the targets were buried have been combined to generate a single, top-down view that contains the responses from every target. This figure shows all four buried targets but the detection of the landmine target is very marginal (the target is a surrogate of a PMA2 landmine, which is a Yugoslavian antipersonnel mine). The images in (a) and (c) show the result of a short-time Fourier transform (STFT) of the radar data for each position over a target. These plots show the spectral content of the signal as a function of time, with the contour lines showing the 25%, 50%, 75% and 95% amplitude levels. These figures demonstrate the richness of the data collected by the prototype dual modality sensor and the possibilities for future developments regarding discrimination and classification algorithms.

The metal detector plots on the right show that each object has different spectroscopic responses. The metal detector responses have two components: one is in-phase with applied signal (known as the real component) and the other is in quadrature (or 90 degrees, known as the imaginary component). Both components are needed to characterise the metal target. For instance, uncooperative soils have a very strong real component and relatively flat imaginary component, whereas minimum metal mines have a step in their real component and peak in their imaginary component at around 10 kHz. These different features can be used to reject the effects of the ground. In addition, different metal objects can be distinguished by the shape of their responses. More conductive objects have the peak in the imaginary response at lower frequencies.

The data above does not represent information in a format that would be presented to an end-user. However, it is very useful in understanding the inherent characteristics of the landmine. Furthermore, the figure emphasises the richness of the measured information as it is representative of the data that can be made available for the development of multi-modal detection, discrimination or classification algorithms.

the deminers. Making this task easier is the main challenge for the designers of the next generation of equipment. Detectors should ideally weigh less than a kilogram and should automatically adjust to the environment and the user. They should be able to not only detect, but classify types of mine and should separate them from clutter such as bullet cases, metal fragments, tree roots, stones, animal burrows and so on. The equipment must also meet near military standards for shock, vibration, temperature and environmental protection at a price similar to the metal detectors used by the humanitarian demining community today.

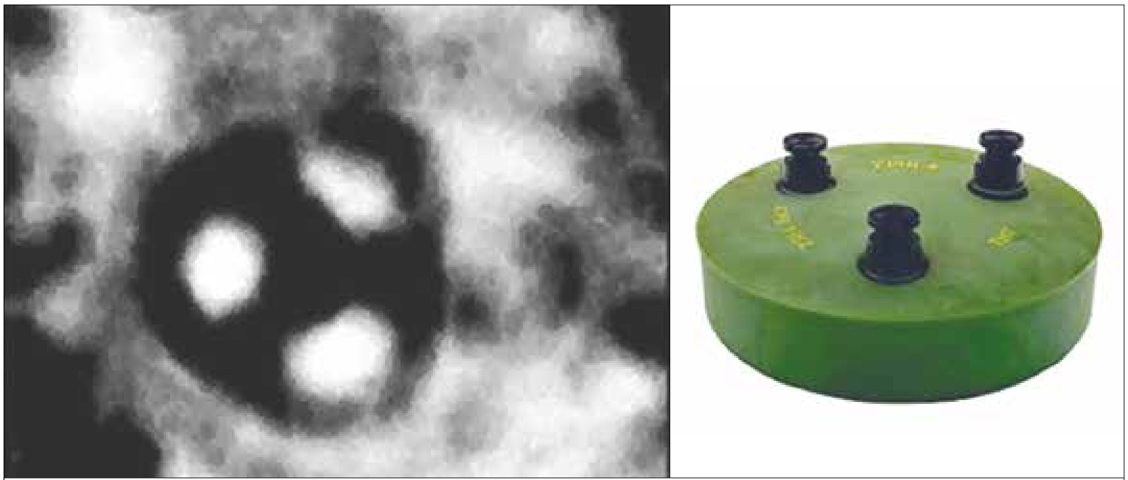
DETECTION TECHNOLOGIES

Existing landmine detection uses a range of technologies: metal detectors, GPR, a combination of the two, radio-frequency quadrupole resonance, microwave and millimetre wave radiometers, thermal imaging, optical methods, vapour detection, X-ray backscatter and acoustic sensors.

Metal detectors are the oldest and mostly widely used detection technology for manual demining. A typical handheld metal detector uses low-frequency electromagnetic induction to detect metal objects at or below the surface. It generates a primary magnetic field, which creates a secondary magnetic field that forms around objects that are magnetic or electrically conductive, such as metal components.

The detectors operate by transmitting and receiving pulsed or continuous electromagnetic waves. Continuous wave detectors produce and monitor magnetic fields continuously to sense disruptions caused by a conductive object's secondary field. Pulsed detectors transmit an impulse-like magnetic field and use the receiver to monitor the decay of the secondary magnetic fields, caused by the ground and any metal target. The detector's sensitivity depends on the strength of the magnetic field and the conductive and magnetic properties, mass, shape, and position of the target. For example, copper and aluminium are good conductors and ordinary steel is magnetic making them easy to detect. It is harder to identify stainless steel as it produces a weaker signal because it interacts less with the magnetic field due to its lower electrical conductivity.

The humanitarian community's reliance on metal detectors is down to several factors. First, there is a good understanding of how the detectors work and several companies compete to bring the most effective detectors onto the market. Second, the technology is relatively inexpensive. Third, current procedures are based on ensuring the ground is free of all metal, and while zero-metal mines exist, most have now been removed so they are hardly ever found. So, effective, safe operating procedures and quality controls can be put in place based on the assumption that no metal means no mines. However, metal detectors have the serious limitation of detecting metal clutter such as fragments of shell and bomb cases, so wasting significant time excavating items that are not dangerous. Ideally, deminers would like to be able to ignore harmless metal items so that they can concentrate on explosive devices.



An image generated by ground-penetrating radar (left) of a buried TMA-4 AT landmine (right). Radar images are lower resolution because the wavelengths are comparable with the target © ERA Technology/Cobham

GPR is an effective technique of detecting both landmines and improvised explosive devices (IED). It can detect antipersonnel mines up to depths of 150 millimetres and larger landmines at greater depths, using adaptive signal processing to compensate for varying ground conditions and largely eliminate false returns from the ground surface. As an easy-to-use, low-power, compact device, it can be integrated with a metal detector to form a dual-sensor detector.

GPR detectors transmit a pulse of energy into the ground and detect the energy scattered back from the buried target. The radiated energy can be either a very short impulse (a nanosecond) or a stepped-frequency continuous waveform with spectral characteristics equivalent to the impulse. The radar transmits over a range of wavelengths that can penetrate the ground. These wavelengths are optimised to achieve good ground penetration while ensuring that the landmine reflects an adequate signal. The signals reflected from a landmine are around one-thousandth to one ten-thousandth of the signal transmitted. This means that sensitive receivers and sophisticated signal processing are required to extract the wanted signal from interference and unwanted targets.

The strength of the received signal depends on the radar cross-section of the target and the losses from the radar signal as it spreads from the transmit antenna, enters the ground, reflects from the target and returns to the receive antenna. The radar cross-section of the target depends on its physical size in comparison to the wavelength of the radar signal. The radar cross-section gets smaller for longer wavelengths whereas the propagation loss in the soil reduces for longer wavelengths. Therefore, the radar designer must choose the wavelengths of operation to optimise detection in terms of target size and soil attenuation.

Although some vehicle-mounted radar systems have ranges of several metres, for handheld detectors, the radar antenna beam moves in a known pattern over the surface of the ground, generating an image on a real-time display. It is possible to create a radar image of the landmine but this is very different from an optical image, simply because the wavelengths are not comparable. Optical images are created because the wavelengths of light are smaller than the object and so achieve very high resolution. Radar images of landmines are generated using wavelengths that are comparable with the dimensions of the target, so image resolution is less than an optical image. The soil also acts as a filter and weakens the smaller wavelengths that results in an image that is highly dependent on the propagation characteristics of the ground. In addition, the antenna's beam pattern spreads widely and this degrades the spatial resolution of the image unless corrected. These are fundamental issues of the physics of propagation that the radar designer needs to understand if it is to detect landmines successfully.

At present, GPR systems do not fully exploit the information available in the reflected signal, which could be used to identify particular types of landmine. This would allow a greater breadth of capability and performance.

CURRENT DEMINING

Dual-sensor systems using both metal detectors and GPR offer distinct advantages over single-mode detectors. This is because GPR does not detect debris and mineralisation from the soil, but both sensors can positively identify landmines, resulting in a reduced false alarm rate compared with that from an individual sensor. The most widely used dual-sensor systems in the world include the US Army's Handheld Standoff Mine Detection System (HSTAMIDS) and the Anglo-German Vallon – Cobham VMR3 Minehound.

HSTAMIDS became the US Army's standard mine detector in 2006. It combines GPR with a highly sensitive metal detector that uses advanced data-fusion algorithms, which combine the output from both the metal detector and GPR to give a single indication of the possible presence of a threat. This allows it to reliably find landmines, without detecting metallic clutter.

The GPR section in HSTAMIDS is based on a wideband, stepped-frequency radar transceiver. The search head has one transmit and two receive antennas. The transmit antenna produces continuous wave, low-power radar. As the search head passes over the surface and the radar signal encounters resistance in the soil, some energy scatters back to the receiving antennas where data-fusion algorithms process the signal to optimise detection. The metal detector sensor incorporates compensation for soils that have high magnetic susceptibility and provides high-sensitivity detection of buried metal objects. Its unique data-fusion algorithms allow the operator to effectively discriminate between real mines and metallic clutter.

While it is primarily military operations that use HSTAMIDS, the US Humanitarian Demining Research and Development Program and The HALO Trust led initiatives to evaluate the technology in humanitarian operations. A field evaluation in Cambodia between March 2006 and June 2008 assessed the performance of 12 HSTAMIDS in field conditions, which included a wide variety of soils, minimum-metal mines and high levels of metallic clutter. The evaluation, with local deminers operating the detectors, cleared 604,375 square metres of land, detecting more than 1.4 million objects. It found 5,610 mines, with 96.5% of the clutter correctly identified. Following the success of the evaluation, The HALO Trust began using an additional 50 HSTAMIDS globally.

In 2001, engineering consultancy ERA Technology began the development in the UK of the dual-sensor Minehound detector for humanitarian demining. It aimed to simplify traditional GPR systems and produce a design that deminers, who were more familiar with the operation of metal detectors, could work with easily. Although much of the complexity of the operation of the radar was removed from the operator, flexibility of operation was still retained. This flexibility is essential to allow the operators to adapt to variability of soil and environmental conditions by changing key operating parameters. The design also avoided an over-reliance on predetermined software algorithms that assumed the operator would be incapable of interpreting instrument readings.

ERA Technology's Vallon – Cobham VMR3 Minehound is an advanced technology, dual-sensor metal detector and GPR system, designed specifically for demining operations. It communicates with the operator through audio signals whereby the depth of the target is related to audio pitch and the amplitude to the strength of the reflected signal, which harnesses the ability of a human brain to process complex information in the same way as listening to music. The system initially operates in metal detector mode, where all metal threats are noted, before using GPR to confirm the presence of a threat. The audio from the metal detector provides accurate information on the position of the item and an indication of metal mass. The GPR provides accurate information on the position, depth and radar cross-section of the target. It responds to even the smallest buried mines while its specially designed antenna ignores small metal fragments,

FIND A BETTER WAY

In 2011, Sir Bobby Charlton set up Find a Better Way after seeing the destruction caused by landmines on a visit to Cambodia, feeling that modern technological advances could develop a more efficient way of negating the effects of mines and improving safety and security for local communities whose lives are affected by them.

The charity commits significant funding to research projects at UK universities that are carrying out cutting-edge research into improving the tools available for the safe removal of landmines. It also funds risk-reduction education programmes and humanitarian assistance in areas populated by landmines.

The University of Manchester is currently working on a programme funded by the charity to research and develop new dual-mode metal classification and radar technology that will help improve productivity of landmine clearance.

www.findabetterway.org.uk

Humanitarian demining is a thorough and time-intensive process, and the standards of the clearance operation and its cost-effectiveness are the keys to successful operation © UN

GLOBAL EFFORTS TO BAN LANDMINES

Implemented just over 20 years ago, the Ottawa Mine Ban Treaty led to a fall in casualties from landmines, the destruction of millions of mines, and a virtual end of their use. Although the majority of the world's countries have signed the treaty, 33 have not and are stockpiling an estimated 50 million landmines. The general landmine problem arises because, although there are internationally agreed military procedures for deploying and recording the position of minefields and individual landmines, these are often ignored in conflicts where civil wars and insurgencies take place.

In 2014, after 15 years of steady decline, the use of mines has increased in many conflicts and resulted in a rise in casualty numbers. In April 2017, global humanitarian demining charities The HALO Trust and MAG International launched the Landmine Free 2025 campaign to reenergise support for landmine clearance.

which results in the rejection of false alarms caused by metallic clutter. The operator can choose to work with the metal detector or the GPR only or with both systems simultaneously, giving flexibility in a variety of different operational situations such as ground types, surface conditions and expected types of threat.

The UK's Department for International Development sponsored initial trials in Bosnia, Cambodia and Angola from 2005 to 2006. In August2010, The HALO Trust began Minehound detector trials in Cambodia. The programme cleared 573,109 square metres. It detected more than 660,000 objects, 845 of which were landmines. In 2013, 95% of the metal clutter was identified.

FUTURE DEVELOPMENT

Engineers now have a much better understanding of how metal targets respond to an applied alternating magnetic field, by representing the response of the metal target with its equivalent 'tensor signature'. The tensor signature offers a concise mathematical formula, suitable for real-time processing that describes this response. For instance, magnetic objects respond differently to non-magnetic objects, long thin objects have a more directional response than more spherically shaped objects, and smaller objects tend to respond more at higher frequencies. This suggests that multi-frequency receivers could determine the tensor signature of the target and not just detect, but also characterise and classify the targets to distinguish between shapes, sizes and material composition to further counter the problem of metallic clutter.

Recent progress in electronics and communications has expanded the availability of cheaper microwave components. The circuitry required for inexpensive and advanced stepped-frequency GPR is similar to that used in modern communication systems, such as high-speed telecommunications, suggesting that it may be possible to develop cheaper, improved performance GPR that is tailored specifically to humanitarian demining.

The HALO Trust has shown in Cambodia that using a metal detector as a primary detector and using GPR to check all the alarms produced by the metal detector can have a dramatic impact on false alarm rates. A low-cost GPR could have significant impact as a confirmation tool, while being within the budgets of most humanitarian organisations.

A low-cost, dual-sensor metal detector and GPR, or a low-cost standalone GPR, would improve productivity within a year or two of widespread implementation. This improved productivity and reduction in person hours needed to clear contaminated minefields would cover the cost of the initial investment. Over the years, this would reduce the cost per cleared square metre.

Over the last 20 years, significant steps forward have been made to rid the world of landmines. However, more action is needed. If this goal is to be achieved, a step change will be needed in clearance rates, which requires significant investment to ensure that deminers have access to the best available technology to undertake their arduous and dangerous work.

BIOGRAPHY

Professor Anthony Peyton has been Professor of Electromagnetic Tomography Systems at the University of Manchester for the past 14 years. He specialises in research on applying electromagnetic inspection systems for a broad range of applications, including non-destructive testing and metal detection.

David Daniels CBE is a Royal Academy of Engineering Visiting Professor at the University of Manchester, and a Fellow of both the Institute of Electrical and Electronics Engineers and the Institution of Engineering and Technology. He has published over 120 technical papers, and several books on sensors for security and counter terrorism.

PROCESSING THE PLASTIC PROBLEM

Plastic waste is an increasing global problem. While efforts are being made to encourage recycling and less usage, plastics – especially those that are hard to recycle – are still causing pollution. Science writer Geoff Watts spoke to Adrian Haworth from Recycling Technologies about a chemical process it is using to create a high-value product from plastic waste.

In recent years, there has been a steady rise in public consciousness of the existence of waste plastic and the threats it poses. Images of plastic bags, bottles and pots dumped as landfill or, even more damning, floating in otherwise pristine oceans far from their original site of use have become ubiquitous. Plastic is now political and this development has led to increasing pressure to do something about a state of affairs that is universally agreed to be unacceptable. But what?

Suggested remedies have ranged from the technical (make more plastic biodegradable, for example) to the behavioural (using it less casually). Recycling is, of course, prominent among the technical solutions and much has already been done.

Figures quoted by the British Plastics Federation suggest that the UK now has a 58% collection and recycling rate for plastic bottles, and 32% for pots, tubs and trays.

Most current recycling is by mechanical methods: chop up the plastic, wash it, melt it and reuse it. However, plastic is not all of a piece [see *Plastic waste: the scale of the problem*]. As described in a previous *Ingenia* article on the recycling of household waste (Recycling household waste, *Ingenia* 62), the advent of near-infrared sorting techniques has boosted the efficiency with which different types of plastic can be identified and separated. These systems rely on shining infrared light onto a conveyer belt carrying a thinly distributed stream of plastic items. The peak wavelength of light reflected from each piece of plastic will depend on the category to which it belongs. A spectroscope mounted above the conveyor belt measures this wavelength for each item and records its position on the belt. At the end of the line, puffs of air blow each piece off the belt in a specified direction, and into a chosen collection vessel, according to its type.

These systems are effective and have greatly boosted the efficiency of recycling, particularly for high-value polymer streams such as polyethylene terephthalate (PET) drinks bottles and high-density polyethylene (HDPE) milk bottles. After sorting, these are shredded, washed and re-extruded to form pellets ready for moulding applications. However, not all plastic is amenable to mechanical recycling methods. Clearly, it would be even more efficient to recycle plastic of all varieties and do so without first having to sort them. Achieving this goal requires chemical as opposed to mechanical methods. In principle – indeed in reality – it too can be done, but the task of implementing it on a commercial scale, and with an acceptable level of emissions, has not proved an easy one.

PLASTIC WASTE: THE SCALE OF THE PROBLEM

Commonly used plastics are not biodegradable and simply accumulate in landfill sites or in the environment more generally. Between 1960 and 2005, the proportion of plastic in the municipal solid waste of middle- and high-income countries rose from 1% to 10%.

Most of the statistics about plastic waste are disheartening. Prior to 1980, the amount of plastic incinerated or recycled was negligible. As a result, around 60% of all the plastic ever made is still with us in the form of waste. Estimates of the quantity of plastic thrown or washed into the world's oceans in just one year range from 4 to 12 million metric tonnes. Another estimate suggests that by 2050 the weight of plastic in the sea will exceed that of fish.

It has even been claimed that because plastic waste is now so ubiquitous, future geologists will be able to use it as a marker of the Anthropocene, the name given to our current geological era.

Plastic is an everyday item, used in everything from food packaging to toiletry products. In 2015, the UK alone generated 2.26 million tonnes of plastic packaging waste, according to government figures
© Recycling Technologies

CHEMICAL RECYCLING

Chemical recycling relies on a process called pyrolysis: the thermal decomposition of materials at high temperature in an atmosphere free of oxygen. In this context, the heating process fractures the large organic molecules that make up plastic into smaller ones. 'Thermal cracking', as this breakdown is generally known, is already familiar as the cornerstone of petroleum refining. In the case of waste plastic, thermal cracking reverses the process by which the plastics being recycled were originally synthesised from smaller starting molecules.

Pyrolysis is not a new idea; in fact, it has been in use since Archimedes and is the basis of charcoal and town gas (a gaseous mixture, used as a fuel, that bituminous coal releases when burned). The very familiarity of the chemistry lying at the heart of the process prompts bewilderment over why chemical engineering companies are not already exploiting it to tackle the waste plastic problem. This in turn drops a hint that, in practice, the task of cracking plastic to make other reusable products is not as straightforward as it might seem.

A few companies, particularly in Asia, have tried chemical recycling. Not all have succeeded, but some are still in business. In Europe, Plastic Energy is a company with UK headquarters and two waste plastic plants in Spain. It is keen to build a plant in the UK, but this is still in the planning stage.

Enterprises already in operation in the UK are thin on the ground. The newest entrant to the field is Oxford Sustainable Fuels (OSF), a company spun out of the University of Oxford's Department of Chemistry that plans to reduce plastic's environmental impact by providing a low-energy process to convert it and other solid hydrocarbon (an organic compound consisting entirely of hydrogen and carbon) waste material into high-quality transportation fuels. Right now, the most compelling evidence that Britain could be recycling mixed plastic into useful products is being provided by engineering company Recycling Technologies.

The technology behind the RT7000 was developed by chemical engineers at the University of Warwick
© Recycling Technologies

When the company's engineers began developing its RT7000 machine they faced a variety of problems, several that they have solved empirically. However, purely engineering hurdles were not the only, or even the toughest, that the engineers had to negotiate. Making the process commercially viable has also depended on achieving several key objectives that range from placing strict limits on the size of the plant to choosing continuous rather than batch processing.

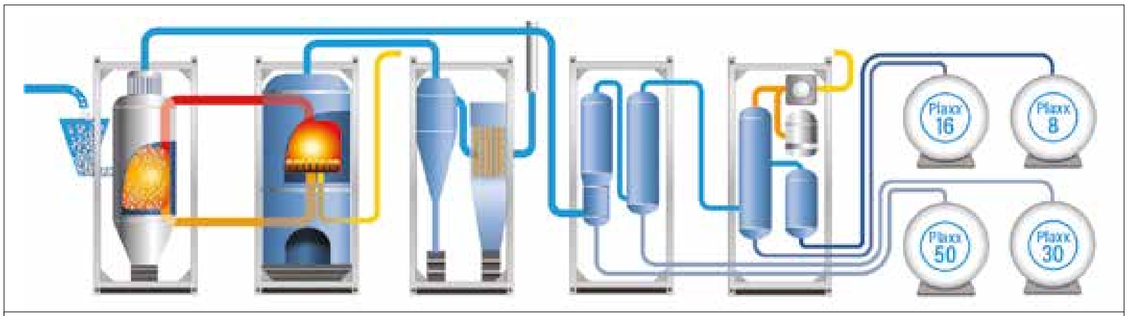
The company's technology grew out of work originally done by engineers at the University of Warwick. Adrian Griffiths, Founder and Chief Executive of Recycling Technologies, saw its potential and raised the money to build a laboratory-scale unit, before developing its current beta plant in Swindon. The local borough council provided some of the first plastic waste to be treated by the plant at a rate of more than two tonnes per day.

USING PYROLYSIS TO PROCESS PLASTIC

The effectiveness of a chemical breakdown process often depends on finding the right catalyst to speed it. The Recycling Technologies machine uses no catalyst; it relies solely on heat. This eliminates the risk of catalytic poisoning in which unwanted compounds in the material being processed bond to the active surface sites of the catalyst, reducing its effectiveness in promoting the desired molecular breakdown. When, as here, the raw material is a waste product, you never know exactly what you might be getting – dyes, adhesives, fire-retardants and other potential catalytic poisons – in addition to the plastic itself.

Another strategic decision in designing the RT7000 concerned the nature of the product to be extracted at the end of the process. One potential output is diesel fuel, and this is what some would-be chemical recyclers have opted for but have not managed on a commercial scale; when there is a varied input of plastic waste, it is extremely difficult to keep to diesel's tight specifications.

Here, the company's 'less is more' approach points to an alternative strategy: to produce a product with the least rigorous specification at which it can still find a buyer. The material that first emerges from the cracking process is too diverse to be easily marketable. By talking to potential buyers, Recycling Technologies found that separating the breakdown products of the waste plastic into four fractions would provide four different materials, with a market for each.



The pyrolysis process, also known as 'thermal cracking', uses heat in the absence of oxygen to break down plastics
© Recycling Technologies

The plant recycles plastics of all kinds that have been separated from other waste, shredded, washed and dried. People might imagine that the first step of the process would be straightforward – feeding the waste into the vessel where the thermal cracking takes place – but pushing shredded plastic fragments into a container at 500°C without simultaneously allowing air in turned out to be tricky. Any air in the vessel would turn the chemical process from pyrolysis to combustion.

A screw-feed system that compresses the waste plastic and drives it into the heating vessel seemed to be the obvious way forward. However, conventional screw feeds do not work well with shredded fragments of mixed plastic in a range of shapes and sizes, and in physical forms ranging from film to particles. The RT7000 relies on a tapered screw to move the plastic mixture forward, compress it, and force out pockets of air. Under the high pressure, the plastic becomes warmer and softer, and can then be squeezed into the reaction chamber in the manner of a stiff toothpaste emerging from a nozzle. The company spent two years developing the system and will be patenting it when fully satisfied that all the wrinkles are ironed out.

Most previous attempts to pyrolyse plastic have used batch processing, in which set quantities of material are fed into the reaction chamber and treated load by load. This is time-consuming and more expensive than the continuous processing favoured by Recycling Technologies.

To heat the plastic inside the reactor vessel, and simultaneously create an even temperature throughout, a very hot and sand-like material is pumped into the vessel using a fluidised bed system. Fluidised bed technology, widely employed by industry for a variety of processes ranging from the gasification of coal to the manufacture of fertilisers, makes a mass of particles behave as if they were liquid. This is achieved by pumping a fluid – either a gas or a liquid – up through the container holding the particles. When the rate at which the fluid entering the container reaches a critical level the particles within it can be stirred or pumped. A football dropped on to bed of fluidised sand will create a splash, and then float on it. (To see fluidised sand in action, watch www.youtube.com/watch?v=uLhblc48NIA).

Sand was the material originally chosen for use as the heating medium in the RT7000. In a container next to the main reaction vessel, the sand was both heated using propane gas and fluidised by forcing the gas through it. The hot fluidised sand was then pumped into the reactor, so mixing with and heating the particles of waste plastic and causing their molecules to fragment into a vapour of various hydrocarbons. Sand that had given up its heat was pumped out of the reactor vessel and back into the heating chamber. However, it soon became clear that sand was not the ideal material for these purposes, and the machine now uses specially synthesised ceramic particles the size of sand grains, but with a more uniform shape. Once the process is up and running at the required temperature, gases released during the thermal cracking process heat the ceramic 'sand', and the propane can be phased out as the process generates its own fuel supply.

One of the key variables in the system is the rate at which heat transfers between the carrier and the plastic. The hydrocarbon vapours released by the cracking of the molecules of plastic are piped to refining columns to remove unwanted compounds such as fire retardants and, most importantly, the chlorine from PVC. This hot-gas filtration system for removing chlorine and other halides is something that the company has had to devise to suit its particular needs. This requirement was vital because of the company's claim to be able to deal with plastic waste of any kind, including (up to a point) PVC. Experience shows that domestic waste in general contains no more than 1% to 5% of PVC, which the RT7000 should be able to cope with. Levels much higher than this might require the waste to be pre-sorted to remove most PVC.

THE PRODUCT

The final distillation stage of the process involves the separation of the hydrocarbon vapour into the four different materials. These are:

- A light oil suitable for use by the plastics industry as feedstock for new plastic production.
- A low-sulphur marine gas oil suitable as a fuel for marine engines or heat and energy generation.
- A low-sulphur heavy fuel oil.
- A hydrocarbon wax suitable for coatings and environmental protection, as a bitumen modifier, and even for candles.

The distillation column splits into four separate units standing side by side. This arrangement means that no one column needs to be particularly tall: a helpful factor in seeking the planning permission required to set up a new plant. Of the original plastic, about 3% remains to be disposed of as a hazardous waste. A key point is that Recycling Technologies is not aiming to produce products to a very tight specification, which would increase the cost and complexity of the plant. Buyers of the product – who know what they are getting and will pay accordingly – are better placed to perform any further purification or refinement according to their needs.

The chemically recycled plastic is broken down into oil and wax fractions. The company has forward sold all the oil and wax product from its first 12 machines to customers in polymer and wax manufacturing for further refinement © Recycling Technologies

NO MEGA PLANTS

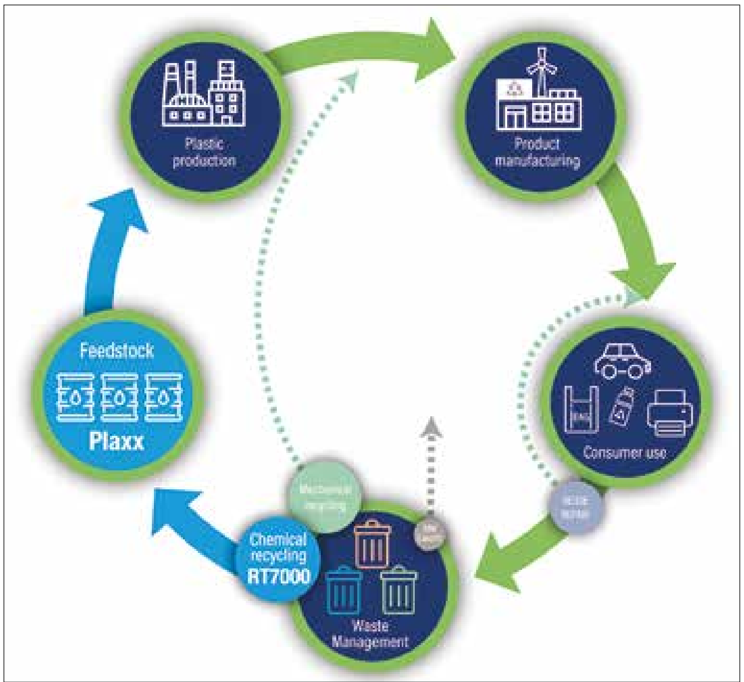
The Swindon beta plant is the prototype, using the suppliers, equipment and standards, for the full-scale commercial RT7000 plant. Recycling Technologies does not envisage a situation where plastic is trucked in from a large area to a central recycling centre. Instead, the commercial plant is about the size that would be required by most borough councils, and installation at an existing recycling site would locate it where the plastic is first separated from the rest of the rubbish. This positioning should also minimise planning permission problems that might be encountered if seeking to install the equipment on a virgin site.

The company aims to manufacture plants on an assembly line basis. Customers would buy what amounts to an off-the-shelf unit, typically for use on an existing recycling site. As this is a field in which innovation is still occurring, future units would incorporate improvements as they became available. The precise economics are still speculative, but if machines were to cost £3 million to install and £500,000 annually to operate, each might produce a revenue of £1.7 million every year from product sales. The plant should pay for itself in less than three years: a speedy recovery of the initial capital. According to present plans, the first RT7000 will be installed in Perthshire and be designed to handle 7,000 tonnes of plastic waste annually.

In summary, making the process commercially viable has depended on several key goals: keeping the plant simple; keeping it small enough for mass manufacturing, so reducing the capital cost; distributing units geographically rather than centralising them; and running them continuously.

A recent *Nature* review of plastics recycling from the University of Houston's Department of Chemical and Biomolecular Engineering drew attention to the advantages of chemical recycling methods. They have lower energy requirements and can handle mixed plastic waste, its authors wrote, and they can encompass traditionally non-recyclable polymers. "The potential annual energy saving that could be achieved from recycling all global plastic waste is equivalent to 3.5 billion barrels of oil worth approximately $176 billion."

While it may be overstating things to claim that "there's gold in them thar plastics", environmental dumping of waste plastic is not only a criminal activity but also, it would seem, a neglected opportunity.



Keeping plastics in the circular economy: chemical recycling enables waste plastics to be converted to oil for making virgin-quality polymers, suitable for all applications, including food-grade plastics © Recycling Technologies

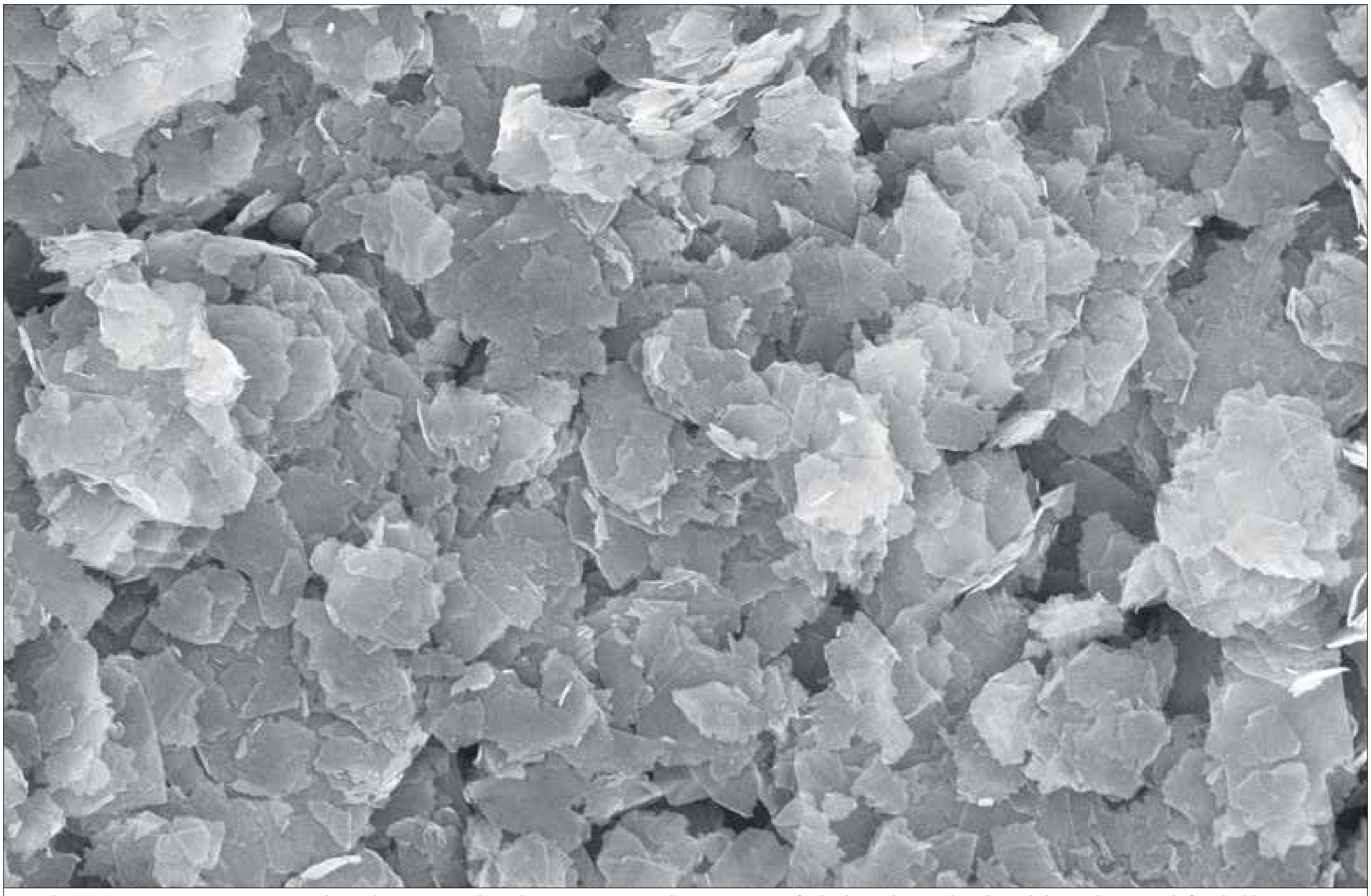
PLASTICS BY NUMBERS

1. ***Polyethylene terephthalate (PET)*** Clear, strong material. Barrier to moisture and resistant to heat and solvents. Used for water and soft drink bottles, pots, tubs etc. Commonly recycled.
2. ***High-density polyethylene (HDPE)*** Strong, stiff material resistant to chemicals and moisture, but permeable to gases. Used for toys, household and kitchenware, carrier bags, food wrapping. Commonly recycled.
3. ***Polyvinyl chloride (PVC)*** Tough material, resistant to grease, oil and chemicals. Rigid, but can be made flexible. Good transparency. Used for window frames, water and drainage pipes, flooring, roofing membranes, car interiors and seat coverings, footwear, packaging, and coated fabrics. Sometimes recycled.
4. ***Low-density polyethylene (LDPE)*** Soft material, easily processed with good flexibility, easily sealed. Used for squeeze bottles, toys, carrier bags, heavy duty sacks, general packaging, gas and water pipes. Sometimes recycled.
5. ***Polypropylene (PP)*** Versatile material, barrier to moisture, resistant to chemicals. Plastic that it easily moulded for a wide variety of uses. Can be recycled.
6. ***Polystyrene (PS)*** Hard and brittle material with good clarity and easily foamed. Widely used as packaging and insulation material. Can be recycled, but with difficulty.
7. ***The rest*** All other types of plastic. There may be as many as 1,000, including some materials manufactured for exotic purposes.

BIOGRAPHY

Adrian (Rupert) Haworth is Sales and Marketing Director at Recycling Technologies. He spent 33 years with GE , covering various roles including Engineering Services Manager, Director of European Service Sales, Region Director for Russia/CIS and Director of GE Energy's Strategic Marketing department in Europe.

GRAPHENE'S MATERIAL PROMISE



Graphene's unique properties mean that it has potential applications in several areas, many of which are being developed through research funded by Innovate UK © Versarien

Just one atom thick but stronger than diamond, graphene's mix of mechanical and electrical properties have seen it heralded as the answer to many questions over the past decade, but the material is yet to have a commercial breakthrough. Science writer Abigail Beall looks at the research that is revealing where graphene's strengths lie in industry, and where it falls down.

Graphene turned up unexpectedly in 2004. Its novelty and, as a new form of carbon, apparent simplicity captured the imagination of the research community. Here was something that materials researchers could investigate with techniques that they had honed over many years, be they borrowed from work on electronics, polymers, metals or even biomaterials.

This outbreak of research into a material that promised to be "stronger than steel, harder than diamond and lighter than paper" created a deluge of publications, and press releases promoting them, that promised all manner of potential applications. In 2011, a research team at the University of Manchester, the birthplace of graphene, offered a paper demonstrating that combining graphene with metallic nanostructures showed "a 20-fold enhancement in harvesting light by graphene, which paves the way for advances in high-speed internet and other communications". In 2014, a team at the University of Sunderland announced that it was a part of a €1 billion EU initiative, the Graphene Flagship, to "conduct a series of tests analysing the properties of graphene to determine how it behaves when it's used to enhance the advanced composite materials used in the production of cars".

There were also announcements about the use of graphene in touch-screen technology, flexible electronics, fuel cells, microwave shielding in satellite communications, 3D holograms, wearable electronics, energy storage, as a bacteria killer, to make fertilisers more efficient, and many others uses.

The interest in graphene also led to a wider focus on 2D materials (those that consist of a single layer of atoms) in general, with significant interest in finding those with unusual characteristics, for applications such as photovoltaics, semiconductors, and electrical and electronics applications.

As the attention on graphene, and 2D materials, waned, articles appeared in the media wondering what happened to the promise of this "not-so wonder material". Any new material – be it graphene, C60, or high-temperature superconductors, to pick examples from recent decades – takes time to move out of the laboratory into commercial use. The material starts as a novelty that researchers have to characterise before anyone can begin to test possible new applications. Then they must devise ways of making and processing the material in commercial quantities.

In the case of graphene, these are still early days in the transition from laboratory through to production lines. One sign of the industrial interest in graphene, and the breadth of its potential applications, is the portfolio of projects that have received backing in a series of funding competitions run by Innovate UK (IUK), now a part of UK Research and Innovation [see *Industry interest*].

DISCOVERING GRAPHENE

In 2010, the discovery of graphene won Professor Sir Andre Geim and Professor Sir Kostya Novoselov from the University of Manchester the Nobel Prize in Physics. By isolating a layer of carbon just one atom thick their research team achieved a goal that had been set out decades before, when the theoretical existence of graphene was predicted by PR Wallace in a paper called 'The Band Theory of Graphite' in 1947.

For decades, physicists knew graphene should exist but could not make it. The first method they found turned out to be surprisingly simple.

According to Professor Novoselov, the laboratory was experimenting for entertainment and its own interest, rather than grant-supported research. The same lab had a history of similar experiments, such as creating adhesive tape based on the physics of geckos' feet. This time, the team wanted to see if it could make a transistor using graphite.

To create a layer of carbon just one-atom thick, the team tried a few different methods, for example, polishing an expensive piece of graphite until it became very fine. None of these worked – the expensive graphite just turned into dust. The team was close to giving up. However, Professor Novoselov noticed another colleague was using sticky tape to clean the surface of graphite to study it in a scanning tunnelling microscope. He picked the piece of tape out of the bin and turned it into a transistor.

This is how the team developed the 'Scotch Tape' method, also known as 'micromechanical cleavage'. All it involves is taking a piece of graphite, placing the tape on the top, and peeling off the top layer of graphite. What is left on the tape is essentially a layer of graphene.

Because of the simplicity of the method, and the openness of the team that discovered it, researchers everywhere soon began to create their own graphene.

A variety of methods exist for producing graphene on a mass scale, but Scotch Tape remains a favourite in labs across the world
© University of Manchester

By 2025, the UN expects that 14% of the world's population will encounter water scarcity. It is hoped that types of graphene-oxide membrane systems, such as this, could be built as small plants, making the technology accessible to countries that need cheaper and more portable ways to develop clean drinking water © University of Manchester

WHAT IS GRAPHENE?

Interest in this novel material stems from the fact that in graphene, electrons behave as massless particles, making the electronic properties of the material unlike anything seen before. The electrical charge carriers in graphene move at speeds 10 to 100 times faster than in today's silicon chips. The material is a better conductor of electricity than copper, it is impermeable to gases, and is stronger than diamond, providing a unique mix of these properties.

According to Professor Novoselov, it was important for the Manchester team to share its discovery. There was a lot to learn about the material. The team was impatient and knew that it would have taken it too long time to investigate all the possibilities. These days, graphene is one of several 2D materials that have significant potential for numerous products and applications. "Graphene, and other 2D materials, have some exciting and unique properties that can potentially improve the performance of an existing product or application," says James Baker, CEO of Graphene@Manchester, a new project that is creating close ties with industry, to facilitate the development and commercialisation of products using the material. Graphene promises to deliver lighter parts in, for example, composites for automotive or aerospace applications, or increase performance, for example creating longer-lasting or faster-charging batteries and energy-storage devices.

Other applications of the material have the potential to provide a much more direct impact on people's lives. For example, microporous graphene membranes can filter dirty salty water and transform it into safe drinking water.

It took years to develop this membrane. At first, the Manchester team discovered that when it is placed in water, a graphene-oxide membrane swells and blocks larger molecules from flowing through it. It also managed to filter out small nanoparticles, organic molecules, and even large salts. However, the filters could not remove soluble molecules such as common salts, producing a problem if the membrane was to be used for drinking water as it could not filter seawater.

"Researchers in our National Graphene Institute Membranes Lab developed a strategy to avoid the swelling of the graphene-oxide membrane in water," says Baker. Instead of the membrane swelling, the team, led by Professor Rahul Raveendran Nair, developed a way to control precisely the pore size in the membrane. They achieved this by producing the membrane in a high-humidity environment, then using an epoxy coating to restrain the size of the membrane pores. This meant that even common salts could be sieved out of salty water, making it safe to drink.

INDUSTRY INTEREST

An early Innovate UK (IUK) project tackled the need to understand the properties of graphene when the National Physical Laboratory (NPL) sought support "to investigate the feasibility of rapid analysis techniques that can be used to monitor graphene produced in a real-world graphene reactor". In partnership with 2-D Tech, NPL also received backing for a project that explored how best to incorporate graphene into other materials, such as thermoplastics and epoxy resins, so that the resulting graphene-reinforced composites maintain the desired mechanical and electrical properties. Along similar lines, Haydale Composite Solutions joined NPL to adapt a patented process for distributing functional materials in polymers for use with graphene, which can be difficult to disperse.

These projects tackle the all-important need for industrially viable processes that can make graphene and incorporate it into other materials. Composites Evolution Limited bid for IUK funding to use graphene in materials where fire resistance is essential, in composites in aircraft for example. Another project on ways of producing graphene materials, which included Johnson Matthey, did R&D into plasma deposition for thermoelectrics. This was for work on fabricating electrodes for thermoelectric devices that can convert a heat-gradient directly into electrical power, with the aim of providing the UK "with an advanced technology to convert waste heat into useful power".

IUK has also backed graphene projects as a part of its programme to support the development of electric vehicles in the UK. One project included R&D into rapid battery charging using graphene supercapacitors. Another supports a feasibility project focusing on the industrial-scale improvement of lithium-ion batteries by adding ultra-high-quality graphene to enhance the life cycle, charging rate and capacity of batteries. Johnson Matthey is also part of the SAFEVOLT project that brings together four leading organisations at the forefront of battery materials innovation, led by Talga Technologies Limited, which has extensive experience in graphene production and R&D.

Some applications of graphene backed by IUK take the material in unexpected directions. For example, it has funded a project on the development of an anti-biofouling coating that hopes to exploit the hydrophobic and antibacterial properties of graphene.

By bringing together different organisations, this raft of projects will help to create strong links between academics and the industrial producers of graphene and other areas of nanotechnology. They also allow companies to see if graphene can bring new opportunities to their existing materials.

"Creating scalable membranes with uniform pore size down to atomic scale is a huge step forward," says Baker. "It opens new possibilities for improving the efficiency – and lowering the costs – of desalination technology across the globe."

TRIAL AND ERROR

However, graphene does not hold all the answers. Not every project that has attempted to utilise the material has worked out, even for the application the team that made the discovery was trying for: to make a transistor. Professor Douglas Paul from the University of Glasgow has made transistors from silicon, germanium and other semi-conductor materials. He says that the problem with transistors is that to build a high-performance integrated circuit, there are up to 20 performance parameters of the transistor that matter, including different voltages, capacitance, currents, power, and temperatures. Typically, there is a trade-off between several of the parameters. Improve one parameter and it usually has a knock-on effect that makes another parameter poorer for the applications.

One such parameter is electron mobility. Transistors can be very different depending on whether there are many electrons with low mobility or few electrons with high mobility. The original papers on graphene transistors concentrated on mobility, but in the latest complementary metal-oxide-semiconductor (CMOS) technologies, mobility is less important than off-current, on-current and the operational voltage.

"These early papers only optimised the mobility and didn't actually address the issues of building transistors that were useful in circuits," says Professor Paul. "Later papers have got better, but the issue now is how to integrate at large scale to deliver a technology with lower cost or higher performance than CMOS and that is very difficult to achieve with the many 10s of billions of dollars spent every year to improve that technology."

Another potential application of graphene that Professor Paul looked at was photodetectors. At first it was promising. Graphene's band structure and the range of energies electrons can have in the material, means it can respond to a wide range of wavelengths of light. The fact that it is a single layer of atoms also means it responds quickly. However, this monolayer of atoms, which is a great advantage for speed, also means that it absorbs very few photons for the shape formations that are used in most cameras, such as the mega-pixel camera in smartphones. This typically produces a very low absorption of light and quantum efficiency; two of the key parameters for photodetectors. Again, this sees a trade off in parameters required to produce the best photodetectors. Graphene has some properties that are excellent but these also lead to poor performance for other parameters.

Regardless of the outcome, graphene has presented researchers such as Professor Paul with an opportunity to try their tools and techniques on a new material. Although it has not been a key material in any of his research yet, Professor Paul says he does not rule it out completely for applications in the future. "It is worthwhile putting in all technologies that meet a certain threshold in performance across several parameters, otherwise you end up with such a long list that it is impossible to see which technologies are the real competitors," he says. Roadmaps such as the International Technology Roadmap for Semiconductors (ITRS), produced every few years since 1999 with input from global semiconductor makers to present the industry's R&D needs, are used to select the best technologies and concentrate developing those. For every £1 spend for research it costs £100 to get to demonstrating the

GRAPHENE'S STRENGTH FOR SPORT

Graphene is extremely strong so could be a replacement for Kevlar, carbon fibre and carbon nanotubes in composite materials already used in items such as armour and sports equipment.

In March 2018, engineering company Versarien announced that it is working with Team Sky to produce graphene-enhanced cycling equipment. The collaboration will explore how adding graphene will benefit bicycle frames, wheels, tyres, helmets and even other equipment worn by the rider, by making them stronger and lighter.

This is not the first use of graphene in cycling equipment. In 2014, Catlike, a Spanish sports equipment company, used graphene to produce cycling helmets. In 2015, international wheelmaker Vittoria released a range of bicycle wheels built from graphene-enhanced composite materials.

Team GB athlete Dom Parsons with the graphene-enhanced sled that helped him win bronze at the 2018 Winter Olympics © Versarien

The use of graphene in sport is not limited to cycling. In 2013, HEAD produced a tennis racket with a graphene coating on the shaft, which aimed to make the racket stronger and lighter. In 2018's Winter Olympic Games in PyeongChang, South Korea, Skeleton athlete Dom Parsons took home a bronze medal with a sled that had an underside made from a graphene-enhanced carbon-fibre material, which provided the desired structural properties while delivering minimal aerodynamic drag. UK-based Bromley Technologies manufactured the sled design with Versarien, which it has been collaborating with since 2016.

technology with an application. It is then another factor of 100 to get from this point to a manufacturable product in the marketplace. Most technologies or materials in research being investigated in a roadmap for a specific application will not get to market.

Graphene is reminiscent of many other technologies that have been discovered. Gallium arsenide (GaAs), organic materials and carbon nanotubes are all examples of technologies that have gone through a similar process, sometimes described as a hype curve. At the start of any new technology, papers claim that the new material or technology is vastly superior to present technologies. This area then attracts a lot of research funding, followed by a rapid rise in the number of papers published and articles written.

"It sometimes feels like the new technology is being cited to do everything," adds Professor Paul, "even things where the performance requirements are exactly the opposite." He says this hype is produced to secure funding. Then, demonstrators appear that allow testing of applications, and it then becomes clear if a technology is competitive.

A BRIGHT FUTURE?

While commercialisation of graphene has been thin on the ground so far, confidence in its properties has led to significant investment. The University of Manchester remains an important place for research into, and development of, graphene. The UK's National Graphene Institute (NGI) opened in 2015 and the Graphene Engineering Innovation Centre (GEIC) will open later this year. Both are part of the university and focus on graphene research and commercialisation. Since 2012, £61 million has been spent on the NGI, and a further £60 million on GEIC.

Cambridge Enterprise, the University of Cambridge's programme to help staff and students commercialise their expertise and ideas, has recently led a £2.9 million seed funding round for spin-out Paragraf. A graphene technology development company, Paragraf develops electronic devices based on graphene and other 2D materials. It has already produced layers with electrical characteristics optimised for producing very sensitive detectors at commercial scale and improved efficiency contact layers for common technologies such as LEDs.

The UK government is also backing graphene. It is investing more than £120 million in "graphene research, training and development", including £40 million towards a "collaboration and investment fund", according to former Minister for Energy and Intellectual Property Baroness Neville-Rolfe, and another £50 million on a Graphene Applications Centre in Sedgefield, County Durham. To date, the Engineering and Physical Sciences Research Council (EPSRC) has awarded grants and funding totalling more than £30 million to institutions researching graphene and carbon nanotechnology.

Looking ahead, the University of Manchester predicts the likely growth in the global market for 'graphene materials' to go from £14.6 million in 2014 to more than £285 million in 2024, and "much higher" for graphene-enabled products.

However, for all the attention that graphene has attracted since the Manchester researchers started wielding their sticky tape in 2004, researchers have just skimmed the surface of possible applications. Thousands of researchers around the world are approaching this new form of carbon from many different angles.

A ROLE IN THE AUTOMOTIVE INDUSTRY

The automotive industry has recently experienced a substantial increase in the integration of electronic control systems, with electronic components currently making up over 30% of the production cost. Position sensors are an example of this key enabling technology to monitor and control systems throughout the car, from engine management through to pedal position. Now, customers expect intelligence as standard and at no extra cost.

Current position sensors are either contact-based devices that achieve low performance at low cost, or contactless devices where performance and cost are both higher. The EU Horizon 2020 project developed GrapheneSens to assess the feasibility of creating novel graphene-enabled contact position sensors for applications in the automotive industry, home appliances and other relevant areas, with a combined worth of over £7.4 billion.

"The unique properties of graphene are its ability to provide excellent low friction and high resistance to wear, regardless of environmental conditions – both humid and dry environments," says Dr Pufinji Obene, Operations Director at Precision Varionic International. "It can also form a barrier layer between the substrate surface and the environment, thereby preventing the permeation of liquids and gases leading to unwanted reactions at the substrate surface." Therefore, graphene could be applied successfully to contact sensors since the surface of the substrate would last a long time. The GrapheneSens project aims to combine these benefits of graphene to develop graphene-based nano-composite coatings.

Abigail Beall spoke to James Baker, CEO of Graphene@Manchester, Professor Douglas Paul, EPSRC Research Fellow in electronic and nanoscale engineering at the University of Glasgow, and Dr Pufinji Obene, Operations Director at Precision Varionic International, to write this article.

MACROBERT AWARD 2018

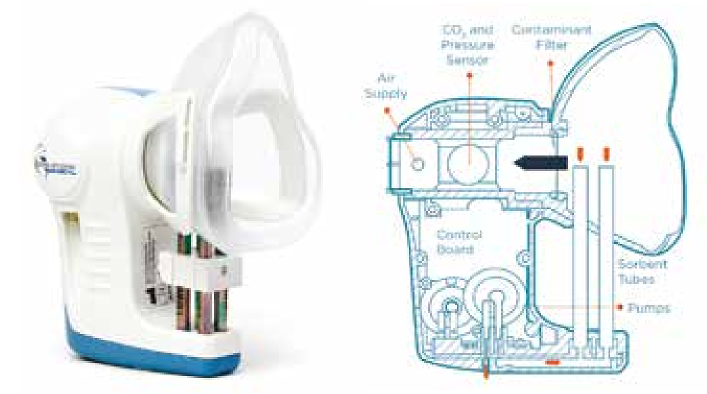
SUPPORTED BY THE WORSHIPFUL COMPANY OF ENGINEERS

The Royal Academy of Engineering MacRobert Award is the premier prize for innovation in UK engineering. It is awarded annually for an outstanding example of innovation that has achieved commercial success and is of benefit to society. It seeks to demonstrate the importance of engineering and the contribution of engineers and scientists to national prosperity and international prestige.

The award was founded by the MacRobert Trust and first presented in 1969. Every submission is reviewed by a panel of judges drawn from the Academy's Fellowship and across engineering. The award honours the winning company with a gold medal and the team members with a prize of £50,000. Here, *Ingenia* showcases the three finalists for this year's award in alphabetical order. The winner will be announced at the Academy Awards Dinner on 27 June 2018.

A QUICK AND EASY WAY TO DIAGNOSE DISEASE

Diagnosing diseases such as cancer usually involves a series of invasive tests and procedures. University of Cambridge spin-out Owlstone Medical has developed a non-invasive procedure that aims to quickly and painlessly identify a range of diseases through a simple breathalyser test.



The ReCIVA Breath Sampler monitors patient breathing and automatically selects a fraction of expired breath to be captured. Breath is directed into four collection tubes, which are packed with sorbents that are optimised to collect volatile organic compounds in breath © Owlstone Medical

The concept of using breath to diagnose disease is not a new one: Hippocrates (460 to 370 BC) first linked breath odour to underlying diseases and the analysis of volatile breath metabolites has been a research topic since the 1970s. Further research has investigated the presence of volatile organic compounds (VOCs) as biomarkers for a range of diseases, but there has been little agreement in identifying those linked to specific diseases, and breath-testing studies were inconsistent and not routinely used in clinical settings.

INNOVATION

Owlstone Medical, founded by Billy Boyle and David Ruiz-Alonso, decided to focus on solving the problems around breath testing. The team discovered that, as well as small and inconsistent studies, the most significant issue was a lack of a standardised technology for collecting high-quality breath samples and analysing them reproducibly. In response to this, it has created the first technology capable of capturing and analysing breath samples in a robust and reproducible way, so that it can be used in large-scale clinical trials.

The ReCIVA Breath Sampler consists of: a handheld unit that attaches to a computer or tablet for monitoring and power; a disposable mask with a built-in filter to avoid cross-contamination; and a Breath Biopsy cartridge for collecting and pre-concentrating VOCs from breath. ReCIVA uses a portable air supply that minimises unwanted VOCs by 'scrubbing' ambient air. The Breath Biopsy platform can then analyse VOCs from precisely collected breath samples.

The platform includes a patented chemical sensor on a silicon chip, based on a technique called field asymmetric ion mobility spectrometry (FAIMS). Human breath contains thousands of chemicals, some of which are telltale markers of disease that the microchip chemical sensor can detect. The diagnostic ability of FAIMS has been demonstrated using a variety of sample types across a range of infectious and inflammatory diseases, as well as different types of cancer.

BENEFITS TO SOCIETY

Breath testing for diseases could aid earlier diagnosis, leading to improved patient outcomes and reduced treatment costs.

Owlstone Medical has initiated the world's largest breath-based clinical trials using the Breath Biopsy platform, including the early detection of lung and colorectal cancer, and a collaboration with Cancer Research UK on early detection of multiple types of cancer. Early detection of cancer is critical to survival rates – for example, if detected early, over 93% of colon cancer patients survive, compared to late detections where less than 5% of patients survive five years. Currently, only 9% of patients with colon cancer are detected at the curable early stage, so increasing the rates of early diagnoses of cancer is a bigger opportunity than developing new drugs.

Non-invasive tests with reliable results would also help to encourage more patients to take part in screening programmes, which have low participation because the techniques used are often unpleasant.

Breath Biopsy can also help to enable precision medicine, which aims to identify the correct treatment for each patient based on condition-specific biomarkers. This could potentially save some of the $400 billion a year that is wasted on ineffective drugs.

COMMERCIAL SUCCESS

In early 2017, Owlstone Medical launched its Breath Biopsy services, which are already attracting high-profile pharmaceutical clients. It has raised $38.55 million to support its 130-person team and develop its healthcare technology and is a partner in several clinical trials. The company is currently working with the NHS in the LuCID breath biomarker trial for early detection of lung cancer with up to 4,000 patients. More than 100 clinics and hospitals across the world use the Breath Biopsy platform.

The company has recently launched a new range of Breath Biopsy Kits and is hoping to announce new partnerships with biopharma by the end of the year.

For more information, please visit **www.owlstonemedical.com**

SPACE-SAVING SOLUTIONS FOR SATELLITES

Harwell space business Oxford Space Systems is pioneering a new generation of deployable antennas and structures that are lighter, can be stowed more efficiently, and are more cost-effective than current alternatives for the global satellite industry.

As the Earth's population grows, the importance of monitoring humans' impact on the planet is ever increasing. One of the most effective ways of monitoring shipping, land use, natural disasters and climate change is from satellites.

However, getting a satellite into orbit is expensive, costing anywhere up to £50,000 per kilogram. Reducing the mass of deployable structures, such as antennas, solar panels and boom systems, can make spacecraft more cost-effective as these often make up a large percentage of the satellite's mass. Deployable structures are used for folding key components of a satellite for transportation and storage, because the space available in a rocket is heavily constrained. Once in space, deployable structures allow the satellite to unfold and become fully functional.

Oxford Space Systems' deployable structures, such as this wrapped-rib antenna, use novel design techniques based on origami so that they can be folded and stowed more efficiently © Oxford Space Systems

INNOVATION

Oxford Space Systems uses novel design techniques based on origami to fold and unfold its space-based antennas more efficiently. Conventional deployable parabolic antennas are complex and expensive, often using cables and pulleys to tension an antenna's wire mesh surface. Oxford Space Systems' 'shape memory' flexible antenna surface removes the need for these traditional systems. When deployed, it naturally adopts its moulded, pre-packed shape in microgravity, making it more reliable and easier to store.

The antenna also uses unique and flight-proven materials, such as its proprietary flexible composite technology, which the company combines with conventional materials to create a new generation of lightweight deployable structures. Oxford Space Systems' antenna structures are highly scalable, ranging from 2 metres to 15 metres in diameter.

BENEFITS TO SOCIETY

The cost and stowage efficiency of Oxford Space Systems' antenna technology means that it can enable the development of a new generation of lower cost, more capable satellites. Lower cost satellites, for example, will provide more readily available Earth observation services at lower prices. This data is used to identify and monitor pollution, track aircraft and ships, assist with fishing protection, measure sea level and temperature, and monitor weather.

One of its two successfully flown AstroTube™ booms is being used in the RemoveDebris mission ('Mission to remove space debris', *Ingenia* 72), which is testing a harpoon system to capture space junk. In the 60 years that humans have been exploring space, significant junk and pollution has accumulated in orbit. As such, space debris removal has increasingly become an active area of research and development in the UK.

Through the successful launch of the AstroTube boom, the company has also set a space industry record, with a material and product design, test and in-orbit demonstration in under 30 months.

COMMERCIAL SUCCESS

Oxford Space Systems is currently a showcase NewSpace company for the UK Space Agency and Innovate UK, having received over £2 million in co-funding support from these agencies. Today, Oxford Space Systems attracts global interest and has contracts in the UK, Europe, Asia and the US, with customers ranging from universities to the largest satellite manufacturers. It works with the European Space Agency and the UK Space Agency, among others.

Two US companies currently dominate the global market for deployable space antennas, but Oxford Space Systems is positioning itself as a more cost-effective and agile UK alternative. Its recent developments have opened the global market, increasing the quality and competitiveness of antenna-enabled services such as data relay, Earth observation and telecommunication.

For more information, visit **www.oxford.space**

REVOLUTIONISING SUPERMARKET CHILLER AISLES

Williams Advanced Engineering takes cutting-edge Formula One technology and applies it to real-world challenges. It has turned its expertise to developing an aerodynamic device that significantly reduces the energy consumed by supermarket refrigerators, partnering with innovative UK startup Aerofoil Energy.

The aerofoil technology can deliver significant energy and carbon savings for supermarkets, as well as other benefits such as improving product temperature, meaning that less chilled food is wasted © Williams Advanced Engineering

Supermarkets and convenience stores account for an estimated 10% of the UK's total energy use, with fridges using around 40% of that. Sainsbury's alone uses nearly 1% of the UK's total energy demand. Most supermarkets use open-fronted, vertical fridges for better merchandising and easier access for all customers. The current design launches a cold-air stream at the required temperature from the top of the fridge, intending to capture it at the bottom without losses. In practice, it is inefficient and a significant amount of the cold air escapes and warm air enters. This increases the temperature of the return air and makes the aisles cold. Because of this, large amounts of extra energy are needed to maintain a uniform temperature in an open-fronted fridge.

INNOVATION

An aerofoil is a structure with curved surfaces designed to give the most favourable ratio of lift to drag in flight, and is generally used as the basic form of the wings, fins, and tailplanes in most aircraft. A similar design is present in the front and rear wings of a Formula One car.

Paul McAndrew, CEO of Aerofoil Energy, realised that applying the principles of an aerofoil, extending forward from each shelf in a refrigeration unit, would act to contain and re-energise the downward flow of cool air in open refrigerators. Paul teamed up with Williams Advanced Engineering to develop the product and business concept. Together, they have designed and engineered aerofoil shelf-edge technology to control the direction of air flow and keep more cool air inside the fridge, as well as developing low-cost manufacturing techniques. Acting as the price label holder, the aerofoil maintains a cohesive and conforming cold-air curtain, ensuring that the cold air cascades down the fridge and prevents its escape into the aisle. Williams' engineering team used computational fluid dynamics to optimise the aerofoil profile and have designed universal attachment systems to make retrofitting existing fridges quicker and easier, learning from experience during early store installations.

BENEFITS TO SOCIETY

Aerofoil Energy's innovation is simple, yet makes a significant energy saving. It could create substantial cost savings for those buying fridges and can be retrofitted to existing stock. It is environmentally friendly, and can help the retail sector meet energy-saving targets and reduce its carbon footprint. Each fridge fitted with the technology uses 15 to 25% less energy than those without. It offers potential annual reductions in UK carbon emissions equivalent to the monthly output of all households in Manchester.

It also has the added benefit of reducing heating costs in store, as less cold air escaping the fridge means that the aisles do not get cold. Studies in several leading UK grocery chains have shown that the average temperature in the chiller aisle is several degrees higher once the fridges are fitted with the aerofoil technology. Many customers do not like feeling cold when shopping in the refrigerated aisles, so supermarkets could increase the time that shoppers spend in their aisles.

The design provides the energy savings of closed-door fridges without the associated negatives. Closed-door fridges are more expensive to make, harder to recycle and have high maintenance costs, as well as being difficult to open for elderly or frail people, or those with a basket in one hand.

COMMERCIAL SUCCESS

By March 2018, the product had been installed in over 1,000 stores, including Sainsbury's, Co-op, Asda and Boots. Since January 2017, 130,000 units have been sold, and an additional 300,000 have been ordered and are in production. Sainsbury's is installing the aerofoils across its 1,400 stores as part of a retrofit programme and all its new fridges will be fitted with the technology. This will reduce the chain's refrigeration costs by 15%, a potential annual saving of almost £10 million.

For more information, please visit **http://bit.ly/WilliamsAerofoil**

FOUNDATIONS FOR A CONSTRUCTION REVOLUTION

Dr Sarah Williamson FREng, Construction Technical Director, BYLOR

For a young Dr Sarah Williamson FREng, summer holidays were spent doing useful tasks on one of her father's building sites. Today, she leads a team of engineers at Hinkley Point C nuclear power station in Somerset, one of the UK's largest construction sites. As Construction Technical Director for the main civil engineering work, she is pioneering the implementation of 'digital engineering' in construction. She talked to Michael Kenward OBE about her vision for the future of civil engineering in the UK.

In her early years as a researcher, Dr Sarah Williamson FREng was happiest investigating the behaviour of reinforced concrete through structural testing – creating and destroying pieces of the material, the larger the better. Today, as Construction Technical Director at BYLOR – a joint venture between Laing O'Rourke and French construction company Bouygues Travaux Publics – she holds significant responsibility for the delivery of Hinkley Point C, one of the largest civil engineering projects in Europe.

Dr Williamson wants to dismantle the construction industry's traditional approach to planning and executing projects. She even objects to the 'construction' label: "We shouldn't talk about construction, we should talk about manufacture and assembly," which she would like to see guided by digital representations and new ways of working onsite.

Dr Williamson's experience of construction sites started young. Her father ran his own building business, assembling sports facilities and houses in Cumbria. "From an early age, I spent as much time as could with my dad onsite," she says. "I had my own tools and became an expert at brick stacking and sweeping up." However, the experience did little to evoke an early interest in an engineering career. She admits to knowing nothing about the subject when she was at school, so opted to study the A levels that she found easiest and most interesting: English, French and geography.

No-one else in Dr Williamson's family had attended university and she admits that she found the idea of it intimidating. Therefore, she chose to join her father onsite. "At age 18, I was working on small building sites, responsible for myself and the work of a small number of men," she explains. "That was an amazing experience. Just imagine what it was like as a woman of that age in the 1980s, I loved it!" After three years, Dr Williamson changed her mind about university, as she puts it: "cold winters and hard skin prompted a rethink about education."

RETURNING TO ACADEMIA

Her first step was an engineering foundation course at Preston Polytechnic. This enabled her to get on the right track and study a degree in civil engineering. She then spent four years at Liverpool Polytechnic, emerging with a first-class degree and a clutch of prizes.

Dr Williamson set out on a career that has been anything but predictable. Indeed, she says with a hint of amusement that she has been accused of having a CV that was starting to look "a bit bitty". Her response to such comments is: "well, you only live once. Throughout my life, I have done what I find interesting and useful. I enjoy ploughing my own furrow and it is advice that I give to young engineers in the team. We live and work in a changing world where flexibility, adaptability, and the ability to think and problem solve are much more important than 10s of years of solid experience in the same field."

After university, uninspiring job offers and a construction industry in one of its regular recessions left Dr Williamson looking for something interesting to do. The suggestion of a PhD piqued her interest and gave her the opportunity to experience a very different kind of environment; moving from a polytechnic in Liverpool to a leafy campus at the University of Birmingham.

She began a PhD project on a topic that has been a consistent theme in her professional career: reinforced concrete and its material properties and structural behaviour. Thanks to problems on Birmingham's highways, the topic of reinforcement corrosion was of local interest at the time. She spent three years "mostly making and breaking small specimens of reinforced concrete" as she set out to understand how corrosion of reinforcement affected structures and what it would take to protect reinforcement from corrosion.

Then came another of those 'follow your interests' moments. As Dr Williamson's PhD was ending, the head of the university's concrete structures research group, Professor Les Clark OBE, was elected President of the Institution of Structural Engineers. The university offered her a lectureship to help cover the period when Professor Clark would be away. Still in her mid-20s, Dr Williamson saw it as an amazing challenge: "There is nothing like trying to explain difficult structural concepts to a bunch of 18- and 19-year-olds when you're only 26 yourself."

A MOVE INTO INDUSTRY

Over the next few years, Dr Williamson spent time in both industry and academia. She moved north to work with Mott MacDonald, then spent time at the University of Salford, and finally returned to Birmingham. She aspired to become a chartered structural engineer and decided that it was time to both move into industry and go home to Cumbria. She joined Atkins as a senior structural engineer in a team of four. Within nine months, Dr Williamson was leading that team, which grew in both size and diversity over the next six years. During her time at Atkins, she went on to become chief engineer, leading teams of civil and structural engineers in projects on nuclear facilities all over the UK. This seems to have been enjoyable work, not least because it was based in a pleasant setting in Cumbria. But that location itself could have caused problems in a business that is often big-city centric. Dr Williamson set out to counter that tendency.

"The office was in a rather inaccessible location – some might say the back end of beyond," she says. "My idea was that you should not have to give up living in a beautiful and rural location to do exciting work. At the time, the two were generally mutually exclusive with the most exciting projects being delivered out of city offices. My plan was to build a team capable of doing that work and stop it from going to the big offices." Dr Williamson came up with a label to describe her thinking: "Our strapline was 'head office work in a rural location'." It seems to have worked: what started with four people became a team of 30, working for nuclear clients all over the UK. "That team is still up there. I am really proud of what we achieved and what it continues to achieve."

This thinking was in line with Dr Williamson's growing awareness of the need to develop teams. "There are three parts to my job," she explains. "There is the technical bit – I am a technical person out and out. Then there is communication." The other part, she says, is: "looking after and nurturing the team. I get great satisfaction from seeing people grow and develop and watching teams gel and evolve together."

Dr Williamson sees team building as a fundamental part of an engineer's professional toolbox. "In my 30s, I became very aware that leadership and communication skills are every bit as important as, perhaps more than, the technical skills." Now working in a UK/

Dr Williamson's role as chief engineer at Atkins was based in Cumbria, where she built up a team of people doing head office work in the rural location. This also, of course, gave her the opportunity to make the most of the setting through activities such as yoga, walking and mountain-biking

Franco joint venture in a team with over 20 nationalities, these skills are vital. "We have to create an environment where everyone, regardless of background or nationality, understands the project, their part in the project, and feels valued and respected – that takes real commitment."

DIGITISING CONSTRUCTION

In 2012, Dr Williamson joined Laing O'Rourke's Engineering Excellence team in a role that included development of digital engineering techniques. She is now Construction Technical Director at BYLOR, responsible for construction engineering at Hinkley Point C, the UK's first nuclear power station since Sizewell B started operations in 1995.

Dr Williamson is very clear that digital technology is key to delivering the project. "Paper drawings are rarely used onsite," she adds. "The full team, which includes engineers and supervision, uses tablets and field stations with computer screens to study digital representations of the structures that they are assembling."

The move to digital technology is part of Dr Williamson's campaign to rewrite the handbook for construction projects. "The thing that gets me up every morning is changing the construction industry," she explains. "There is so much opportunity to change the way we work, using technology and data. From that, comes the opportunity to attract more and different types of people into our industry."

Her first move would be to ditch the 'construction' label, saying that it is just a part of a process that comes after the extensive design work and planning that must be completed before anyone can move on to a site. "I am really passionate about integrating design and construction," she adds. "The two should go in absolute harmony, so that by the time that you get to site, what happens is a structured assembly process rather than the more complex and emergent traditional construction process."

The process starts by sitting down with the client. "I spent four years working with the designer and client in the design phase," Dr Williamson explains. Living in Kent at the time, she made regular visits to EDF Energy's engineers in Paris. The EPR, a third-generation pressurised water reactor, is she says, "a challenging structure to build". It has certainly seen construction delays on other sites. "EDF was very determined that this time it would be done differently. As we are the main civil works contractor, they engaged with us early to explore the opportunities offered by digital engineering."

To make that happen, Dr Williamson turned to the digital techniques that she pioneered at Laing O'Rourke. "One of our first challenges was to understand whether it would be possible to detail the reinforcement in three dimensions. Modelling a few bars is simple but contemplating preparing production information for quarter of a million tons of reinforcement using this technique was a different proposition," she explains. "After

On the Hinkley Point C project, everything that is going to be built is first created in a model. "We want the model information, because we want to use that to totally change the way that we go to work on site. There are models for everything; all the roads are modelled, all the cranes are modelled, everything is built on the model, not just because it looks really nice but because it allows us to properly plan our work."

some significant effort, we came to the conclusion that yes, it is."

There was a lot of talk about 'collaboration' but what does that really mean? "The language that we use is about meeting the needs of the designer and the constructor." In practice, the team building the model ensures that it includes inputs from the constructor as well as the designer. Everyone works together to ensure that the end product is buildable. "We take a design, we check that we can build it," Dr Williamson explains. "We call it a virtual build, or an assembly check, and that is a real thing, it is not something that we do for a presentation. We do our assembly checks so that we know that the thing will go together."

Models are only as good as the information that goes into them. Building the model is a complex process. "We specify to the client what we need to see in the model in terms of data," she adds. "The model is a representation of a series of databases." It covers just about everything that is done onsite. "Having that one-to-one scale model is the best way to control the inventory of material that you bring to site. If you model it, that means you need to buy it and you need to put it where you showed it in the model. You should end the project with not one more or one less component than you put into that model."

The model data supports all the site processes, which is why tablets are ubiquitous – used by steel-fixers, for quality checks, and to call off materials. The digital approach also has advantages for regulators. All construction projects should be built to the required specification, but nuclear projects have a regulatory requirement to demonstrate this. The feedback from regulators so far has been good. "The regulator focuses in several key areas: two of these are process control records. Our use of the model and field technology allows clear visibility of how we control the construction sequence and generate digital quality records. They see this as a real positive."

To get to this stage, the engineers at Hinkley Point C had to go back to basics. "We need everyone in the team to understand the importance of quality and make sure that 100% of the time the focus is on getting it right. Because of the size of the project – and because the client has been progressive in the way of thinking about how they will give the information to us – we have a real opportunity to maximise the use of technology and data to support the project's delivery, as well as a change in the industry."

TIME FOR CHANGE

Dr Williamson's passion for integrating design and construction is just the start of the quiet revolution that she advocates in the battle cry "manufacture and assemble". In this new approach, the old way of design and construction gives way to design, manufacture and assemble. The approach is "a kit of parts", she says. "The aim is to plan and organise the components that need to be assembled then hand over with a full set of instructions."

For example, the model behind Hinkley Point C will ensure that the many miles of steel reinforcement arrive on time and in the right quantities, but this will not be taken to its final location for fixing, Instead, it will go to a separate fabrication facility to be turned into cages, which will later be installed in the final position. This is so that the cages are manufactured in a controlled environment where it is much easier to control the process and the quality. As Dr Williamson describes it: "One of our key principles is componentisation. The traditional construction process requires piecemeal installation of many elements. Our aim is to minimise the number of components required to form the final structure and thereby simplify the process of assembly. The components can be manufactured in more controlled environments." The construction industry has a label for this plan to move welders into their own 'factory', it describes the process as 'componentise and assemble'. "This a key concept," says Dr Williamson. For her, it is a driver for industry change.

Dr Williamson foresees significant changes in the shapes of the teams needed for construction projects of all sizes. To begin with, everyone on a project will need the skills required to develop, and use, those all-important computer models. "Sometimes people think that model-based working is for specialists." She disagrees. "We call it digital content and we are increasing it in many of our roles, creating new skill sets in existing teams and recruiting roles that would not normally

At Hinkley Point C, the welding is carried out at a separate fabrication facility. This approach to assembly is something that Dr Williamson feels will be instrumental in industry change

be seen in construction teams, such as data engineers and analysts."

DIVERSITY IN ENGINEERING

As a woman with a senior role in engineering, Dr Williamson naturally finds herself called on for her views on gender issues. She is happy to play that game, but takes a broader view on the bigger topic of diversity. Forget about ticking boxes, she insists: "It is not about meeting quotas, it is about a fundamental right to equality for all regardless of background, gender, ethnicity, or anything else. In terms of business success, for me, it is simple: diversity is a key ingredient in teams that are creative and successful, and therefore necessary."

Dr Williamson sees her own career as an example of this broader diversity. She now takes pride in those comments about her 'bitty' CV, with its relatively late conversion to engineering and that 'polytechnic' first degree, followed by moves in and out of academia and a rapid rise in industry working in different businesses. "I think that what I did is a great model: some practical experience, some broadening and then do some deepening in a technical subject. It almost sounds like it was a plan!" She sees nothing wrong in recruiting undergraduates with arts A levels, and what is the fixation with degrees? "A lot of the roles that we need to deliver a big civil project do not need a degree," she insists.

Dr Williamson would rather recruit people who can learn. "What I am really trying to do is to bring people in to do jobs that we can train them to do relatively quickly, either through off-site or onsite training, and then give them the opportunity to progress if they have got the aptitude and the desire," she says. "I just love the idea of giving people the opportunity to really fulfil their potential."

Dr Williamson sees Hinkley Point C as a test bed for this new way of thinking about construction projects, regardless of their size and complexity. "My idea is that we will deliver the project, it will be successful, and that the people who come out of it will have a very different idea of what a construction project looks and feels like." It is also part of Dr Williamson's grand plan to take this "once in a lifetime" opportunity to change the industry's thinking. "I am not going to say that it will change the industry in one go, but it really will open up people's eyes as to how we can go about construction in a different way." As a senior member of the Institution of Structural Engineers, she is taking her message beyond Hinkley Point C and her current job.

Spreading the word seems to be as important to Dr Williamson as completing Hinkley Point C. "I have spent five years of my life pushing this new way of going to work in construction. Step one was to get the design delivered in the way that suits our working practice. Step two is to demonstrate that we can implement those working practices and that they make a difference." At the end of the project, she adds: "We will have a team that looks and feels different to a traditional construction team, that works differently, and is motivated and constantly hitting the targets, getting safety right, getting quality right." That would certainly lay down some evidence-reinforced foundations for a revolution in construction in the UK.

BIOGRAPHY

Michael Kenward OBE has been a freelance writer since 1990 and is a member of the *Ingenia* Editorial Board. He is Editor-at-Large of *Science|Business*.

CAREER TIMELINE AND DISTINCTIONS

Born, **1969**. Awarded a degree in civil engineering from Liverpool John Moores University, **1995–1999**. PhD in structural engineering at the University of Birmingham, **2000–2003**. Lecturer in structural engineering at the University of Birmingham, **2003–2006**. Member of the Institution of Structural Engineers, **2006**. Chief Engineer at Atkins, **2006–2012**. Technical Director at Laing O'Rourke, **2012–present day**. Fellow of the Royal Academy of Engineering, **2017**.

INNOVATION WATCH

A TOUGH LOCK TO BREAK

A successful online Kickstarter campaign helped to launch an award-winning, lightweight cycle lock that is now sold in over 70 countries and is the only bike lock on the market that closes without a key.

After having several bikes stolen on the streets of London, Neil Barron decided to use his 30 years' experience as an aeronautical engineer and then designer to disrupt the cycle lock market. He could see that bicycles were getting ever lighter but the locks were getting heavier, and resolved to create a high-security but lightweight bike lock.

Barron, a Royal Academy of Engineering Visiting Professor in Innovation at the Royal College of Art, London, decided to totally rethink the design and materials that form a lock. The only items that he has not recreated from scratch are the discs inside the cylinder lock; everything else about the Litelok Gold Lock is new.

Barron and his team developed an innovative patented metal and polymer composite called Boaflexicore, which forms the flexible band welded to the lock mechanism. The material consists of several components, including 2,000 strands of high-tensile steel in the form of filaments whose format and specification allow the material to be tough and flexible.

Bicycle thieves using cutters will usually attempt to break a lock by creating a nick that turns into a crack. This is because once a fracture starts in a continuous metal, it can spread all the way through. The new material is non-continuous, which means that the crack needs to be constantly restarted and so does not get bigger. Boaflexicore spreads and squashes by placing more material in front of the cut so that it is harder to cut through.

This novel property of the new lock strap initially caused problems in the manufacturing of the lock. Boaflexicore is produced in a process that makes 10 kilometres of the material at a time. However, when it had to be cut to length for each lock, the cutting tool in the large hydraulic presses could not manage more than a hundred cuts before blunting. The team developed a new sintered tool to cope with the new material through a process of compacting and forming a solid mass of material by applying heat or pressure.

The resultant tensile strength of Boaflexicore is 177 kilonewtons – or nearly 40,000 pounds-force. The strap is then welded to a patented hardened steel lock that was developed with lockmakers Henry Squire and Sons. In order to make the lock as slim as possible, the lock housing is used as part of the structure and the more the structure is pulled the stronger it becomes.

In March 2015, Litelok, the company that Barron had formed two years before in South Wales, started an online crowdfunding campaign on Kickstarter. It raised over £232,000, enabling the company to establish the tooling and the accreditation needed for the lock and brand.

The Litelok lock was presented to Sold Secure UK, the testing and certification house for security products. The testers used the usual street weapons of thieves including

The Litelok Gold Original Bike Lock is made from Boaflexicore – a tough and flexible metal and polymer composite

bolt croppers, hacksaws and cable cutters, before the lock was awarded the Bicycle Gold rating, the top rating for bikes. With this independent assessment, Litelok could market the 1.1 kilogram lock as the lightest flexible lock for its strength on the market.

Now, with more than £1 million worth of backing from the Development Bank of Wales, Innovate UK and a syndicate of Business Angels, Litelok is looking to invest in more hi-tech manufacturing techniques. The company already has 20 employees based around Swansea and aims to develop complementary security products using Boaflexicore.

www.litelok.com

HOW DOES THAT WORK?

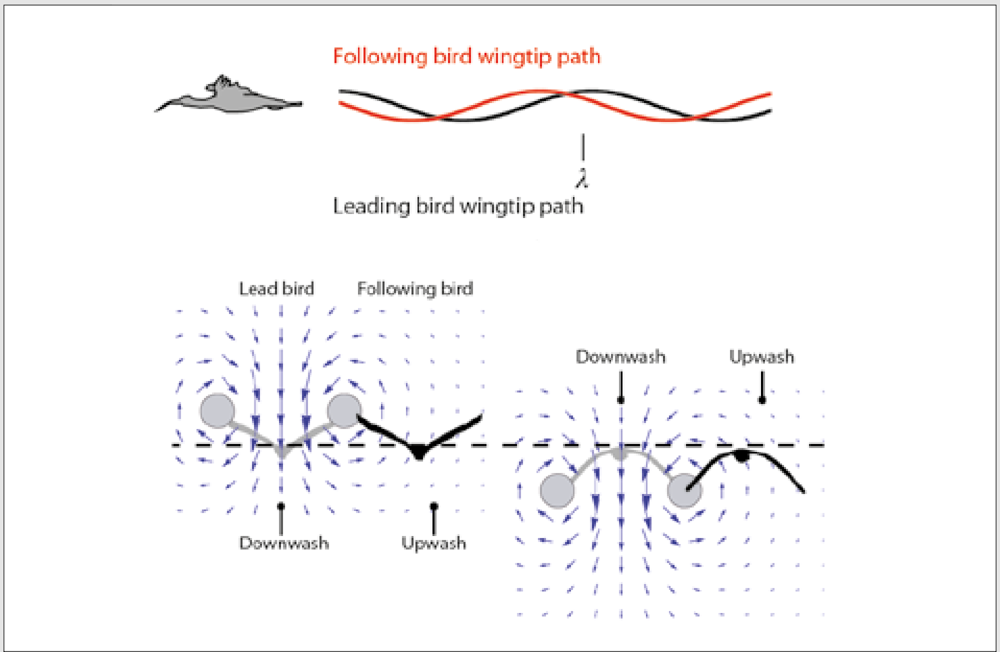
BIRDS FLYING IN A V FORMATION

Migratory birds such as ducks and geese fly in a symmetric V-shaped flight pattern, known (not unexpectedly) as a V formation. The reasons for this follow from the applications of aeronautics, fluid dynamics and energy minimisation.

Although it had long been thought that flying in V formation was more efficient, it was only in 2001 that researcher Henri Weimerskirch first showed, by fitting pelicans with heart-rate monitors, that birds flying in the back of a V formation had lower heart rates and hence energy consumption. It was assumed that the reason for this was that, apart from the first bird in the formation, all the birds fly in the upward-moving air produced by the wings of the bird ahead. However, how they did this was unknown until a study in 2014 used a flock of northern bald ibises that had been trained to follow a microlight.

The study found that birds are not only visually aware of where the others in the flock are, but are also able (somehow) to sense the direction of the airflow from the vortices shed from the edge of the wing ahead. By positioning themselves accordingly, and by adjusting their rate of flapping, they can make maximum use of the upward-moving air generated by the bird in front. During flight, birds move their wings at a slight angle that deflects the air downwards, so that air flows faster over the wing than underneath. Air pressure builds up beneath their wings and the pressure above reduces, and this difference in pressure produces lift. Flapping the wings creates additional forces: the upward force, thrust, and the downward power stroke.

During the downward stroke, the wing's angle is even steeper and provides the majority of the thrust. This creates a very brief downward dive through the air, using the bird's own weight to move forward, but it remains airborne as the wings continue to generate lift. The bird folds its wing inwards slightly during each upstroke, which reduces resistance.



By positioning themselves accordingly, birds can make use of the 'upwash' generated by the bird flying in front of them © Reprinted by permission from Springer Nature: *Nature*, 'Upwash exploitation and downwash avoidance by flap phasing in ibis formation flight', Steven J. Portugal, Tatjana Y. Hubel, Johannes Fritz, Stefanie Heese, Daniela Trobe et al. 2014

With each flap a rotating vortex of air rolls off each wingtip and, by positioning itself in the upward part of this, the following bird gains free lift similar to how a glider can climb or maintain height indefinitely in rising air. The birds clearly need to avoid each other's downwash, as that pushes them down and would result in them using extra energy. It is not yet known how they sense the upwash, but it may be that the wing feathers are themselves the sensors, or perhaps the birds also sense the total energy needs of flying and therefore accommodate themselves to the most comfortable rhythm.

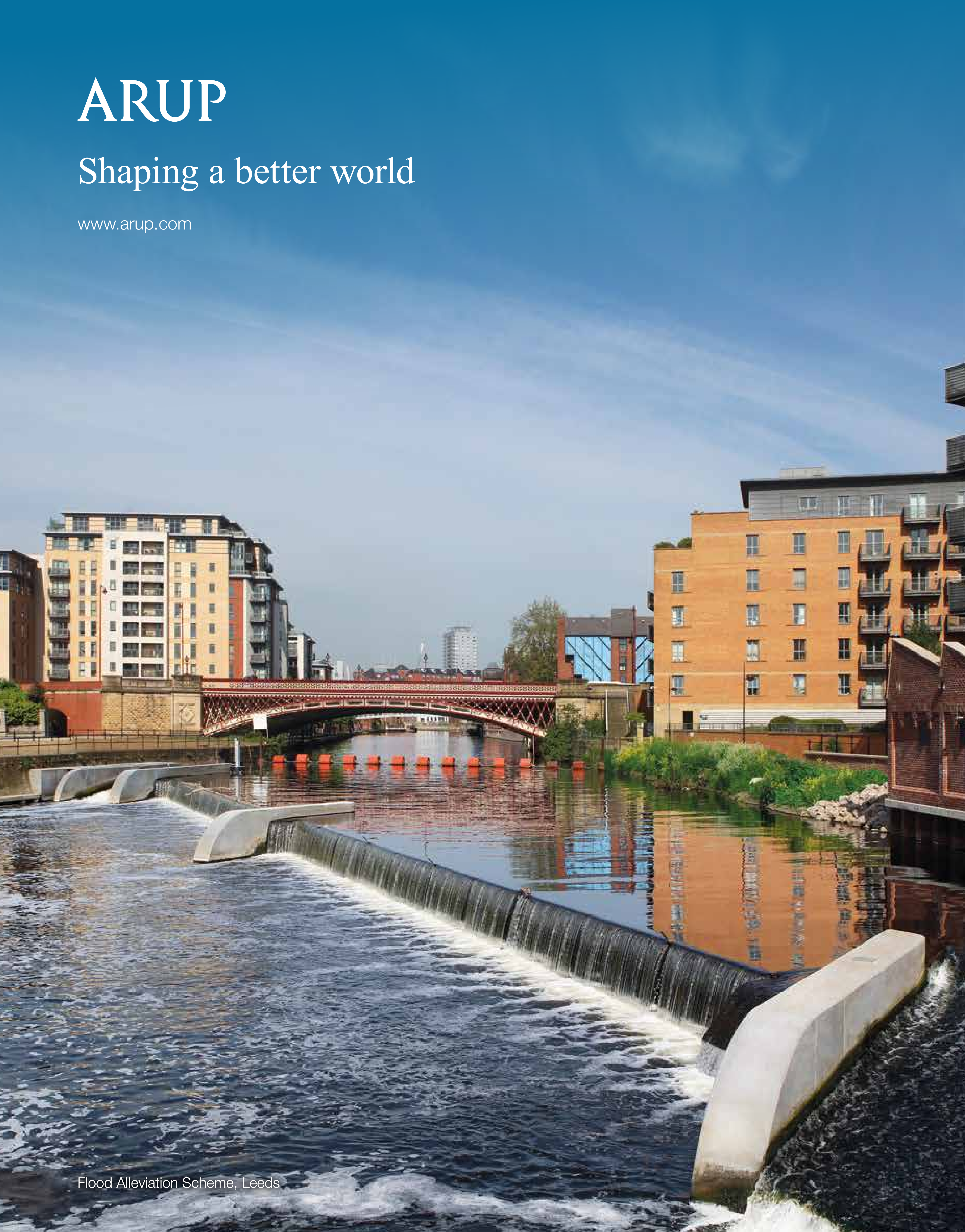
In large birds like the ibis, each bird flies around a metre behind the bird in front, and a metre off to the side. They tend to swap positions and the front bird is rotated in a timely cyclical fashion so that flight fatigue is spread equally throughout the flock (much like cyclists in a peloton). Early studies had found that in a V formation of 25 members, each bird can achieve a reduction of induced drag and increase their range by 71% as a result. The 2014 study showed that birds' heart rates decreased when they were flying together in a V formation, demonstrating that the formation saves energy.

Many air forces employ the V pattern during military flight missions and it was used as early as the First World War, where the 'Vic' formation improved fuel efficiency and allowed pilots to see each other's aircraft. More recently, it has been used in swarms of drones to extend range.

ARUP

Shaping a better world

www.arup.com



Flood Alleviation Scheme, Leeds