

Institution: University of Surrey
Unit of Assessment: UOA 12 Engineering
1. Unit context and structure, research and impact strategy 1.1 Context and Structure Engineering at Surrey is a community of students, staff, partners and collaborators working together to create and share knowledge, to educate the next generation of innovative and entrepreneurial technologists, and to help society address its current and future challenges. Our ethos embraces diversity in many forms – ideas, scale, history and people – to deliver excellent research that creates impact through solving real world problems. We strive to work in teams that bring together researchers at different levels, from a variety of disciplines and backgrounds, to add value to the research outcomes and to enhance career prospects and aspirations. During the REF period, we have awarded 659 doctorates, invested in 22 additional research staff positions and produced over 5,800 outputs, with 22% in the top 10% cited in their field, with two colleagues being Clarivate Highly Cited Researchers. We have exceeded our strategic funding aims, attracting research funding of £170M with an average of £25M per annum compared with £14M per annum in REF2014. We have developed the UK's first private 5G network, located on the University's campus, which is home to the national 5G test bed. We have established a 5G Innovation Centre (5GIC) bringing together 26 major companies and over 300 small and medium enterprises (SMEs) to shape UK strategy in 5G. Our research in aspects of artificial intelligence (AI) is world-leading, ranked first in the UK and 11th in the world for Computer Vision (csrankings.org). In terms of global impact we have: (i) demonstrated the world's first capture of space debris (in collaboration with Surrey Satellite Technology Ltd. (SSTL), a University spin-out); (ii) premiered the first demonstration of a 5G remote controlled driverless car, with the car on our campus and the driver at ExCel London (over 60km away); and (iii) created a new cultural artefact and global brand – Vantablack™ – a new pigment, licenced for sole artistic use by Sir Anish Kapoor. We have formed a Strategic Partnership with the National Physical Laboratory (NPL), jointly with the University of Strathclyde, and backed by the Department of Business, Energy and Industrial Strategy. We enjoy excellent collaborations with a range of industrial partners, from multi-nationals to SMEs, including over thirty sponsors of doctoral students in our Engineering and Physical Sciences Research Council (EPSRC) Centre for Doctoral Training in Micro- and NanoMaterials and Technologies (CDT in MiNMaT), which has been delivering an Engineering Doctorate (EngD) since 2005. Our Global Centre for Clean Air Research (GCARE) has active ties with >20 academic institutions spanning five continents, on projects linked to many of the United Nations Sustainable Development Goals (SDGs). Throughout the REF period, we have continued to host: the EPSRC UK National Ion Beam Centre; the Environmental Flow wind tunnel, EnFlo, which is part of the National Centre for Atmospheric Science Atmospheric Measurement and Observation Facility and the National Wind Tunnel Facility; and a Rolls-Royce University Technology Centre in Thermo-Fluid Systems. Our Unit of Assessment (UOA) submission includes all staff in the Departments of Civil and Environmental Engineering (CEE), Chemical and Process Engineering (CPE), Electrical and Electronic Engineering (EEE) and Mechanical Engineering Sciences (MES), complemented by staff with engineering-focused research from the Centre for Environment and Sustainability (CES) and the Departments of Chemistry and Physics. All Departments have research groups centred around common interests, with EEE more formally structured into four Research Centres, namely: Advanced Technology Institute (ATI), which includes colleagues from Physics;

Centre for Vision, Speech and Signal Processing (CVSSP); Institute for Communication Systems (ICS); and Surrey Space Centre (SSC), which is joint with MES.

We have chosen to present Engineering at Surrey in terms of five themes which describe the intrinsically cross-disciplinary research culture. These are **Materials and Devices, Resilient and Sustainable Systems, Technology and Society, Future Mobility and Space** and **Innovation for Health**. The themes are not exclusive; whilst the work of colleagues may be applicable to more than one theme, the primary affiliations of staff in this UOA are given in Table 1.

Table 1: Engineering at Surrey – Themes and Affiliations

Theme	No. of Staff	Staff Affiliations
Materials and Devices	51	ATI, CEE, Chemistry, CPE, MES, Physics
Resilient and Sustainable Systems	49	CEE, CES, CPE, MES
Technology and Society	36	CVSSP, ICS
Future Mobility and Space	31	MES, SSC
Innovation for Health	17	CEE, Chemistry, CPE, CVSSP, ICS, MES

1.2 Strategy for Research and Impact

Achievement of REF2014 Aims

In our REF2014 submissions we recognised the importance of interdisciplinary research aligned with national/international needs in addition to the delivery of research excellence and high-quality outputs and outcomes. This has been our focus throughout the REF period. More recently, the University's Research and Innovation Strategy was refreshed, with these broad aims articulated in the form of four over-arching strategic goals with accompanying key performance indicators.

In line with our REF2014 aspirations, we have **grown our research activity** through a number of strategic initiatives.

Increasing and diversifying our staff complement from 162 (153.3 full-time equivalent, FTE) eligible staff in REF2014 to 184 (166.1 FTE) in 2020. To support all colleagues and allow greater time for research, there has been further investment in Teaching Fellows at all career stages, increasing from 7 FTE in 2014 to 18.6 FTE in 2020. We have chosen to **concentrate activity** whilst taking the opportunity to diversify our staff complement in terms of gender and career point (see section 2), thus **building strong teams**, and being mindful of succession planning.

Supporting emerging and established research leaders by embracing external development opportunities at all career stages e.g., Royal Academy of Engineering Industrial Fellowship (Vellio: skin-bioreactors with Unilever), EPSRC Future Leaders Fellowship (Jurewicz: Advanced Materials, £1.6M) and EPSRC Fellowship (Plumbly: AI for Sound, £2.1M). We have promoted 14 staff to Professor, and a further 37 to Reader, recognising and rewarding their contributions to achieving our strategy.

Strengthening strategic initiatives by, for example, introducing a School of Computer Science and Electronic Engineering to develop synergies across these areas of research excellence, and a School of Chemistry and Chemical Engineering to promote research at the interface of these disciplines.

Ensuring exploitation of research to maximise impact by interacting with organisations such as Airbus, NPL and Rolls Royce and founding successful spin-out companies (e.g., Securium, SilverRay and Surrey Sensors Ltd). In the REF period, over 40 separate inventions have been patented.

As we have grown, we have remained committed to the delivery of excellent science-based engineering research. In REF2014, staff in this UOA were submitted in UOA13 Electrical and Electronic Engineering, Metallurgy and Materials (86 staff) and UOA15 General Engineering (59 staff). We highlighted the Digital Economy, Energy, Global Security, Health, Living with Environmental Change and Infrastructure as key challenge areas, directly leading to the evolution and focus of our themes. Evidence of the notable successes that this strategy has brought within the REF period is given below.

Materials and Devices

This theme recognises the synergies across CEE, Chemistry, CPE, MES, Physics and the internationally renowned ATI.

Building on the diverse materials activity presented in 2014, Materials and Devices now has two primary foci that reflect critical national and international needs: Materials for Energy Applications and Materials for Demanding Environments (recognising the link to Global Security).

Across the theme, materials engineers have experimental and modelling expertise that spans fundamental materials science, supported by *ab initio* modelling, through design for devices, multi-scale modelling, manufacturing, to whole system integration. The manufacturing activities are facilitated by (i) the EPSRC Nanomanufacturing Centre, in collaboration with NPL, and (ii) the Sustainable Printing Applied Research Knowledge Hub, developed as part of a 5-year EPSRC Materials Substitution for Safety, Security and Sustainability grant. At its heart, the theme is driven by the linking of the property-processing-microstructure relationships that are essential for not only understanding material behaviour but also in designing and engineering materials, devices and systems. The theme is underpinned by excellent materials characterisation facilities and highly experienced technical staff (see section 3.2).

In Materials for Energy Applications, the energy storage emphasis has expanded from supercapacitors to also include batteries, with work on Li-ion, Li-S, and Na-ion batteries, funded by EPSRC and The Faraday Institution Lithium-Sulfur Technology Accelerator (LiSTAR). The energy generation and conversion activities have involved an expansion in the types of photovoltaic and fuel cell systems being developed, along with work on piezoelectric, thermoelectric, triboelectric and other functional materials, moving from solely power generation to more novel applications in the 'wearable technology' and 'dispersed technology' space supporting the Internet of Things (IoT) agenda. Most of the research into functional aspects has been conducted within the ATI, which has a £22M portfolio of 'live' EPSRC grants.

Within Materials for Demanding Environments, the work on ceramic armour systems has expanded and evolved into looking at a wider range of material combinations and exploiting our expertise in joining, adaptive materials and sensing (e.g., following participation in the Materials and Structures Technology consortium on Ceramic Composites there were two follow-on PhD projects with Dstl, with one student winning a prestigious Royal Commission of the Exhibition of 1851 Industrial Fellowship). Activity now encompasses a broader protective agenda with research including identification of degree and location of damage as well as energy management for ballistic impact, vibration control and impact under high strain rate and extreme conditions in terrestrial and space environments. This has led to AWE choosing to partner with us to form a Centre of Excellence in Materials, Ageing and Life Prediction.

Resilient and Sustainable Systems

This theme brings together expertise in sustainability, process engineering, infrastructure and environmental systems from CEE, CES, CPE and MES. Addressing the challenge of living sustainably and well, our work has had a major influence on the Sustainable Development research and policy-making agenda, as well as civil society, since the establishment of CES as an inter-departmental Centre in 1992.

Building on our international reputation in environmental systems analysis, infrastructure asset management, and chemical/bio-chemical process and energy conversion systems, our staff have pursued research into inter-disciplinary tools for the design and management of technologies, systems and infrastructures. Our work has expanded into a range of cutting-edge approaches such as dynamic simulation, agent-based and data-driven modelling, and uncertainty quantification. We have proposed improved and new processing routes required to convert available resources to useful products, transform/convert waste (plastic and water) to energy, recycle unused material and reprocess used material, within frameworks that encompass criteria relating to resilience and sustainability. Whether considering a critical infrastructure, supply chain or energy demand, we aim to adopt a holistic systems approach and develop new concepts of hierarchical modelling based on the integration of spatial-temporal data from wide-ranging sources and time points within a smart sensing framework. We place particular emphasis on bringing the latest research to bear in developing practical approaches to support decision makers and policy analysts confronted with complex and conflicting issues from the various stakeholders involved. Epitomised by the work of the Centre for the Understanding of Sustainable Prosperity (CUSP), we address the technical, economic and social challenges of achieving sustainable prosperity and making the transition to a fairer, greener economy (see Impact Case Study).

Engineers at Surrey have collaborated closely with Thames Water Utilities Limited (TWUL, see Impact Case Study) and Network Rail to support investment in asset maintenance and renewal strategies (>£1M industrial funding in period). This includes the creation of digital twins for physical assets, e.g., by integrating numerical modelling with in-service monitoring, field and controlled laboratory testing at different scales for an entire railway bridge. We have undertaken bespoke testing and design orientated research on offshore wind foundations with: (i) key industry partners, such as RWE, SLPE and Tokyo Electric Power Services Co, who have provided funding (>£300k in period) and contributed operating data and expertise; and (ii) academic partners in Europe, India and China. During the REF period, we have been awarded six prizes from the Institution of Civil Engineers, for publications ranging from geo-synthetics and waste to complex structures and asset management.

Our research on clean air (see Impact Case Study), a nascent activity in REF2014, has been supported by a grant portfolio of c.£8M over the REF period. It has generated tools and guidance, e.g., on green infrastructure (GI) used both locally (Guildford Living Lab) and internationally (>10 Official Development Assistance (ODA) countries) and has featured in over 1500 news articles. Work in this area extends into innovative ways to understand the impact of air pollutants, as well as viruses, on human health. We use a multi-scale approach across biological length scales from the cell, lung, person (surrounded by GI) up to the neighbourhood scale (EPSRC with Imperial College and Edinburgh). We have targeted exposure mitigation of children in prams to harmful air emissions, in collaboration with BRIZI Ltd. Research in this theme has strong interfaces with other themes, particularly Innovation for Health.

Technology and Society

This theme unites two internationally leading research centres, ICS and CVSSP, that collaborate with the broader University community e.g., Surrey Business School, School of Law, School of Health Sciences and School of Psychology, to ensure that their world-leading technical innovations find applications across all sectors of society. CVSSP founded and leads the AI@Surrey network bringing together over 30 groups and 300 researchers across the University to foster application of leading AI technology in domains from healthcare to personal data privacy and new business platforms.

CVSSP is an internationally recognised leader in audio-visual machine perception research. It is unique in bringing together expertise in audio and visual machine understanding with the central goal of creating machines that can 'see' and 'hear' to understand the world around them. The Centre's research is the realisation of fundamental advances in AI and machine perception and their application for the benefit of society and the economy, spanning healthcare, security, entertainment, robotics, communications and audio-visual data analysis. CVSSP is ranked first in the UK, third in Europe and 11th in the world for Computer Vision (csranking.org). During the REF period, CVSSP has grown from 90 to 180 researchers, with a research project portfolio of £29M (with £21M 'live' EPSRC awards). The national importance of CVSSP research is recognised by the Centre being a lead partner in the BBC Audio and Data Science Research Partnership, two flagship EPSRC programme grant awards in audio-visual signal processing (S3A: Future Spatial Audio for an Immersive Experience at Home, see Impact Case Study) and facial recognition (Face Matching for Automatic Identity Retrieval, Recognition, Verification and Management), leadership of the EPSRC Centre for the Decentralised Digital Economy (DECaDE), an EPSRC platform grant funding in Audio-Visual Media Research, a Multidisciplinary University Research Initiative (MURI) award in Semantic Information Processing and two Dstl programme grants in signal processing.

In 2013 the University was awarded £12M from HEFCE, matched by £24M from industry, to set up the world's first 5G Innovation Centre (5GIC), including a national 5G test bed, with the aim of putting the UK in the driving seat for 5G (see Impact Case Study). A new Institute (ICS) was formed with University co-funding, subsuming the existing research centre and incorporating the new 5GIC. During this REF period 5GIC has built a collaboration with 26 major industrial partners and over 300 SMEs and increased industrial funding to £75M. We have established one of the world's first standards-compliant 5G networks including developing our own Core network, ahead of industry, and established a 70 small-cell 5G mobile network covering the campus and surrounding area. ICS has established seven research work areas with a new paradigm of integrated industrial research which have produced outputs that have contributed to standards and enabled the UK to be one of the first in the world to roll out 5G. We have driven UK Government policy on 5G including a £200M Department for Digital, Culture Media & Sport (DCMS) research programme and roll out of 5G to the UK regions, in addition to promoting and establishing 5G Pioneer frequency bands across Europe.

Future Mobility and Space

This theme combines the expertise in MES and SSC in automotive, aerospace and space engineering.

In 2014, automotive engineering was an emerging activity with two members of staff; today the Centre for Automotive Engineering (CAE) includes eight academics, one technician and more than ten research fellows. The Centre is unique in bringing together expertise in vehicle dynamics, advanced control, and electric powertrains, with the central goal of creating new control solutions for the next generation of electric vehicles with multiple chassis actuators and automated driving capabilities (see Impact Case Study). During this REF period, CAE has been awarded c.£10M of research funding through a portfolio of 15 UK Research and Innovation (UKRI) and European projects (being one of the most successful academic research teams in Europe within the Green Vehicle calls of Horizon 2020), as well as industrial projects funded by leading car manufacturers and their suppliers. Synergies have been built with the 5GIC regarding connected and automated vehicles in the EPSRC Cloud Connected and Edge Connected and Autonomous Vehicles project, as well as with CVSSP for industrially funded research on advanced state estimation integrating conventional vehicle sensors with vision-based systems. CAE has also developed its own vehicle platform for research on automated driving, i.e., the ZEBRA (Zero Emission test Bed for Research on Autonomous driving) vehicle.

In REF2014, the Rolls-Royce University Technology Centre (RRUTC) in Turbomachinery was recognised as a key strength of our aerospace research. Evolving into the RRUTC in Thermo-

Fluid Systems, it has grown its staff complement (from 2 to 4 core academics) and expanded its remit, such that the expertise in numerical work (see Impact Case Study) now has additional funding from European projects (with the German Aeronautical Research Program, the German Aerospace Center and Dresden University of Technology). In addition to exploiting modern computing architectures for computational fluid dynamics (CFD) codes, RRUTC staff have worked in collaboration with colleagues in Enflo contributing to the Innovate UK funded PINES project on novel heat exchanger technology.

Researchers in the SSC have expertise in many varied aspects of satellite design, control and robotics, and have developed a world-wide reputation for developing innovative solutions in life-cycle satellite engineering that have been adopted by the space industry (see section 4 and Impact Case Studies). The Surrey-led EPSRC Future AI and Robotics for Space (FAIR-SPACE) National Hub was launched in 2017 with an £8M research grant from UKRI and the UK Space Agency, matched by a £7.5M industrial fund and a projected £15M business development fund. It brings together leading experts from academia, industry and government, and aims at pushing the boundary of AI robotics for future space utilisation and exploration. The hub is advancing knowledge and technologies in orbital manipulation, extra-terrestrial vehicles, and robotic support for astronaut missions. SSC has also been awarded £2M to develop a tool that will provide the UK Met Office with global maps of radiation levels in the atmosphere during solar storms; this project is part of the Space Weather Instrumentation, Measurement, Modelling and Risk programme funded by the Natural Environment Research Council (NERC).

Innovation for Health

Work in this theme leverages our engineering core expertise to deliver innovative solutions across a range of areas and demonstrates our ability to translate from laboratory to product by having an integrated approach to research and innovation. We have strengths in technique and sensor development for disease detection and health monitoring, including wearable technology, and model development for understanding, optimising and innovating formulated products, including pharmaceuticals, foods and nutrients for a healthy nation. The hardware developments (e.g., the 'sneezeometer' (see section 4)) are complemented by advanced signal processing, frequently using machine learning approaches, to interrogate data more quickly, accurately and reproducibly than humans, in the field of epilepsy, dementia and medical imaging. In terms of treatment, we are researching bio-nanomaterials for scaffolds for hard and soft tissue regeneration, biodegradable polymers and glasses for drug delivery and novel composites for dentistry.

Building upon our research in particle technology, we have created a strong group in formulated products, recruiting six additional academic staff during this REF period and establishing extensive industrial collaborations, including a strategic partnership with Unilever. Our research focuses on two areas: i) innovation in product development and manufacturing; and ii) innovative tools for topical drug delivery. For the former, we have been working closely with major global players in pharmaceuticals (such as AstraZeneca, MSD, Janssen and Genentech), and fast-moving consumer goods (such as Unilever). We have developed physically rigorous digital models for formulation development and product manufacturing, which are now capable of simulating industrial scale manufacturing processes. This research is supported by over £10M from industry, the Royal Society, EPSRC and the European Union (EU). Our research is further enhanced with a recent €1.8M collaborative project on Pharma 4.0 with Janssen Pharmaceuticals and Ghent University, funded by the VLAIO, Belgium.

In terms of innovation tools for drug delivery, we have pioneered the development of multiscale *in-silico* models, capable of predicting transdermal permeation and absorption without relying on fitting to experimental data. Our computer-aided design and risk assessment tools for topical drugs, personal care products and agrochemicals do not involve animal testing. Unilever is using these tools to support fast screening of skin care additives and safety assurance. Our research in this area led to Cosmetics Europe funding our participation in their model evaluation programme in 2017. Our research has received sustained funding from the US Food & Drug Administration, European Crop Protection Association and Innovate UK (with projects with three

SMEs) and three Biotechnology and Biological Sciences Research Council (BBSRC)/National Centre for 3Rs (Replacement, Refinement, Reduction) studentships.

Our Centre for Environmental Health and Engineering, a designated World Health Organization (WHO) Collaborating Centre for the protection of water quality and human health, has developed guidance for small water supply systems and contributed to the protection of aquatic environments from micro-plastic pollution.

We are drawing on our extensive track record in air quality to support the fight against Covid-19, particularly in the field of airborne transmission by partaking in joint EPSRC projects with Cambridge and Imperial (CO-TRACE: COvid-19 Transmission Risk Assessment Case studies - Education Establishments; COVAIR: Is SARS-CoV-2 airborne and does it interact with particle pollutants?) and other stakeholders (e.g., Guy's and St Thomas' Charity), as well as contributing to the Royal Society's Rapid Assistance in Modelling the Pandemic (RAMP) initiatives, including leading a Task 7 subgroup on case studies in enclosed environments.

The Surrey-Imperial Dementia Research UK £20M Care Research and Technology Centre (CRTC) was established in 2019. It brings together CVSSP expertise in AI and machine learning with Surrey's Sleep Research Centre to advance the understanding of chronobiology and sleep/wake behaviour to develop interventions to monitor and support individuals with dementia. Research is pioneering the non-contact analysis of sleep behaviour through multi-modal sensing to develop new practical, low-cost healthcare technologies that can be deployed at home and in care facilities. The CRTC built on award winning research in the Department of Health/NHS Technology Integrated Healthcare Management (TIHM) programme of research led by CVSSP and ICS, which developed IoT and AI sensing capabilities for monitoring behavioural change of dementia patients at home for early intervention. This pioneering research received wide recognition including the 2018 HSJ Award for Improving Care with Technology.

1.3 Generating Impact

As a University, we aim to increase societal benefit through enhancing our already strong innovation ecosystem. Working with the users of research to co-create programmes that will lead to impact is part of our funding strategy and its success is manifest in the high proportion of publications from members of this UOA co-authored with an industrial partner, ~12% over the REF period.

The Innovation Strategy Directorate has several teams that work with staff in the UOA to generate impact from their research. As well as managing intellectual property matters (patents and licences) and supporting University start-ups and spin-outs (the Technology Transfer team), the University has a Partnerships team that manages schemes such as the EPSRC Impact Acceleration Account (IAA) and its predecessors, (in addition to IAAs from three other RCs) and Knowledge Transfer Partnerships (KTPs). So far 58 projects from applicants from Engineering have received support, totalling £1M from the EPSRC IAA and matched with £1.36M from industrial partners (including Arup, BP, EADS Astrium, Network Rail, Proctor and Gamble, Samsung, Tata). In the REF period, eight KTPs, with a total of 273 months of KTP Associate time have been completed and four more projects are in progress. To help our engineers to foster better connectivity with the Professional Services teams, we have seconded two colleagues from the Faculty to the Partnerships Team to be Commercialisation Fellows for six months (in 2020), supported by the EPSRC IAA.

Throughout the REF period we have had Impact Leads within each Department, run events and provided grants to facilitate the impact agenda. Our final selection of Impact Case Studies (ICS) was made from a much wider array of submissions; some of these other examples of impact are included in Section 4. The chosen ten Cases showcase the success of our strategy and support for impact, across the whole UOA. They show the breadth of our impact, encompassing long-standing relationships with individual companies (e.g., with Rolls-Royce, SSTL and TWUL) pioneering first in-kind demonstrations, only made possible through industrial collaboration (e.g.,

5G, electric vehicles, new audience experiences, nanotechnology products and space debris removal) and advancing policy and stakeholder engagement for global change (e.g., sustainable prosperity in a post-growth economy and shaping urban air pollution guidance). The ICS exemplify Surrey's approach to creating teams that bring together partners and collaborators, staff and students at different levels. Dissemination and outreach activities undertaken by GCARE and the RemoveDEBRIS project (led by SSC to demonstrate space debris removal technologies) include undergraduates on individual projects working together with PhD researchers, encouraging our student body to share our passion for solving real world problems.

1.4 Future Strategy for Research and Impact

The spectrum of research undertaken across the UOA includes numerous national and international priority research areas, e.g., autonomous systems, nanomanufacturing, sustainability and resilience, future mobility and the digital society. The development of our priorities is an on-going process, remaining agile to these national and international priorities and opportunities; as such, the strategic priorities are reviewed annually and evaluated as to their contribution to the institutional Research and Innovation Strategy and inter-disciplinary themes in: Lifelong Health; Sustainability; Technology and Society; and Urban Living (see Institutional Environment). Oversight of the Engineering strategy is the responsibility of the Faculty Research Committee (FRC), chaired by the Associate Dean Research and Innovation (ADRI) and with academic and professional services representatives from across the Faculty and reporting to Faculty Executive Board (chaired by the Executive Dean). Our future strategic priorities for Engineering at Surrey are to:

- **Build critical mass in areas of excellence, improve connectivity between those areas to leverage synergies, building on our unique attributes.**

Research in 5G communications is moving to 6G. A roadmap for the 6GIC, developed in conjunction with the numerous stakeholders of 5GIC, has been published, highlighting the vision for 'teleportation' in which all the senses are stimulated to mimic the experience of physically being in another location. To realise this concept will require a massive collaborative effort, bringing together engineers within the 6GIC with other researchers, such as those working on new materials, and incorporating colleagues with expertise in human behaviour and human-machine interfaces. We have funded four internationally renowned Professors via part-time appointments to work with Surrey research teams on key 6G technologies. Similarly, we are using the pan-University AI@Surrey network, established in 2019, as the foundation of a future Institute which will enable us to continue to expand our AI expertise into 'people centred' application areas, bringing together researchers working on face recognition with experts in ethics and law. In the area of Sustainability, we will use our research to spearhead the University effort to be net carbon zero by 2030; from formulating policy to delivering engineering solutions, such as our novel solar cells including hybrid perovskite devices, and engaging directly with key industries and civil society.

- **Expand the number, depth and nature of our partnerships with research users.**

We will continue to co-create programmes of mutual benefit that plan for a seamless transition from research to impact. For example, our new £15M EPSRC Prosperity Partnership with the BBC aims to provide global audiences with AI-enabled personalised experiences, improving accessibility and inclusion for mass media. We will use our new Centre of Excellence in Materials, Ageing and Life Prediction as a platform for reaching out to other potential partners concerned with the protection of assets to form a hub-and-spoke model based at Surrey.

- **Continue to be a partner of choice for other academic institutions.**

The Universities of Oxford, Birmingham, Cambridge, Reading and Southampton alongside Imperial, Queen Mary, and University College London are examples of our extensive academic collaborations with UK institutions during this REF period. We will strengthen these further by building on the foundations provided by the RRUTC, GCARE, AI@Surrey and FAIR-SPACE. Internationally, in addition to the collaboration that exists within our University Global Partnership Network (UGPN), a consortium of North Carolina State University (USA), the University of São Paulo (Brazil) and the University of Wollongong (Australia), we will work with other institutions, including the ten with which we have formal Memoranda of Understanding, specific to this UOA. For example, the University of Tokyo has chosen CPE as their primary collaborative partners to develop numerical methods for industrial scale process modelling. The collaboration has received funding from the Japan Society for the Promotion of Science.

- **Extend the opportunities for research on campus and within the local community.**

We will do this via, for example, Citizen Science initiatives and maximising use of our Living Lab initiative, now in its second year. We will continue to bring together and build on previous initiatives e.g., energy use and behavioural aspects of travelling to work, novel renewable technologies for clean energy, clean air and engaging the local community, including school children, in monitoring air pollution and looking at the beneficial effects of green infrastructure.

- **Develop the next generation of research leaders and build strong teams.**

From PGRs to established academics, we will continue to provide support and development opportunities to enable researchers to build their careers, thereby ensuring a healthy 'talent pipeline'. We will encourage and actively support Fellowships (such as the 5 year EPSRC Fellowship obtained by one of our early career researchers (ECRs, Sporea). To underpin the growth in research activity we plan to nucleate more CDTs, following the example of CVSSP, which has established a hub for high-quality cross-disciplinary post-graduate research (PhD) and taught (MSc) training in AI and Machine Perception for industry. The Centre's annual PhD intake has grown from 12 per annum in 2013/14 to 27 in 2020/21, with >50% of the cohort sponsored by industry.

1.5 Interdisciplinary Research

Referring to Table 1, all our research themes bring together engineers and scientists from various backgrounds. Their activities are complemented by the expertise available within the Faculty, more broadly within the University and by working with collaborators globally from both academia and other organisations (see section 4). We encourage and support this in a number of ways; offering opportunities for colleagues to showcase their research to other colleagues at networking sessions, such as annual Festivals of Research, monthly Faculty Research Focus events and through networks such as AI@Surrey.

Our work on sustainability is pan-University; colleagues from all engineering and physical science disciplines work with social scientists, behavioural scientists, economists and experts in policy and law, to ensure that the technical solutions are fully integrated with the human factors, which can be drivers for, or barriers to, adoption. This area also benefits from input from mathematicians with expertise in modelling complex systems, such as the weather, which has a pivotal role in the dispersion of pollutants.

Within the University's One Health agenda, members are working with a range of clinicians and scientists. The CRTC brings together experts in AI with mathematicians and colleagues from the Sleep Research Centre (Surrey) and with neuroscientists (Imperial).

1.6 Research Integrity and Open Research

The Engineering at Surrey culture promotes open, transparent practices, making research data and outcomes available to all. ORCID profiles are encouraged and all manuscripts accepted for publication, e-theses and other outputs are deposited in the University's open access repository. Staff in the UOA have received awareness raising presentations and participated in the University's Open Research Working Group (Wang, Yeomans).

Staff conduct research with the highest standards of integrity and ethics, applying the University's 'Code on Good Research Practice' and playing an active role in the University's wider infrastructure including: Chair of the University Ethics Committee (2019- to date (Wells)), Representative on the Human Tissue Research Operations Group (Sui) and the ADRI (Yeomans) is a member of the University's Research Integrity and Governance Committee.

We have, however, gone far beyond that over the REF period, following the leadership of the Vice-Chancellor, who is Chair of the UK Forum for Responsible Research Metrics. The ADRI is also working with the University's Metrics Advisor to develop more responsible and effective use of metrics in the development of research strategy.

2. People

2.1 Staffing Strategy and Staff Development

Our strategy has been to promote excellence through creating fewer but more focused research themes and to use planned growth and changes in the staff complement to increase the diversity of our staff, principally in terms of gender and career stage, to build strong teams. We note that in terms of protected characteristics, the recruitment and progression of women is still the biggest issue for our disciplines, so we are pleased to report that in growing from 162 to 184 staff, we have increased the proportion of women from 14% in 2014 to 21% now.

In creating a supportive and diverse community, we recognise that staff (and students) can face a variety of wellbeing and mental health issues, so we have significantly expanded our support in this area, through the creation of a Wellbeing Centre which brings together a number of services, which were separate at the start of the REF period, to provide an enhanced and more holistic approach. More locally, we have Wellbeing Champions and we have rolled out training to equip mental health first aiders.

Academic staff hold teaching-only, research-only (Research Fellow, Senior Research Fellow and Professorial Research Fellow) or teaching and research contracts (Lecturer, Senior Lecturer, Reader and Professor). Full-time equivalent positions from 0.2 to 1 are available on fixed term and open-ended contracts. There are no 'zero hours' contracts and only 13 of the 184 staff in this UOA are on fixed term contracts.

In addition to facilitating part-time working, we have deliberately used fractional appointments to enable key researchers to engage with us whilst maintaining a position in industry (e.g., within CPE, Professor Guoping Lian, Unilever and Dr Belsey, NPL). We have used the prestigious Vice-Chancellor's Fellowship Scheme to enable eminent researchers in overseas institutions to have roles at Surrey (e.g., Prof. Razal, Physics and Deakin University; Prof. Cheng, ATI and Tsinghua-Berkeley Shenzhen Institute; and Prof Morawska, CEE and Queensland University of Technology).

All staff new to an academic role start with a reduced teaching load for the first two years and are assigned a Senior Colleague, who will offer advice on all matters, including establishing an independent research career and how to go about securing funding. To support new investigators, the Head of Department provides a small 'start up' fund (typical £5k) for the new appointee to use in their first year. We also prioritise funding for doctoral studentships, to help initiate research, and assist our new starters to establish their network of collaborators and take advantage of matched funded studentships.

All staff have an annual appraisal/development review. We operate a workload allocation model (WAM) which recognises work undertaken in support of collegiality, administration, leadership, management and engagement, as well as research and teaching. The WAM protects time for scholarship and personal development; we aim to have at least one day a week when colleagues do not undertake timetabled activities.

As well as identifying training needs, the staff development review helps to identify ways in which colleagues can build a case for promotion, well ahead of an application. When colleagues are ready to make such a case, they are supported by workshops appropriate to their career stage. We recognised that whilst women are as successful as men when they apply for promotion, they apply less frequently, so we have run annual sessions specifically for female engineers.

During the REF period there have been seven annual promotion cycles. During that time, 76 individuals have been promoted, 9 of them twice (four to Senior Lecturer and then Reader; five to Reader then Professor) and one person has been promoted three times, from Lecturer to Professor, giving a total of 97 promotions. Of these 97 promotions, 23 (24%) of these were awarded to women.

2.2 Support for Researchers

Early Career Researchers

We have prioritised support for ECRs. During the period we have hosted 7 Marie Skłodowska-Curie Actions Fellows, a Royal Academy of Engineering Fellow (Mustafa, CVSSP), a Royal Society University Research Fellow (Sacchi, Chemistry), a Leverhulme Early Career Fellow (Malleson, CVSSP) and two EPSRC Early Career Fellows (Jurewicz, Physics and Gao (Yue), ICS). Within the Faculty, we have established a Fellows Network for colleagues with such Fellowships and Senior Research Fellows; 14 are included within this UOA. The network has two functions: to enable the Fellows to access the broader networks associated with the Fellowships and to provide a framework for the Fellows to advise and support other researchers.

Whilst Faculty and University funding is available on a competitive basis for all staff, ECRs receive preferential consideration and, for example, in the last two years, three (Bussemaker, Guo and Harris) have been awarded funds from Surrey's Institute of Advanced Studies to run workshops and host fellows for short visits. As a University, we have recently run a call specifically for ECRs to bid for capital equipment, with two colleagues in Engineering receiving c.£400k. All staff can access a mentor; this is particularly encouraged for ECRs; all PGRs can also request a mentor from academia or industry facilitated by the Doctoral College.

For newly appointed permanent academic staff our support is both financial (provision of studentships) and administrative (bespoke support and a mandatory peer review process). This has been translated into high success rates for New Investigator Awards (NIAs) (or the predecessor First Grants) and 19 of our colleagues (15 men; 4 women) have successfully applied for funding under these schemes in the REF period. We also recognise the challenges faced by colleagues returning from a career break and have funded and hosted four Daphne Jackson Fellowships in the REF period (in Chemistry, CEE, CVSSP and SSC) as well as hosting a Wellcome Trust Career Re-entry Fellow (Florescu, CVSSP).

Exchanges Between Academia and Industry

From the integrated year of Professional Training in our undergraduate programmes, our Practitioner Doctorate in Sustainability and EngD in MiNMaT, to our Strategic Partnership with NPL, we have always fostered meaningful interactions with industry. These are facilitated in various ways, for example, three colleagues (Cox, Evans, Zhao) have joint appointments with NPL. Others have secondment arrangements such as: Collomosse (CVSSP), currently with Adobe for 50% for three years; Lee, J (CES) spent one year working 50% with Temple Group

Management Ltd.; and Marti-Cardona (CEE) spent 5 months working 50% with Agrimetrix on remote sensing for sustainable agriculture. These are in addition to colleagues in industry having fractional appointments at Surrey (e.g., Belsey (NPL) and Xiang (Samsung)). Further, a number of colleagues have fellowships specifically aimed at promoting academic-industrial exchanges, such as RAEng Industrial Fellowships (Bussemaker and Velliou, CPE), Royal Society Industrial Fellowship (Dikaivos, CVSSP and Chen, CPE), NERC-UKRI Industrial Innovation Fellowship (Gadkari, CPE and Harris, CES) and Royal Society of Edinburgh Enterprise Fellow (Steer). In October 2020, Jurewicz was awarded a Future Leaders Fellowship with Advanced Materials Ltd. She will spend 80% of her time with the company returning to Surrey for one day a week over the next four years.

Staff use our Visiting Researcher scheme to nurture international and industrial relationships; in a typical year, 40 visiting researchers are actively contributing across Engineering. In 2019 they came from Austria, Canada, Italy, Iraq, Japan, Kuwait, Mexico, PR China, Romania, South Korea and Turkey, in addition to the UK.

2.3 Research Students

The UOA is fully aligned with the practices of the Doctoral College (DC). The University Research and Innovation Strategy 2019-2022 positions postgraduate, postdoctoral and early-career researchers at the heart of the University research and innovation ecosystem. Over the REF period, we have seen doctoral graduations rise from an average of 87.6 to 94.1 per year, equating to an increase from 3.2 to 4.0 per FTE academic submitted to REF2014 and REF2021, respectively. Our current PGR population is 450 students (31% women; 11% part-time; 38% international).

Funding for studentships comes from several sources including 24% and 12% funded by the EPSRC and EU, respectively. In addition to students who support themselves or have personal studentships, there is the EPSRC Doctoral Training Partnership (DTP), CDT in MiNMaT, the NERC SCENARIO (SCience of the Environment: Natural and Anthropogenic pRocesses, Impacts and Opportunities) DTP (joint with the University of Reading) and DC competitions. We make extensive use of industrial contributions to fully or partially support students, e.g., the Practitioner Doctorate in Sustainability and the Postgraduate Institute for Measurement Science, which was established in 2015 as part of the NPL-Strathclyde-Surrey partnership.

The Doctoral College Studentship competition has bought an additional 30 fully-funded research studentships to the UOA since 2018, with a focus on support of early career academics and researchers (19 studentships), and international excellence (6 studentships). A further 20 studentships were supported 50% by the DC and 50% by industrial partners, representing an external investment of ~£590k into doctoral training. A Vacation Internship programme provides an early experience of research for undergraduates and an early experience of supervision for ECRs.

All students have at least two supervisors from the University; many have an industrial supervisor in addition. This means that the supervisory team has a mix of complementary skills and is an ideal way to bring colleagues at the start of their academic careers into the process. Improvements in student monitoring have resulted in the earlier identification of issues and improved completion rates. For those cohorts substantially completing within the REF period, the fraction of students submitting on time increased from 65% to 92% (2009/10 and 2015/16 cohort values from linear trend), while the overall completion rate was maintained at 82%.

In addition to the extensive formal and informal training and support offered by the DC, including the services of career specialists specifically for PGRs and the mentoring scheme, we recognise PGRs as an integral part of the engineering research community. They receive all Faculty Research and Innovation Newsletters, attend faculty research events and are members of the cross-university networks.

We also encourage our PGRs to engage with communities nationally and across the world, to undertake exchanges, present their work and participate in competitions, so that they can see their work in a global context and receive feedback on their endeavours. In 2018 we hosted the 15th BGA Young Geotechnical Engineers Symposium (>60 delegates from UK universities). We have also established a number of collaborative PhD training programmes with universities, including a trinary PhD training programme jointly with Unilever and the Institute of Process Engineering at the Chinese Academy of Science, and a dual doctorate with the University of Wollongong, as well as partnerships with Wuhan University of Technology, Zhengzhou University and the Southern University of Science and Technology (SUSTech) in China.

Through the mechanisms described above we provide a lively and supportive environment in which we champion the achievements of our PGRs. In the annual VC Awards, there is a Postgraduate of the Year category with a Faculty winner, as well as an overall University winner; in 2018 and 2019 the overall winners were students from Engineering. We also encourage participation in external competitions and our PGR achievements include: the British Machine Vision Association Sullivan PhD Thesis Award for the most outstanding UK PhD researcher in Computer Vision, which was awarded to CVSSP students Dr Karel Lebeda (2017) and Dr Oscar Mendez (2019); Pavlos Giannakou winning the IET Hudswell Award for Postgraduate Research (2020) for outstanding work in printed nanomaterials; and MiNMaT EngD student Maria Cann winning the Institute of Materials, Minerals and Mining (IoM3) Young Persons' Lecture Competition in 2015. Additionally, seven MiNMaT students have been awarded prestigious Royal Commission for the Exhibition of 1851 Industrial Fellowships in the REF period.

2.4 Equality and diversity

The University is committed to creating an inclusive environment in which everyone is encouraged to reach their full potential. Whilst our data show that within engineering we have increased diversity over the REF period and are above sector average, we are not complacent. Three Departments (CES, EEE and MES) contributing to this submission have Athena SWAN Bronze Awards, whilst Physics has Juno Practitioner status. Alongside Departmental groups, the Faculty has an Equality, Diversity and Inclusion (EDI) Committee, which reviews data, monitors/updates action plans and organises events to celebrate, for example, International Women's Day, Women in Engineering and Black History Month. Colleagues within the UOA have also played pivotal roles in ensuring that University policies support the wellbeing of all staff and students, including those with protected characteristics.

Within this UOA, equality of opportunity is promoted effectively and applies to all research activities including bidding, conference attendance, promotion, and flexible/remote working. All meetings are held between the core hours of 10 to 4 and the University's Flexible Working Policy considers a wide range of arrangements. A significant number of the people in this UOA are working part-time (27 individuals, representing 15% of the return). We have examples of men and women working part-time to facilitate caring responsibilities and others making use of flexible working, including compressed hours.

During the Covid-19 pandemic most staff and PGRs have been working from home. The University was prompt in providing practical support such as the provision of office furniture, IT equipment *etc.*, in addition to the broader extensive support for staff and students, co-ordinated by the Wellbeing Centre. Supervisors were regularly advised and supported, through PGR Directors and DC staff, on how to respond to the changing nature of requests from PGRs facing particular challenges during this period.

Everyone involved in recruitment and/or line management of staff and students must undertake enhanced face-to-face Unconscious Bias training in addition to on-line training, which is mandatory for all staff. Improved recruitment and work practices have helped to increase the diversity of staff in Engineering, resulting in increases of under-represented groups, such as women (from 14% in REF2014 to 21% of the current UOA) and Black, Asian and Minority Ethnic (BAME) colleagues (from 24% in REF2014 to 32% of the current UOA).

In 2018, the Vice-Chancellor's Inclusion Career Investment (VICI) Awards were formalised (after a short pilot). They are available to all permanent staff and research-only staff on fixed-term contracts. These offer financial support for those staff needing to provide cover for caring responsibilities whilst attending conferences, workshops *etc.* Further, the scheme has been expanded to incorporate the VICI Academic Returner Awards, which provide £5000 to research-active staff returning from Maternity Leave, Shared Parental Leave or Career Breaks, to help them to re-establish their research activities. This is accompanied by a commitment to release these colleagues from teaching and/or administration duties to enable them to concentrate on their research in their first year of returning to work. Recognising the relative newness of the scheme, only one member of this submission has benefitted from this type of funding, but it is being actively promoted.

In accordance with University policies, all staff involved in selecting the UOA output portfolio underwent both on-line and group-based training in equality and diversity. Selection meetings were attended and overseen by the University's Head of Research Performance who monitored compliance with the Institutional REF Code of Practice; some were also observed by a member of the REF2021 EDI Working Group. The Code paid due regard to the importance of making a submission to REF that is cognisant of equality and diversity issues. This extended to the selection of the output portfolio, where 33% of outputs are attributed to BAME staff, who represent 32% of all staff in the UOA. 17% of outputs are attributed to women, who represent 21% of the UOA currently, from a starting point of 14%; this reflects the ongoing work to improve gender balance across all career stages, particularly Professor and Reader. We are encouraged by the trajectory in Lecturer/Senior Lecturer roles and have active plans to achieve balance across all career stages.

3. Income, Infrastructure and Facilities

3.1 Research Income

Since REF2014, Engineering at Surrey has recognised the need to grow its research income and thus sets annual targets for Departments and Research Centres. Alongside growth, a second aim during the REF period was to increase the amount of funding from Research Councils, especially from EPSRC. This has been achieved such that Surrey is a Strategic Partner University (currently Tier 1), is in a strong position to renew the Impact Acceleration Account and has increased funding available via the Doctoral Training Partnership (DTP).

We have met our aims, achieving significant growth with research income rising from £15.5M in 2013/14 to **£29M** in 2019/20. This equates to a rise per FTE from £530k in REF2014 to **£1.05M** now. Income from bodies that now make up UKRI was £4.47M in 2013/14 rising to **£10.4M** in 2019/20.

All researchers at any career stage have access to a wide range of support services, including a Faculty-run peer review process for research proposals. Colleagues preparing larger or more complex bids are allocated a Bid Support Manager from Research Strategy. Alongside the more general support, Engineering benefits from the services of three dedicated members of the Partnerships Team. Part of our strategy for increasing funding from UKRI was to increase the scope of the bids, rather than simply increase the number of bids. The support available to researchers has enabled us to build consortia to enable us to meet our aims. We have 21 grants with over £1M attributable to Engineering at Surrey (*e.g.*, EPSRC Stepping Towards the Industrial 6th Sense, Gu, CPE; EPSRC Manufacture of Safe and Sustainable Volatile Element Functional Materials, Dorey, MES; EU Optical Ultra-Sensor, Pollnau, ATI; Model for Atmospheric Ionising Radiation Environments, part of the Space Weather Instrumentation, Measurement, Modelling and Risk programme, led by the Science and Technology Facilities Council with NERC, Ryden, SSC) and a further 36 over £500k.

3.2 Infrastructure and Facilities

Engineering at Surrey benefits from an impressive suite of experimental and computing facilities ranging from those that we host for the benefit of the UK to bespoke infrastructure to meet the needs of individual researchers. This physical infrastructure is supported by a range of Technical (63) and Professional Services (45) staff. Over £34M has been spent upgrading equipment and space used by researchers over the last REF cycle.

National Facilities

The EnFlo wind tunnel facility is unique in the UK and among fewer than five worldwide that can generate flows to simulate the stratification of the Earth's atmosphere. One of its primary uses is the study of how airborne pollutants are dispersed in urban environments (EPSRC Managing Air for Green Inner Cities). As well as providing advice to the Home Office, in the current REF period, Surrey researchers using EnFlo have also advised the Norwegian Defence Research Institute, Public Health England and oil companies (via Concawe). The facility features a four-channel fast-flame ionization detector enabling dispersion and air quality research, as well as a 3D laser doppler anemometry system, the "Smart Cube" (a national calibration standard for urban canopy flows funded via a NERC grant for £140k) and a rake of five advanced seven-hole probes. The EnFlo facility is part of both the National Centre for Atmospheric Science Atmospheric Measurement and Observation Facility, and the National Wind Tunnel Facility. The laboratory has achieved a level of automation unmatched in the UK, enabling the fully remote operation of facilities and instrumentation and a 24-hour working cycle. We offer one of our undergraduate students an opportunity to undertake a year of Professional Training with EnFlo as part of their degree programme.

The University of Surrey Ion Beam Centre (SIBC) leads the EPSRC UK National Ion Beam Centre, which provides a single point of access for the UK research community to world-leading ion beam modification and analysis infrastructure and expertise. SIBC provides ion beam implantation and analysis facilities for academia and industry predominantly in the UK, but also around Europe, the USA and China. It has been ISO9001 certified since 2007 and is part of the EU project RADIATE: Research And Development with Ion Beams – Advancing Technology in Europe. The SIBC runs two implanters for implantation and irradiation, allowing implantation to be provided from 2 keV up to 4 MeV. We have commissioned two single ion implanters to support solid state quantum technology applications (using an EPSRC grant for £2.95M); these are capable of implanting a single ion with 20 nm accuracy and can produce an ordered array of 100,000 atoms in a few hours. These are still at the experimental stage being the first instruments of their kind.

The analysis facilities are based around a 2 MeV tandem accelerator with beam lines for analysis of samples in and out of vacuum using Rutherford Back Scattering (RBS), Elastic Recoil Detection (ERD), Particle Induced X-ray Emission (PIXE) and other nuclear probe techniques using a scanned beam, which can be focussed down to just sub-micrometre allowing elemental maps to be made. Two recent EPSRC grants have led to upgraded facilities: £500k to provide a molecular imaging probe (DAPNE) to expand the elemental analysis facilities by providing spot high resolution molecular analysis and £1.5M to upgrade the current elemental analysis facilities.

Materials and Devices

The facilities in the SIBC are part of a broader set of Characterisation Facilities that are available to everyone in the UOA but most heavily used by researchers in Materials and Devices. These include a range of light, confocal and electron microscopy (scanning and transmission) services, alongside two focused ion beam (FIB) instruments (Ga and plasma), X-ray photoelectron spectroscopy, time-of-flight secondary ion mass spectroscopy, Auger electron spectroscopy, various atomic force microscopes and two Raman suites. Over £6M has been invested in the area since the last REF submission

Investment and innovative use of the FIB has resulted in a wide range of both 2-dimensional and 3-dimensional structures. These include the world's most sensitive superconducting quantum interference devices (in conjunction with NPL), aspheric micro-lens arrays, and single electron transistors. The pioneer of these advances, Dr David Cox, authored the book '*Introduction to Focussed Ion Beam Metrology*'.

We have also refurbished laboratories to support incoming staff and the expansion of our materials research, for example, establishing the Sustainable Printing Applied Research Knowledge Hub developed as part of a 5-year EPSRC Materials Substitution for Safety, Security and Sustainability award (Dorey). Through a £2.8M laboratory refurbishment scheme, we have created a new materials for energy applications laboratory to support our growing research activities in batteries, fuel cells and catalysis.

The Surrey-NPL Non-linear Microwave Modelling and Measurement (n3m) laboratory is a world class facility for studying the multiple physics interactions in microwave devices. Allied to this are an electric field scanning probe, which uses a Pockel's effect probe, laser and polarisation analyser to map the rapidly changing electric field above the device, and a thermo-reflectance probe that allows temperature measurement of micrometre scale elements of the device with measurement time in the 30 ns range. Taken together, these offer a unique insight into the operation of real devices. This is complemented by comprehensive device modelling supported by a high-performance computing cluster.

Resilient and Sustainable Systems

The Mechanical Testing Facility (MTF) is a comprehensive experimental facility for investigating the mechanical properties of infrastructure materials and structural components at multi-scales. The facility includes an integrated suite of 11 Instron servo-hydraulic and electromechanical testing machines with a capacity of up to 1MN. It has dedicated specimen preparation areas for composites and construction materials. The MTF is currently expanding its capabilities through: (i) a new Instron drop-weight impact machine to support research on the performance of materials and components under extreme loading; (ii) a new Instron fatigue test frame with an environmental chamber to allow fatigue and corrosion testing jointly (a rare capability in UK laboratories); (iii) a new integrated Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM) space for construction prototyping by additive manufacturing (total investment of ~£500k).

The MTF has supported unique research in developing management strategies for enhancing the resilience of infrastructure systems such as national rail as well as clean water and wastewater networks. Through focused tests, the MTF has enabled fundamental research into the cyclic/fatigue performance of existing infrastructure components, structural health monitoring and damage assessment, the performance of low-carbon construction materials, and sustainable light steel framing structural systems. The MTF equipment also supports key research into inflatable structures, deployable structures for space applications, and additive-manufacturing research of metallic alloys.

The SAGE (Surrey Advanced Geotechnical Engineering) laboratory focuses on advanced testing of soil, scaled models of foundation systems and geo-thermal energy applications. The apparatuses were used for calibrating soil stiffness for seismic liquefaction applications and can be used for other applications such as bridge and nuclear power plant reactor foundations. Scaled model testing facilities, consisting of bespoke apparatus and monitoring sensors, are used in studying novel foundations for offshore wind farm developers, quantifying pipeline-soil interaction in fault crossing zones and calibrating numerical models for geothermal energy piles.

The Air Quality Lab (AQL) of the GCARE supports laboratory testing via state-of-the-art instruments and custom-built rig setups and experimental field campaigns. It is supported by numerous multi-million-pound consortium projects e.g., H2020 iSCAPE and OPERANDUM, EPSRC INHALE and COVAIR, NERC ASAP-Delhi, Innovate UK Global Home and Pollution Guardian, and Global Challenges Research Fund projects CArE-Cities and CArE-Homes

involving 11 ODA countries. The AQL houses advanced equipment including: monitors to measure fine particulate matter size distribution/number and concentrations, nano/ultrafine particles and gases; aerosol generator; weather station; high precision microbalance; relative humidity generator; furnace; leaf porometer; and data loggers. GCARE researchers have designed, built and tested custom-made experimental rigs such as our Environmental-Pollution (Envilution®) Chamber and our Filter Testing Rig for facemasks that is supporting the COVID19 research.

Technology and Society

CVSSP has state-of-the-art research facilities for audio-visual acquisition, robotics and high-performance machine learning computing. The Audio-Visual Media Laboratory is a unique production quality studio facility, with 16 UltraHD 4K studio cameras for 4D volumetric performance capture and markerless human motion measurement, and a 25 HD camera light-field video array for immersive content production together with a 64-camera scanning cage for photo-realistic digital double creation. Specialist spatial audio facilities include the Surrey Sound Sphere with 72 loudspeakers, a 48-channel microphone array and an ITU p.800 soundproof booth for critical listening experiments. We were awarded £1.5M EPSRC Equipment Funding to upgrade the Centre's unique multiple camera research facilities to portable UltraHD 4K video capture to support collaborative research in entertainment and healthcare. These facilities have enabled ground-breaking research supported by UKRI including the first use of light-field video for interactive cinematic virtual reality (VR) production (Best VR Experience – Raindance, Limina film festivals), pioneering research in immersive spatial audio (TVB Awards – Achievement in Sound), and the first real-time non-contact measurement of human and animal motion used in both healthcare and visual-effects.

The 5GIC 5G testbed covers four square kilometres of the Surrey campus with 70 small cells and a macro cell and offers 5G infrastructure including 4G and 5G core networks, mobile edge computing and access network (such as 4G and 5G radio access network), GEO Avanti satellite backhaul connection, Wi-Fi, and LoRA. We have a fully equipped 5G van with base station and two cars equipped for vehicle-to-vehicle testing plus drones with 5G base stations for UAV testing. We also have a precision NPL connected time source for network timing applications.

To complement the above we have link level and system level simulators calibrated against standards bodies and updated for 5G NR at millimetre bands. Our WiFi Simulator is based on the network simulator 3 (NS3) platform for performance evaluation of WiFi under dense deployment. The wireless testbed platform consists of several hardware components including USRP (Universal Software Radio Peripheral) x310 software defined radio modules, synchronised using an external module designed for distribution of a high-accuracy timing reference. The platform exploits also a 3.4-3.8GHz 128-element rectangular antenna array arranged in an 8x8 fashion. The Internet of Things (IoT) Testbed provides a range of facilities that allow the testing and prototyping of a wide range of IoT and robotic applications and investigations into the enabling technologies and software platforms.

The Antennas and Signal processing laboratory includes an anechoic chamber with fully automated antenna measurement software, controlling a vector network analyser and turntable. There is also a GHz sensing experiment platform (GBSense), a flexible hardware platform and application software that enables real-time over the air GHz bandwidth signal sensing, analysis, and communication at both sub-6GHz and mm-wave frequency bands. A wideband multiple-input and multiple-output channel sounder (PropSound) includes several antenna arrays, supporting up to 54 transmit channels and 32 receive channels at 2GHz and 5GHz bands. A network analyser up to 67GHz enables characterisation of mmWave systems. We also have a mmWave Transceiver System (MTS for two-way over the air communications and channel sounding, combined with LabVIEW software).

Future Mobility and Space

As evidence of our commitment to fund more demonstrators, as outlined in our REF2014 submission, we invested in the Zero Emission test Bed for Research on Autonomous driving (ZEBRA) *i.e.*, an electric quadricycle with controllable actuation on the steering, brake and drive systems, and equipped with the appropriate sensor set.

We have also invested in significant power infrastructure which allows us to undertake experimental aerothermal work, providing complementary experimental capability to the aerothermal simulations being carried out by the RRUTC. The capability is being applied to our growing activity in automotive aerodynamics, by coupling internal cooling flows with external aerodynamics, specifically for the case of electric vehicles (which have drastically different cooling requirements to conventional internal combustion vehicles).

Within the Surrey Space Centre, the Daedalus propulsion test facility consists of a vacuum chamber under near space conditions allowing for qualification and lifetime tests for electric propulsion devices. Our Aquarius air-bearing microsatellite simulator has a 3 degree of freedom platform incorporating an inertial measurement unit, control moment gyros and secondary inclinometer and complements Orion which is our air-bearing nanosatellite simulator. Commercial robotic platforms for algorithmic validation and software testing, including Pioneer 3AT, Seekur Jr, Pepper and MIRO are also available.

There are also extensive robotics facilities, which include the Surrey Autonomous Vehicle testbed, a bespoke electric car for autonomous vehicle research and a suite of robotic platforms including humanoid Pepper and Baxter platforms and mobile turtlebot units. This is complemented by the Surface Robotics Testbed Facility, which includes the Surrey autoNoMous software And Rover hardware Testbed (SMART), which is reconfigurable and customisable in terms of the Rover chassis options and has an adjustable gravity effect. We are able to simulate Martian and lunar (icy and non-icy) regolith for lab-based testing and experiments, including subsurface drilling and sampling. We also have a physical simulation testbed of 6 degrees of freedom orbital dynamics and motion of cooperative or non-cooperative target objects in free space, provided by an air bearing table and multiple robotic arms.

Innovation for Health

The water quality laboratories are the core facilities supporting research activities in our WHO collaborating centre for water quality and human health. This facility supports researchers in the context of engineering for international development and the UK's water and environmental engineering research needs in protecting aquatic environment. Researchers in this theme use two unique parts of this facility: (i) water and environmental chemistry, and (ii) water and environmental microbiology.

We have renovated the particle technology laboratory to enhance our research capacity in formulated products, which has been equipped with a wide range of analytical and process equipment, including material characterisation apparatus for particles and liquids, such as particle size analysers, porosimetry, rheometers and flowability testers, and process equipment, such as granulators, mixers, mills and extruders. This provides a unique facility for characterisation, optimisation and design of new formulations and products. It also houses bespoke equipment developed using EPSRC, International Food Policy Research Institute (IFPRI), and EU grants, which has significantly improved our research capability, leading to increasing collaboration with industry.

Use of Facilities External to Surrey

Researchers take advantage of unique facilities worldwide that complement capabilities at Surrey. Examples include advanced characterisation facilities offered by Diamond Light Source, ISIS, The Institut Laue–Langevin, Grenoble, CERN and Advanced Light Source, Lawrence Berkeley National Laboratory, ARCHER and JADE: Joint Academic Data Science Endeavour in addition to facilities at are University Global Partnership Network (UGPN) partners and NPL.

4. Collaboration and Contributions to the Research Base, Economy and Society

This REF period has seen many significant indicators of our research excellence. Three colleagues have been made Fellows of the Royal Academy of Engineering (Aglietti, Hilton, and Watts) and were joined by Tafazolli in the latter part of 2020. Silva was awarded a CBE in the New Year's Honours. In 2016 Sweeting was named as one of the Top 20 Engineers by The Sunday Times. Two of our colleagues are Clarivate Highly Cited Researchers (Jian Liu, CPE, 2018-2020 and Wei Zhang, ATI 2019-2020). Staff and research students have won numerous prizes and have contributed to the discipline, society, and the economy, as evidenced below.

4.1 Collaborations and Interdisciplinary Research

Over 53% of the papers published by members of this UOA have an international collaborator, and over the period our local, national and international collaborations with academia, industry, and other sectors have continued to grow.

A formal structure of collaboration exists within our UGPN, a consortium with North Carolina State University (USA), the University of São Paulo (Brazil) and the University of Wollongong (Australia). The UGPN provides starter funds catalysing research collaborations across the network and reports a 6:1 return on investment in leveraged funds.

In addition to University-wide agreements, including the UGPN, the Departments/Centres in this UOA have numerous formal international agreements with Universities and Higher Education Institutions, overseen by our International Engagement Office e.g., China Academy of Electronics and Information Technology, Hubei University, University of South Australia, Zhengzhou University. Our focus on linking research to UN SDGs is enabling such collaborations to grow from bi-lateral to multi-lateral in areas such as air and water quality and clean energy. In the same spirit, we have a plethora of collaborative students working overseas including at the American University in Cairo (Egypt), De La Salle University (Philippines), National Institute of Technology, Warangal (India), Texas A&M (Qatar) and University of Valencia (Spain).

A number of joint appointments support our collaborations (see Section 2.2) with, for example, Adobe, NPL, Samsung and Unilever. As engineers, we collaborate extensively with the following institutions (volume of outputs published in period are noted in brackets); Queen Mary, University of London (313), Imperial (282), University of Oxford (246), University College London (180) and National Physical Laboratory (139). Internationally our collaborators include: Zhengzhou University, Queensland University of Technology, CNRS, KTH Royal Institute of Technology, Harvard University, California Institute of Technology (CalTech) and NASA Jet Propulsion Laboratory (NASA/JPL).

A selection of our collaborations during the REF period are detailed below.

Materials and Devices

- Members of the UOA (CPE) hold multiple EPSRC and EU grants with colleagues at UCL, the Universities of Newcastle, Edinburgh and Technical University of Eindhoven, alongside physicists at Denmark Technical University, exploring anion exchange membranes in clean energy technologies. We are also part of a National Natural Science Foundation of China project led by Prof Tongwen Xu at the University of Science and Technology of China (Hefei) which is a C9-league Chinese University and the only one run by the Chinese Academy of Sciences.
- We are a partner and one of the four work package leaders in LiSTAR, the Lithium-Sulfur Technology Accelerator, one of nine Faraday Institution projects, aiming to place the UK at the forefront of battery technology. Our partners are Imperial College, UCL and the Universities of Cambridge, Oxford, Nottingham and Southampton.
- The ATI has a number of strong cross-disciplinary international collaborations, including Mai Research Group (Wuhan University of Technology), Guosheng Shao Lab (Zhengzhou University), Dalian Institute of Chemical Physics (Chinese Academy of Sciences), QinetiQ Energy and Johnson Matthey, to develop high-performance electrochemical energy storage devices and techniques for electrochemical monitoring.

Resilient and Sustainable Systems

- Saroj (CEE) is working with collaborators in the Philippines: De La Salle University, De La Salle Araneta University and the Society for the Conservation of Philippine Wetlands, funded by a Newton Prize in 2019. The team is installing a full-scale fertilizer production plant and monitoring its impact on agricultural output.
- In the DeSCIPHER project (Designing sponge cities for multiple benefits: Integrating nature based solutions to create sustainable places, co-funded by national agencies in the UK, China and Norway; Hagen-Zanker, CEE) we investigate how nature-based solutions to urban challenges such as flooding, water quality, high temperatures and air pollution can deliver co-benefits across these areas and beyond. The project builds on an existing collaboration between the University of Surrey and the Centre for Ecology and Hydrology with partners at the University of Oxford and University of Bath, and collaborators in the UK (Earthwatch, who are specialists in citizen science), Norway (Norwegian Institute for Water Research/NIVA; University of Oslo) and China (Institute of Urban Environment, Chinese Academy of Sciences/IUE-CAS; Tsinghua University).

Kumar (CEE, GCARE) has extensive collaboration with industry (e.g., Global Home, Pollution Guardian) and academia within the UK (Cambridge, Imperial, Edinburgh, Birmingham) and overseas across over 12 countries (in Asia, Africa, Latin America and the Middle-East) funded by UKRI and international funding bodies to provide opportunities for networking and benchmarking studies, thus broadening the skills of researchers in air quality and fostering collaboration towards UN SDGs

- We host (Sadhukhan, CES) one of the three themes of the Environmental Biotechnology Network (EBNet): technology interfaces for process integration, techno-economic and sustainability assessment. It is supported by the BBSRC and EPSRC and the University of Surrey is working alongside the University of Southampton, Cranfield University, Heriot Watt University and Newcastle University. We are also collaborating with the University of Oxford, University of Sheffield, University of South Wales and Newcastle University on the EPSRC liquid fuel and bioenergy project to develop a viable, integrated, efficient and economic system combining bio-electrochemical and biological processes for sustainable liquid fuel production.

Technology and Society

- CVSSP has established international joint AI labs with Beijing University of Post and Telecoms, Jiangnan University, and with industry partner iFlyTek to establish the Surrey-iFlyTek Joint Research Centre on AI, funded by iFlyTek Ltd for £1.5M in 2019. All research results and software from the iFlyTek collaboration are available under open-source permissive licences.
- The 5GIC has enabled the University of Surrey to build a large collaborative network of industry partners including BT, EE, Fujitsu, Huawei, Samsung, Telefonica, Teoco and Vodafone, and universities including Bristol, Glasgow, Kings College, Imperial, Lancaster Oxford, Southampton and UCL. This has enabled academia and industry to work together to influence UK 5G policy and secure over £200M for research (see Impact Case Study).

Future Mobilities and Space

- The FAIR-SPACE National Hub, led by the University of Surrey (Sweeting, SSC) and including Imperial and the Universities of Edinburgh, Liverpool, Salford and Warwick is supported by investment from the UK Space Agency and UKRI. It is working with a host of industrial partners, including BAE Systems and Thales Alenia Space UK Ltd.
- Colleagues in this UOA (MES) collaborated with Ford Otasan on the €4.9M TrustVehicle project, funded by the European Commission. The project looked to increase reliability and trustworthiness of semi-autonomous vehicles by developing advanced technical solutions capable of assessing critical situations in mixed traffic scenarios, ultimately improving safety.

Innovation for Health

- In close collaboration with NPL through joint posts and projects, we have developed a novel measurement technique for topical drug delivery using coherent Raman scattering and fluorescence microscopies. The US Food and Drug Administration has since identified this new approach as a non-invasive method to evaluate the bioavailability of a topically applied drug in the skin and has funded further research.
- Through our WHO Collaborating Centre on water quality, Pond (CEE) and others have pursued joint research and dissemination projects with more than 10 ODA countries in Asia and Africa.

One way that our broader contributions to the international agenda have been recognised is via prizes including the President's Award, The Government of Sri Lanka, for contributions to Sri Lanka Science and Society and the Outstanding Overseas Scientist Office Award, Henan Province, China, both to Silva, and the Friendship of the Chinese Government Award to Kittler.

During this REF period, this UOA has received over £11M in philanthropic research funding from organisations such as Adobe Systems Inc., Facebook Reality Labs, Guy's and St Thomas' Charity and Huawei. Our Advancement Team helped facilitate these gifts, including an £850k alumnus gift to establish a Marcus Lee Lectureship in Energy Materials.

4.2 Engagement with Research Users

We are committed to working on real-world problems and this is evidenced by nearly 12% of our research outputs having a co-author from industry. This gives us a strong platform on which to develop impact. Our ability as engineers to innovate is enhanced by our access to the Surrey Research Park (SRP), which was founded in 1984 and occupies 28.5ha within the University's grounds, supporting ~170 businesses. Our outstanding strength in knowledge transfer at Surrey has been amplified through SETsquared, located in the Surrey Technology Centre on the Park, in operation since 2002. Working with the universities of Bath, Bristol, Exeter and Southampton, SETsquared has supported over 4,000 UK high-tech start-ups since its inception, helping them raise more than £1.8bn of investment and creating £8.6bn of economic impact to date. Since

2018, the University has been an inaugural partner of SPRINT, involving five universities supporting SME engagement with the Space sector, in which Surrey has been nationally leading since the emergence of Surrey Satellite Technology Ltd (SSTL).

In addition to our Strategic Partnership with NPL, and substantial interactions with entities such as Airbus, AWE, BBC, Dstl, Network Rail, QinetiQ, RR, TWUL and Unilever, we interact with a significant number of SMEs, for example, through our CDT in MiNMaT (e.g., local companies PlasmaQuest and TISICS). The success of these interactions is illustrated by our impact case studies which involve a number of these partners and our continued collaborative grant success such as the upcoming EPSRC Prosperity Partnership with the BBC.

4.3 Wider contribution to the economy and society

Our contributions to the economy and society have increased and become more varied over the period, as exemplified by our impact case studies. We work with companies of all sizes, evidenced in the following examples from our themes:

Materials and Devices

- We have been working with local SME, TISICS, via a number of EngD projects (Crocombe, Ogin and Whiting, MES), throughout the REF period. TISICS is one of only two companies world-wide (and the only one in the UK) producing silicon carbide monofilament, which is used to reinforce metals to produce metal matrix composites for use primarily in the space and aerospace industries, where it offers weight-savings. The research has led to a substantial increase (over 200%) in the maximum run time of the production process that, coupled with improved recycling of the by-products, has led to productivity gains and cost reductions, alongside an enhanced monofilament. In turn, this has led TISICS to expand its market-reach and marked an important milestone to delivering advanced composites to achieve the UK's ambition for Net Zero aviation emissions by 2050.
- In one of our 'outstanding' KTPs, chemists (Turner and Watson) worked with Advanced Engineering Ltd to develop Jally® Strips, commercial biocide tablets that provide superior microbial control than previous products in refrigeration units. They are responsible for thousands of pounds reduction in costs year on year per supermarket. Strips have been installed in Tesco (as part of the maintenance check list), Sainsbury's and Asda.
- A team from the ATI (Silva and Sporea) and Airbus have developed a nano-barrier, applied via a custom-built deposition system, that bonds to the surface of polymer or composite materials, protecting them from erosion in low-Earth orbit. The new cutting-edge nano-barrier allows for large-area, conformal coatings on complex 3D structures such as spacecraft and optical mirrors. This eliminates the risk of contamination and the need to wrap instruments with multi-layer insulation, opening up opportunities to increase satellite performance.

Resilient and Sustainable Systems

- CES (Christie) partnered with IKEA UK & Ireland in the design and implementation of IKEA's pioneering initiative Live Lagom, which researched new ways to enable hundreds of consumers to live more sustainably at home. The success of Live Lagom in inspiring and maintaining action by a new community of consumers has led to its conversion from a research project into an on-going corporate programme, which is to be adapted and implemented by IKEA in other countries as well as developed further in the UK and Ireland. Live Lagom won the award for CSR Engagement/Marketing Campaign of the Year in the 2019 EDIE Sustainability Leaders Awards.
- The MyGlobalHome Demonstrator project is funded by £8M of UK Government Industrial Strategy Funding to develop a new approach to home production. Wehrmeyer (CES) and Kumar (CEE) are working with MyGlobalHome and its partners (e.g., BuroHappold, Bouygues) to demonstrate the state-of-the-art modular, smart (digitally enabled) home

concept on the University campus. The University will deliver a package of pre- and post-occupancy evaluation studies focussed on managing air quality and energy efficiency as well as social scientific studies and occupant behaviour.

- Staff participate in Eurocode working groups in areas that include concrete shear and robustness (Sagasetta, CEE), bridges (Mitoulis, CEE), as well as the development of industry standards (Network Rail) for scour and fatigue assessment of bridges (Imam, Chryssanthopoulos, CEE). Lawson (CEE) acted as Chair of the UK Light Steel Forum. Bhattacharya's textbook (Wiley, 2019) on foundation design for offshore wind turbines has led to numerous invited lectures and many interactions with designers and consultants worldwide.

Technology and Society

- Developing novel techniques in image and video analysis and retrieval and algorithms for shape analysis and image/video fingerprinting, work from CVSSP (Bober) has contributed to organisations including the Metropolitan Police, RAI Television and the BBC, and influenced international standards within MPEG. This research received recognition by the Home Office and won the world-wide Google Landmark Retrieval Challenge in 2018.
- The EPSRC S3A Programme Grant in Future Spatial Audio (Hilton) introduced new approaches to improve accessibility by delivering sound according to individual hearing requirements. The technology has been used for mass-audience broadcasts such as BBC Casualty. CVSSP's world-leading position in machine perception of human movement has also been used to translate sign language into written English. This technology has been well received by Britain's deaf community. With 700,000 people in the UK registered profoundly deaf and around 250,000 people using British Sign Language (50,000 as their first language), the development of a fully automatic translation system will allow this community to participate more fully in the digital revolution.

Future Mobilities and Space

- We (Doherty, MES) are developing the world's first all-electric ducted fan propulsion system via instrumentation development and model testing for the EMPAS project (Electric Motors for Powered Aerodynamic Simulation), funded by Innovate UK and led by QinetiQ together with Boeing UK, Goodrich Control Systems, Aerodynamic Test Equipment Ltd. and Mts Systems Ltd.
- Members of this UOA (SSC) are working in collaboration with the California Institute of Technology (CalTech) and NASA Jet Propulsion Laboratory (NASA/JPL) on the autonomous assembly of a reconfigurable space telescope (AAReST). AAReST is a novel approach to the issue of placing telescopes with a diameter of over 20 metres into orbit. Instead of using high-precision formation flying to deliver the satellite, AAReST allows for the telescope to be assembled while in orbit.

Innovation for Health

- Using part-funding from the EPSRC IAA, Birch (MES) worked with Surrey Sensors Ltd (a Surrey start-up) to patent the 'Sneezometer' an ultra-high precision, high-speed spirometry technology that may help diagnose and localise damaged lung tissue and other lung problems, including the effects of long-term COVID-19. The machine can respond faster than a person can sneeze and was part of a collaborative project between the University and the King's College Hospital Chest Unit.
- Our WHO Collaborating Centre for the Protection of Water Quality and Human Health led by Pond (CEE) works to assist low-income countries address specific challenges associated with water and sanitation towards the delivery of SDG6. We have developed training material

and guidance documents for strengthening drinking water surveillance using risk-based approaches in current revisions to the WHO Guidelines for Small Drinking Water Supplies due to be published in 2021. We have delivered training to environmental inspectors in the use of risk assessment in Iceland, Uganda and Malawi to improve the management of small drinking water supplies (partners are Iceland University, Kyambogo University and The University of Malawi). Related work includes testing and developing fluorescence sensors in Malawi in collaboration with British Geological Society (NERC-SCENARIO project).

4.4 Engaging with diverse communities

Our engineers engage with diverse communities and the public in a variety of ways. Nationally, we have participated in Royal Society Summer Exhibitions (e.g., *Cleaning Up Space Junk*, 2016) and various Science Festivals. A number of our research leaders contribute to national and international media e.g., Tafazolli has given interviews in the UK on BBC, ITV and Sky and internationally in Germany, US, China and Japan on 5G technologies, whilst Jackson, Aglietti, Kumar have all featured in a wide range of online, TV and newspaper articles, including the New York Times, Telegraph, CNN, ITV and BBC International.

To engage the local community, we participate in University of Surrey Bright Club and Pint of Science outreach events; 6 members of the UOA (Birch, Bridges, Dorey, Singh, Sporea and Whiting) have presented at these events since 2017. Several thousand people attend Guildford Borough Council's Innovate Guildford Festival each year; University space robotics and nanotechnology demonstrations featured in 2019. We run a series of public lectures which were attended by over 6,000 people in 2018/19. High-profile examples relevant to this UOA include the annual Adams-Sweeting Lecture (recent past speakers include Lord Rees, Sir Paul Nurse and Dame Jocelyn Bell Burnell) and the Roland Clift Lecture (recently presenters include Joanna Yarrow from IKEA and Professor Johan Rockström of the Stockholm Resilience Centre).

We also involve the local community in Citizen Science projects. The iSCAPE project (led by Kumar) aims to integrate and advance the control of air quality and carbon emissions. The local community were part of the data collection team and participated in workshops with great success. Our Living Lab, launched in 2019, enables collaboration between students, academics, staff and community partners to address real-world issues using the University campus and surrounding Surrey communities as a testbed.

Members of the Technology and Society theme (CVSSP) play an active part in Guildford.Games, which is an initiative delivered by the Enterprise M3 Local Enterprise Partnership (EM3 LEP) providing a hub for the video games industry in Guildford. It runs an annual Guildford Games Festival. The 2020 Festival was entirely online, with over 180 businesses taking part and 2.7 million views of videos, giving colleagues strong engagement with the regional games industry.

The University (through representatives including Murphy and Silva) is a member of the Surrey Energy Partnership (SEP). SEP grew out of the University's Living Lab and now includes representatives from Surrey County Council, Enterprise EM3 LEP, SSE Enterprise and ThamesWey Group amongst its 57 full members. The group was formed to bring collaborators together to deliver projects and action linking to national and regional strategies, while building on local and county-wide strengths.

The University (representatives include Murphy and Christie) is a founding member of the Surrey Climate Commission, the UK's first county-level climate commission, which aims to fill a vital gap between national and local efforts to accelerate the scale and pace of action to address climate change.

Influencing Policy Nationally and Internationally

Several members of this UOA have produced work that has been cited in national and international government and industry reports and policies and are, or have been, members of bodies reporting directly to members of governments. The most prolific is Professor Tim Jackson, Director of the Centre for the Understanding of Sustainable Prosperity (CUSP), which addresses the technical, economic and social challenges of achieving sustainable prosperity and making the transition to a fairer, greener economy (see Impact Case Study). Yeomans was a member of the Advanced Materials Leadership Council (2014-2016) chaired by the Minister of State for Universities, Science, Research and Innovation. Tafazolli advised London Mayor (Boris Johnston) on London Infrastructure requirements for 2050. Silva has continued to accompany Prime Ministers (previously Blair; Cameron and May in this REF period) on overseas UK Technology Fairs to help promote the best in Britain technologies. Robins contributed to the *Blackett Review on wide-area biological detection* (2014), Murphy has been a Member of Defra Hazardous Substances Advisory Committee since 2013 and Kumar has contributed to Public Health England and Defra reports on air quality. Wu was a member of the Chemical & Materials Cluster Advisory Board of A*STAR, Singapore (2020), assessing scientific excellence and industrial relevance, as well as advising on strategies for A*STAR to remain competitive globally.

Since its publication in 2018, Russell's work on explainability and fairness in AI 'Counterfactual Explanations' (Harvard Journal of Law & Technology) has been influential internationally, receiving over 2,500 downloads and 13,000 views, and has already been cited in the guidelines to General Data Protection Regulations (GDPR) and discussed in the House of Commons' Science and Technology Committee inquiry on algorithms in decision-making. Software based on this research has also been integrated by Google in its 'what-if' tool, which is part of the leading tensorflow toolkit for deep learning, used by industry and researchers worldwide with over 120,000 users.

4.5 Wider Influence, Contribution and Recognition**Contribution to the sustainability of the discipline*****Service to UKRI***

Currently 51 members of this UOA are members of the EPSRC Peer Review College (36 Full and 15 Associate members) and 2 (Kumar, Robins) are members of the NERC Peer Review College. Yeomans is a member of the EPSRC Strategic Advisory Network having previously been a member of the Engineering Strategic Advisory Team (SAT). Collomosse is currently a member of the Information and Communication Technologies SAT (as was Plumbley previously) and the UKRI Digital Economy Programme Advisory Board. Tafazolli is a member of EPSRC Oversight Board for National Research Facilities. Yeomans has chaired sift and interview panels for the UKRI Future Leaders Fellowship scheme.

Editorships

During the REF period, colleagues have served as associate editors or on the editorial boards of over 100 journals. This is in addition to the Editor-in-Chief (or equivalent) roles for the following publications: *Atmosphere : Air Quality section* (Kumar), *IET Microwaves, Antennas and Propagation* (Brown), *International Journal of Satellite Communications and Networking* (Evans, B), *Journal of Energy and Environmental Materials* (Silva), *Journal of Field Robotics* (Gao, Yang), *Powder Technology* (Wu), *Proceedings of IMEchE, Part C: Journal of Mechanical Engineering Science* (Chew) and *Surface and Interface Analysis* (Watts). Tafazolli was the Chief Editor of the Wiley 5G Reference book.

Conferences

Collectively we have delivered over 600 keynote and invited presentations at a wide array of national and international conferences.

Fellowships and Prizes

During the REF period, Smith was made a World Fellow of the International Committee of Composite Materials. Silva was awarded the Institute of Materials, Minerals and Mining (IoM3) Platinum Medal (2015) and the Institute of Physics James Joule Medal and Prize (2018). Hilton received the Institution of Engineering and Technology (IET) Achievement Medal Award (2018). Jackson (T) was the Hilary Laureate for Exceptional International Leadership (2016). Gao (Yang) received the prestigious 2019 Mulan Foundation Network Ltd. Contribution to Science Award. Hare won the 2015 IChemE Nicklin Medal for Early Career Researchers. Watts received Le Prix Dédale de La Section Française de l'Adhésion, Société Française du Vide (2017) and the Wake Memorial Medal of The Society for Adhesion & Adhesives/IoM3 (2019). Saroj was awarded the 2019 UK-Philippines Newton Prize. Lawson, Sagaseta, Mulheron, Singh have all received ICE prizes (6 in total).

The SSC project 'RemoveDEBRIS' won the 2019 Sir Arthur C Clarke Award for Space Achievement – Industry/Project Team and the Aviation Week Network 63rd Annual Laureate Award 2020, SPACE - Technology & Innovation.

A Surrey AI team (led by Bober, CVSSP) won the prestigious Google Landmark Retrieval Challenge 2018, fiercely contested by 218 worldwide teams, using advanced visual recognition technology developed through the iTravel InnovateUK project.