Institution: University of Salford

Unit of Assessment: 12

1. Unit context and structure, research and impact strategy

Unit context and structure

Engineering at Salford in this REF period has been characterised by substantial external and internal investment in both staff and infrastructure and the expansion of our postgraduate research community. Compared to REF2014, in REF2021 our **staff submission has increased by 125%**; **our number of PhD degrees awarded has increased by 109%**; and through recognition as a leader in research in robotics and autonomous systems, we have secured ERDF and HEFCE funding to develop the £17.6m **North of England Robotics Innovation Centre (NERIC)**. This closely follows the development of our new **£65m Science, Engineering and Environment building**, to house additional engineering research facilities from 2022.

In REF2014 the Electrical and Electronic Engineering, Metallurgy and Materials panel identified **79.4% of our outputs to be of an internationally excellent or world-leading standard** and we have continued to contribute notably to our discipline. We have authored 861 outputs and between 2014 and 2019 our field-weighted citation index (FWCI) for 'Engineering and Technology' was 1.8 compared to a UK average of 1.45 and our FWCI for 'Physical Sciences' was above UK average at 1.55 compared to 1.5, indicating the value of our work within these disciplines (metrics obtained from SciVal).

With a focus on the challenges of our industry partners and society stakeholders and the development of effective collaborations with both, Salford Innovation Research Centre's (SIRC) activities have supported excellent research and impact within 4 main themes. Members are listed against their primary affiliation, although the cross-cutting nature of our engineering-in-context research results in close collaborations across themes:

i) **Autonomous Systems and Robotics (ASAR) (4.6 FTE: Davis**, **Howard**, **Nefti-Meziani** (lead), **Theodoridis**, **Wei)** includes cognitive robotics, robot/machine design, dexterous end effectors, biologically inspired robots, exoskeletons and human movement technologies (prosthetics and orthotics) and autonomous systems and their control (with Infrastructure Engineering).

ii) **Engineering for Sustainability (8.2 FTE: Abbas**, **Babaie**, **Burby**, **Enyi**, **Nasr** (lead), **Nourian**, **Uzomah**, **Scholz**, **Wang)** includes decarbonisation of energy systems such as petroleum and natural gas, clean air through improved spray and aerosol systems and engineering solutions for sustainability of natural resources, such as water and fossil fuels.

iii) **Infrastructure Engineering (9.0 FTE: Asr**, **Beg**, **Byzyka**, **Currie**, **Mei** (lead), **Nelson**, **Shirley**, **Weekes**, **Whittleston)**, including development and implementation of advanced and sustainable engineering materials, audio engineering in the built environment and modern methods of construction. Members contribute, with ASAR, to engineering solutions for the integration of autonomous systems with infrastructure.

iv) **Materials, Physics and Chemistry (MPC) (13.0 FTE: Arrigo**, **Bull**, **Chadwick**, **Christian**, **Hughes**, **Leontiadou**, **Lehr**, **Martinez Maestro**, **McDonald**, **Morrison** (lead), **Proctor**, **Shen**, **Yates)** including physical sciences research into the synthesis, characterisation and modelling of new, advanced materials that include thin films, graphene, supercritical fluids (especially around energy generation) and biomimetic catalysts for the energy and decarbonisation sectors.

Research and impact achievements 2014 – 2020

SIRC was formed in 2015 and launched with a research strategy to span 2015-2020. This focused on the prominence of **engineering as a driver of economic productivity** for the UK and globally. SIRC's strategy ensures we continue to align our research and impact activities with external priorities, and those of the funding bodies, using our expertise and reputation to advise and influence these evolving agendas, while regularly reviewing progress against our goals. In 2015, our aim was to become an interdisciplinary and outward-facing team, growing our research in quality and quantity, and establishing a critical mass of researchers. Our strategic priorities were to:

i) **Grow our research base**, investing in and developing our researchers, especially early career researchers;

ii) **Diversify our funding portfolio and invest in key facilities** that support our strategic research programmes;

iii) **Grow our community of postgraduate researchers (PGRs)** and provide them with an excellent research training experience.

Over the last 7 years, we have grown our academic research community significantly, as shown by the **125% increase in FTE, from 15.5 in REF2014 to 34.8 in this submission**. We will continue to invest in recruiting new staff with excellent track records and exceptional research promise in alignment to the research priorities for SIRC, the School of Engineering and Environment and the University. 11 early career researchers (new lecturers; 4 female, 7 male) have joined during this REF period, making up 32% of our submission, **ensuring the sustainability of all groups** within engineering. Our research students are at the heart of a strong research environment and we have supported **95 PhD degree awards; an increase of 109% from 46** reported in REF2014.

We have received substantial external investment for new infrastructure, securing **£13m of ERDF and Research England funding** (match funded with £4.6m from the University) for the **North of England Robotics Innovation Centre (NERIC)**. The University is also investing £65m in a new building for the School of Science, Engineering and Environment (SEE) (work began July 2020; to open in 2022/23) supporting new facilities that will benefit engineering alongside other disciplines. We have also successfully diversified our funding portfolio, including increasing our participation in large-scale EU schemes (FP7 and Horizon 2020). We have been involved in projects with a total award value of nearly €28m across all partners and EU funding **has increased to 34% of our income** for this REF period, up from 18% in the previous submission.

We have facilitated impact from our research through our own spin-out companies and partnerships with the public and private sector. Through spin-out Salsa Sound Ltd., **Shirley's** research (REF3) has been applied to virtual crowd production for sports events, proving exceptionally relevant for broadcasters showing live matches during 2020 under COVID-19 restrictions. The technology has been used across **10 leagues within 5 sports in the UK and USA and has won 2 awards** from the Royal Academy of Engineering (2017) and International Association of Broadcast Manufacturers (2018). **Nasr's** case study (REF3) demonstrates the commercial and environmental relevance of an aerosol valve patented and produced by spin-out The Salford Valve Company (Salvalco Ltd.) that substantially **reduces the release of volatile organic compounds**, thereby reducing air pollution. Further positive environmental impacts have been achieved through research by **Scholz** (REF3) into improved management of wetland systems. In the UK, this has informed DEFRA and Environment Agency approaches, and through adoption by local authorities, government bodies and the water industry, has contributed to the improved management of urban and rural landscapes at **hundreds of locations globally**, including in Europe, Australia, China and the USA.

Key achievements within each research theme

Autonomous Systems and Robotics (ASAR)

Members of ASAR undertake impactful, industry-collaborative research in traditional and **soft robotics**, such as building unique prototypes and real-world demonstrators of robotics applications, including developing patents for novel gripper technology for areas such as **health innovation** and **extreme environments** (e.g. **FAIR-SPACE**; EPSRC). ASAR has generated £1.9m in research income since 2014 and has been at the forefront of strategic developments (e.g. for BEIS, DEFRA, UKRI/EPSRC, EU), shaping industrial strategy through hosting the National Advanced Robotics Research Centre, including 2 EPSRC Networks and a Centre in Food Automation. ASAR has hosted the Industrial National Robotics Network (with Innovate UK), which was established in 2015 with the support from Sellafield (**Nefti-Meziani**) and Autonomous Intelligent Systems Partnerships involving leading **nuclear sector** organisations and representation from the **oil and gas**, **offshore**, **aerospace** and **transport** sectors (see Section 3). This has led to one of the group's intelligent robotic adaptive grippers being trialled in real life applications as part of Innovate UK's SBRI Integrated Innovation for Nuclear Decommissioning scheme, in collaboration with Sellafield and the National Nuclear Laboratory (NNL).

ASAR contributes to the **Human Movement Technologies (HMT)** group within the Health Sciences Research Centre (School of Health and Society), undertaking collaborative work in the area of biomedical engineering, particularly around prosthetics. Joint projects include 'Energy Efficient Lower Limb Prostheses' (**Howard,** EPSRC, £400k) and Howard also contributes to the EPSRC Centre for Doctoral Training in Prosthetics and Orthotics (£5.5m) led by Salford and in partnership with the Universities of Strathclyde, Southampton and Imperial College London.

Our **Automotive and Autonomous Vehicle Technology (AAVT)** research involves ASAR, Infrastructure Engineering and Informatics disciplines (linking data analysis and network infrastructure) to focus on smart and clean vehicle experimental and simulation research. Collaboration between academics with expertise including **mechanical and automotive engineering**, **data science**, **robotics** and **cybersecurity** work closely with AAVT in collaboration with academic and industry partners. Salford is developing autonomous control systems as part of the £3.7m Innovate UK-funded **Synergy** project (2017-21), led by Westfield Sports Cars Ltd., which aims to further develop innovative technologies for connected and autonomous vehicles.

Engineering for Sustainability

Key research outputs in the sustainability engineering area include the design and implementation of new urban drainage and wastewater systems, including the implementation of green infrastructure (**Scholz**, **Uzomah**) and the development and introduction of sustainable construction materials (**Wang**, with Infrastructure Engineering). The strategic theme of sustainability in the built environment has involvement in a major EU network, **WATER-AGRI**, (EU €7m; **Wang** and **Scholz**) and is further evidenced in a REF3 submission; associated research has been incorporated into national and international guidelines on the design, construction and management of wetland systems.

Petroleum, gas, and clean air engineering expertise contributes to decarbonisation of energy systems and developing clean sprays and aerosols for industrial applications. Research strengths of the group are in the area of gas and petroleum engineering with recent work focused on utilising hydrogen in gas networks and carbon dioxide sequestration, linked to decarbonisation and clean growth. Commercial exploitation has emerged through Knowledge Transfer Partnerships (KTPs) with Carlisle Fluid Technologies Ltd., and Autac Ltd. (Section 3) and through the work of Salvalco Ltd. **The Salford Eco-valve**: Cutting hydrocarbon emissions through novel aerosol valve designs (**Nasr** and **Burby**) (REF3) won the **Times Higher Education Award for 'Outstanding Contribution to Innovation and Technology'** in 2014.

Infrastructure Engineering

Working closely with the other themes, research outputs include the development of innovative motor control systems and suspension for the railway industry (**Mei**), as well as the investigation

and development of new sustainable materials linked to the built environment, including steel, concrete, asphalt and composite materials (**Byzyka**, **Nelson**, **Weekes**) and simulation of their performance (**Asr**). An example of successful industrial collaboration in this area is a KTP with Technocover Ltd. concerning the development of materials that support high-quality security products for the construction industry (**Currie**). Other areas include applications of nanofluids in the engineering domain (**Beg**) and sound engineering in the built environment (**Shirley**). **Shirley** is part of the wider Acoustics research group (14 FTE total), which sits across SIRC and built environment research areas (UoA13), with applications in both. In REF2014 the assessment panel determined there to be '*outstanding impact in acoustics for the built environment*'. As a long-standing member of staff, his work builds on this previous success with the development of new technologies for virtual crowd production in sports stadiums, adopted widely since COVID-19, based on novel machine learning techniques to automate real-time sound mix production (REF3).

Materials Physics and Chemistry (MPC)
The group has secured over £2m in income in the REF period for research into new, advanced materials and surfaces of technological interest, including synthesis, characterisation and modelling. Impact from recent work in the area of **Chemical Vapour Deposition** (CVD) has been developed through the Salford Antibiotic Resistance Network, a cross-University collaboration with SEE bioscientists, the School of Health and Society, Salford Royal NHS Foundation Trust and clinical partners at 2 Ugandan Regional Referral hospitals. This team are developing and testing biocidal surfaces for use in clinical settings and has an impact action plan in place to support activities (**Yates**). **Yates** is also testing and developing improved surfaces for solar energy capture through CVD methods. Complemented by access to national and international facilities including synchrotron radiation sources (Diamond and the ESRF) and neutron sources (ISIS and the ILL), significant outputs include fundamental studies of the properties of supercritical fluids (**Proctor**), studies of complex hydrides for hydrogen storage (**Bull**), hydrogen isotope diffusion in palladium (**Steel**), studies of nuclear graphite (**Roach**) and the development of biomimetic catalytic surfaces towards decarbonisation and future energy storage (**Arrigo**). A further focus is fluid mechanics with influential research publications in new mathematical approaches to solving the Navier-Stokes equations (**Chadwick**). MPC in-kind income from national facilities totals £715k over this REF period.

Sustainability and future research and impact plans

Vision: *to have a global reputation as a leader in engineering research linked to robotics and autonomous systems through the use of new materials and methods, and the translation of this knowledge into innovative applications for industry, particularly SMEs*.

Aims:
We aim to develop NERIC as a centre of research and innovation excellence for University-SME manufacturing collaboration. Through this we will become an influential voice in the shaping of public policy around engineering innovation and collaboration with industry. Through **Nefti-Meziani's** appointment in 2019 to the **UK Government Robotics Growth Partnership,** Salford will contribute to the action plan to drive the UK's capabilities in robotics, unlocking its potential for the economy and society. This will position us to use our expertise to **influence government policy** in this area, ensuring our research generates measurable impact in engineering industries and also through development of regulatory frameworks around new technologies. NERIC will enable us to undertake sector-leading research within three specific areas:

1. Developing innovative engineering solutions to the challenges faced by the healthcare service and patients needing bio-engineering assistive technologies.
2. Developing novel solutions to engineering and societal challenges presented by autonomous automotive vehicles.
3. Developing new materials to use in engineering solutions in construction and other industries.

To fulfil these aims we will:

- ***Increase the number of interactions and scale of collaboration with industry*** through the work of NERIC. This will expand the impact of SIRC research across many sectors.
- ***Increase the diversity and number of staff***, by making appropriate strategic appointments, increasing our proportion of women engineers and developing new and early career researchers (ECRs) through the three-year research plan process.
- ***Increase the number of postgraduate researcher (PGR) enrolments and completions*** in Robotics and related disciplines through domestic and international recruitment. This will allow us to boost our knowledge base, enrich our scholarly community, build our global partnerships and collaborations and grow the next generation of scholars.
- ***In light of Brexit and changes to Government we will increase the value and duration of external research funding*** to allow for greater stability and depth in our activity. This will be achieved through increasing collaborative research grant applications, enhancing our reach and reputation internationally and strengthening our international networks.

The University's impact development framework (designed by Research and Knowledge Exchange, RKE) supports researchers with formalised annual impact action plans. In addition to ongoing work by **Nasr**, **Shirley** and **Scholz**, we are seeking to develop impact from our research:

- Through NERIC's involvement with SMEs across the region addressing industry's robotics and automation needs (**Davis**, **Nefti-Meziani**, **Theodoridis**)
- Collaboration with Human Movement Technologies to develop new patient assistive technologies (**Howard**)
- Influencing public policy and regulations around the use of autonomous systems in the public realm (**Davis**, **Nefti-Meziani**, **Theodoridis**)
- Through addressing design issues in the geotechnical and geo-environmentally informed sustainable construction industry (**Asr**)
- In steel reinforcement corrosion, porous material property characterisation, green concrete technologies and environmental engineering (**Scholz**, **Wang**), exploiting the prolific number of outputs we have produced in this area
- In atmospheric pressure (thermal) chemical vapour deposition (APCVD), applying the findings to environmental, construction, healthcare and biotechnology sectors, resulting in commercially viable processes and products, such as antimicrobial surfaces (**Yates**).

Research integrity and open research practices

Integrity is supported by the School Research and Enterprise Committee (SREC), a research oversight committee of academics, technicians and PGR representatives chaired by the Associate Dean for Research and Innovation (ADRI) and the School Ethics Approval Committee (SEAC), a school ethics oversight committee of Ethics Panel Chairs, with academic and student representation. These committees refer to the institution's Research Code of Practice and Academic Ethics Policy, which incorporate and develop the principles of the UK Research Integrity Office's Code of Practice for Research and Universities UK's Concordat to Support Research Integrity (REF5a). All projects involving primary data collection or research participants require approval from the School ethics review panel (**Arrigo** is Chair of Research Ethics).

To ensure data are sustainably accessible and discoverable and to enhance the integrity and efficiency of data sharing, validation and re-use, our researchers are committed to the University open access strategy, managed through the University Library. Researchers are encouraged to deposit outputs as open-access pre-prints or final versions in the University of Salford Institutional Repository (USIR) or on external repositories such as arXiv. Open Access (OA) funding is available for UKRI-supported Article Processing Charges (OA Gold). Institutional Open Access Funds were additionally available based on internal peer review of the paper by the Research Centre Director and ADRI. Agreements with several academic journal publishers also reduce or

remove the cost of publishing open access in their journals and 55 outputs benefitted from Gold OA via Salford, UKRI or through publisher deals.

2. People

Staffing strategy

The staff submission comprises 8 Professors (7 male, 1 female), 4 Readers (3 male, 1 female), 5 Senior Lecturers (5 male) and 19 Lecturers (15 male, 4 female). We have appointed 13 new staff during this REF period, bringing expertise that contributes to all four themes in line with our strategy and areas of existing high performance. In ASAR, **Wei** was appointed to bring expertise in bio-robotics, manipulation and grasping. In infrastructure and sustainability engineering we recruited the following expertise: **Asr** (geotechnical engineering), **Babaie** (low emission and smart vehicles), **Beg** (heat transfer, fluid dynamics and coatings for medical, aerospace and solar collection applications), **Byzyka** (sustainability of building materials – concrete/asphalt), **Uzomah** (sustainable drainage and wastewater systems) and **Whittleston** (structural engineering with carbon nanomaterials). In MPC, **Arrigo** and **Lehr**, as chemists, work on nanotechnology, design of functional materials and molecular interfaces, **Hughes** focuses on quantum computation, **Leontiadou** has expertise in novel photovoltaics, **Martinez Maestro** researches biophysics and materials and **Proctor** has a background in graphene/carbon nanotubes, supercritical fluids and high pressure/high temperature physics.

Equality, diversity and inclusion is a central aspect of our staffing strategy. CSE was awarded an Athena SWAN bronze award and **Yates** supports the School's activities through her membership of the University Athena SWAN self-assessment team and committee. In addition, MPC was awarded the Institute of Physics Juno Practitioner status in 2019 and is working towards the Juno Champion status led by **Leontiadou**. As part of our Athena SWAN action plan, we have ensured that wording on job adverts states our commitment to inclusivity and highlights activity relating to Athena SWAN and Juno. This has opened opportunities for conversations from prospective female candidates with **Leontiadou** and **Yates**, which led to candidates applying for lectureship posts in physics. Of our new appointments 4 (31%) are female, demonstrating commitment to moving towards a more balanced academic workforce. Nine submitted staff (26%) identify with a BAME background with 4 having been appointed since REF2014.

The selection of staff for REF submission and outputs followed our Code of Practice closely. Our School review panel for three-year research plans, determining which staff were to be given 'significant responsibility for research' included both female and BAME representation and all staff underwent training including barriers to academic career progression for staff with protected characteristics. In alignment with our REF2021 Code of Practice, the attribution of REF2 outputs to staff has been subject to an equality impact assessment. Our REF2 submission represents the work of female engineers well, with 25% of outputs attributed to a female author (+8% compared to the proportion of female submitted staff). 30% of outputs are attributed to staff from a BAME background (-3% compared to the proportion of BAME submitted staff).

Staff development

Formal career development processes
All staff have annual Career Conversations (Performance and Development Review; PDR) with their line managers, which allows for feedback and advice on the individual's research trajectory, setting of research objectives and measurement of achievement. Three-year research plans feed into PDR discussions so that objectives are set for specific activities and each member of staff can receive the necessary support from their line manager, group lead and ADRI. Research workloads are set in line with the outcome from their three-year plan assessment, with a minimum of 20 workload units for staff with 'significant responsibility for research' as described in our REF2021 Code of Practice.

Academic staff can apply for promotion to Senior Lecturer, when appropriate opportunities arise, or promotion to Reader and Professor through the University's Professional Promotions Committee, usually on an annual basis. Workshops are held to encourage a range of applications from diverse applicants for these posts. Five Engineering staff were promoted during the REF period: **Beg** and **Davis** and were promoted to professor, the latter mentored by **Nefti-Meziani**. **Theodoridis** and **Yates** (the former also mentored by **Nefti-Meziani**) were promoted to Reader and **Currie** was promoted to Senior Lecturer. Salford PhD graduates **Shirley** (2013) and **Uzomah** (2016) are submitted to this REF, having been mentored by **Scholz** and UoA13 acoustics colleagues respectively.

Supporting high quality bidding, outputs and impact activities
Staff have access to internal financial support to pump prime research or help with dissemination (e.g. conference attendance, open access journal fees) through the School and University. £55k of funding has supported 12 members of staff to attend international conferences and provided pump priming grants for 14 projects. Additionally, 3 researchers (**Davis**, **Nelson**, **Wei**) received a Vice Chancellor's Scholarship with enhanced research workload for 1 year.

Complementing Salford's Early to Experience Career Research & Enterprise Training (SECRET) programme, through SEE and SIRC, staff receive more tailored guidance for bidding, publication quality and impact activities. The SEE ADRI discusses available external grant opportunities and facilitates cross-disciplinary bid development through regular School meetings. The School has established an internal peer review process, which provides mentorship and interdisciplinary, constructive feedback to grant applicants to help develop rigorous proposals for successful external funding. Major applications with alignment to the School and University strategy benefit from dedicated support from a SEE Research Development Manager. To support staff to produce high-quality research outputs, SIRC organises an internal peer review process that provides feedback to authors on their publications using the criteria of originality, significance and rigour.

Development of research impact is a strategic priority and supported in multiple ways. Internal funding from the University's Research Impact Fund is available through 2 funding calls per year. Annual impact action plans were introduced in 2018 to support researchers to develop their impact in a strategic manner to maximise the benefits of the research for wider society. The School Impact Coordinator meets regularly with plan holders to discuss future activity and currently we are supporting four areas of future impact, for **Asr**, **Davis** and **Nefti-Meziani**, **Wang** and **Yates**. Additional research workload has been provided to support the development of impact case studies included in REF3.

To ensure a supportive and collaborative research community and enhance School-wide development two staff networks have been established: the ECR and Professorial Networks. Communication of grant opportunities is managed via regular group and theme meetings, monthly Professoriate meetings and ECR informal network meetings. SEE holds a weekly research meeting led by the ADRI to communicate funding opportunities and provide a forum for regular focus on research matters in the School. The four research themes each have a professorial lead who is responsible for strategic alignment and direction, mentorship of junior staff (directly or indirectly) and, with support from the ADRI, monitoring and management of research integrity.

Support for ECRs
New staff and early career researchers (ECRs) are provided with mentorship through the theme leads. Newly appointed staff are placed on a 1-year probation period and are allocated a senior mentor to support their integration into SEE. Additional workload is provided as an investment for the first 2 years (total of 40% research time) with a reduced teaching workload. Further support for newly appointed or early-career staff includes guarantees of PhD studentships or fee-waivers in support of New Investigator grant applications. All staff new to supervising undertake mandatory postgraduate supervision training on appointment that is regularly reaffirmed. Supervisory teams are usually comprised of a main supervisor and a co-supervisor; ECRs are paired with more senior researchers to develop supervisory experience for new staff.

Ensuring an excellent postgraduate researcher (PGR) experience

We invested £589k in 2017 (from HEFCE with University match funding) in refurbishment of our PGR office infrastructure to create an enhanced PGR student experience. This modernised the facilities, creating a new open office space to facilitate interdisciplinary discussion, a suite of meeting rooms and social space, a new PC suite and a PGR boardroom for formal meetings. Additional funding included £118k match funding as part of the FAIRSPACE programme (see section 4) for two PhD students.

Alongside increasing the number of PhD degrees awarded, from 46 to 95 in this period, we have made process improvements to support the student journey within the areas of student progress monitoring (supported by a workloaded SIRC PGR director) and mandatory regular supervisor training for all supervisors. This ensures that the supervision teams are formally trained and educated in supervisory skills and this participation is monitored alongside PGR progression through SREC. Any issues with student progression are identified and resolved at an early stage through the supervisory team and the ADRI. All supervisors actively engage with learning agreement development and annual progression points, ensuring a common understanding of expectations across supervisory teams and an independent audit of PhD progression. Students have monthly formal meetings with their supervisory team, ensuring an excellent supervisor-supervisee relationship develops. In addition, targeted support for fee waivers helps recruit students from a range of backgrounds. Staff have access to discretionary funds (managed by the ADRI) to support PGR students with conference attendance and pump-priming activities.

The Doctoral School provides workshops as part of the Salford Postgraduate Research Training (SPoRT) programme that cover progression monitoring, preparation for annual progress reviews and the final *viva voce*, as well as academic writing including conference presentations and journal papers. This is complemented with subject-specific programmes that include research and software development methodologies and data analysis. Bespoke research training for a student can involve participation in Master's-level modules (e.g. Advanced Materials PGRs can attend MSc Physics materials characterisation and modelling modules).

SEE organises an annual research showcase event where staff and students can present their research through both presentations and posters. The former School of Computing, Science and Engineering (CSE) organised an annual postgraduate research conference, where students received feedback from referees and the audience during their presentations, which helps students develop their paper writing and presentation skills. The proceedings are published with an ISBN and are made available through the British Library. SEE events are complemented by the Salford Postgraduate Annual Research Conference (SPARC) where students and ECRs interact with the University's wider PGR community. Research centres organise thematic symposia to facilitate interaction between SEE PGRs and to help students prepare for participation in international conferences.

Post-qualification destinations of our PhD graduates since 2014 have included:

- *Academia:* Over 20 graduates have obtained academic-related positions both in the UK and internationally, e.g: *Almuktar*, Associate Professor at Basra University, Iraq and Postdoctoral Research Fellow at Lund University, Sweden; *Pawley*, Lecturer at the University of Maastricht; *Smith* has undertaken postdoctoral positions at the University of Nevada and Argonne National Laboratory, USA. Others include lectureships in Jos and Ugbomoro, Nigeria, Mosul and Baghdad, Iraq and Egypt.
- *Industry:* Our industry collaborations have led to many graduates taking up employment in industry, including: *Assaf*, a researcher on Deep Learning and predictive analytics for IBM at the Zurich Research Laboratory, Switzerland; *Marshall,* who was initially employed by the UoS Energy House as a researcher and is now employed as an energy modeller at Vital Energy Utilities Ltd.; *Penketh,* a Project Engineer at Fugro; *Russo*, now a Postdoctoral Researcher for the Swiss Federal Institute of Aquatic Science and Technology; and *Steel*, who is employed at

the Culham Centre for Fusion Energy based on the expertise attained during his studentship co-supervised with AWE Ltd.

3. Income, infrastructure and facilities

Research income

Our income relates to **77 projects** with a total income value to Salford of **£5.2m**. Within this, £2m was from EU Programmes (FP7 and Horizon 2020); £1.8m from Research Councils (EPSRC and MRC); £0.5m from Innovate UK's KTP programme; £0.25m from industry, with the remainder originating from a range of sources including charities and local government. In addition, **£715k income-in-kind** was generated through time awarded at national and international facilities, such as the Diamond and ERSF synchrotron radiation sources and the ISIS and ILL neutron sources.

Autonomous Systems and Robotics awards include:

- **SMART-E** (Sustainable Manufacturing through Advanced Robotics Training; **EU FP7; €3.9m, £797k to Salford**, 2013-2017) was a Marie Skłodowska-Curie Innovative Training Network (ITN), led by Salford, which developed a world-class doctoral training and research programme for the next generation of graduate engineers to progress advanced robotics for Industry 4.0 manufacturing. The network focused on 3 key areas: dexterous, soft and compliant manufacturing; reconfigurable and logistics robotics; and safe human-robot interaction and cooperation. The industrial partners on the project included Airbus, BAE Systems and BMW. The UK nuclear industry recognised the potential of the SMART-E gripper developed by one of the PhD candidates and this led to a Phase 2 project led by Wood Group plc **(Innovate UK, ISF, NDA, Sellafield,** £1.5m; £11k to Salford) to develop and demonstrate a new heavy-load soft gripper with embodied intelligence for nuclear decommissioning, which has now progressed to Stage 3 and is undergoing testing at Sellafield (**Davis**, **Nefti-Meziani**).

- **FAIR-SPACE** (Future Artificial Intelligence and Robotics hub for SPACE; **EPSRC; £7.9m with £532k to Salford**, 2018-22) combines new Robotics and Artificial Intelligence for space applications. The project brings together over 20 aerospace industry partners who bring a further £7.5m matched funding to the project alongside a £15m business development fund. Research led by Salford include soft exoskeletons and soft slip sensors systems to augment astronaut strength and control and intelligent dexterous gripper technology for use in the retrieval of space debris and interplanetary exploration (**Davis**, **Nefti-Meziani**).

- **Synthesis of metamorphic mechanisms for multi-task applications** (**National Science Foundation China (NSFC): £337k** 2016-20). This project designed and developed novel mechanisms for improving manufacturing or operating processes around Advanced Manufacturing. Both fundamental theory and key technology have been developed and successfully applied in the electricity transmission system in north China (**Wei**).

- **SYNERGY** (**Innovate UK; £4.8m with £304k to Salford**) is concerned with developing innovative technologies for connective autonomous vehicles, in part operating in a platoon formation from Stockport to Manchester Airport (**Davis**, **Nefti-Meziani**). The initiative includes Manchester Airport, Transport for Greater Manchester (TfGM) and Westfield Sports Cars Ltd. as industry partners.

- **Theory and key technology for a soft-rigid hybrid biped walking robot** (**NSFC: £300k to Salford**; 2019-23) investigates the biomechanics and key technology of a novel soft-rigid hybrid walking robot system. A highly anthropomorphic walking robot will be developed and tested based on the biomechanics of human anatomy and musculoskeletal system (**Wei**).

Howard works with Human Movement and Rehabilitation (in our School of Health and Society) on bio-engineering research in prosthetics and orthotics, for example:

- Fit-for-purpose, affordable body-powered prostheses (**EPSRC: £1.4m**).
- Energy efficient lower limb prostheses (**EPSRC: £671k**).
- A smart electrode housing to improve the control of upper limb myoelectric prostheses (**NIHR i4i: £770k**).
- An electrode housing to improve myoelectric signal acquisition in sockets that accommodate growing residual limbs **NIHR (Starworks 2: £36k)**.
- An adjustable electrode housing device designed to improve myoelectric signal acquisition and prosthesis control in sockets that accommodate growing residual limbs NIHR (**Starworks 1: £43k**).

Engineering for Sustainability funding includes:

- **WATER-AGRI** (**EU: €7m with £206k to Salford**; May 2020-24). This international collaboration aims to re-introduce and enhance sustainable solutions for water retention and nutrient recycling to enable agricultural production that can sustain growing populations and cope with present and future climate change challenges. It brings together partners including Lund University, TUDelft and industry partners Agricolus and VTT Technical Research Centre of Finland Ltd. This builds on our previous environmental engineering research, which has generated substantial impact (**Scholz**, **Wang;** REF3).

- **Commercial research project with Salvalco Ltd.** (£14.5k, 2014-2016). To produce the novel domestic aerosol, **Eco-Valve**, new methods have been employed for moulding tooling of the components and the valves' autonomous assembly machines, which have been pivotal in the development and commercialisation path of Salvalco's breakthrough products. Researchers provided knowledge exchange to Salvalco on developing patents and supported the company in securing two TSB 'Smart' research grants (£994k, 2014) for the generation and development of volatile chemical free aerosol valves and actuators. These projects have led to over £10m external investment in the company in the UK with new manufacturing partners in China and Taiwan and taking the initial laboratory prototype to full industrial commercialisation (REF3).

- **KTP with Carlisle Fluid Technologies Ltd.** (CFT) (**Innovate UK: £140k**, 2017-19). CFT are a company that manufactures equipment for the supply and application of paints, coatings and sprayed materials for the automotive industry. The KTP benefitted from Salford expertise and facilities for spray and aerosol research, applied to the development and commercialisation of innovative, high-efficiency, environmentally friendly (low-Volatile Organic Compounds (VOCs)) painting products (**Nasr**, **Nourian**).

- **KTP with Vax Ltd.** (**Innovate UK; £121k**; 2013-15) to utilise in-house clean air expertise to map and analyse cleaning mechanisms relative to performance and efficiency, to design a highly innovative, premium range of vacuum cleaners (**Burby**, **Nasr**).

Infrastructure Engineering funding includes:

- **KTP with TechnoCover Ltd.** (**Innovate UK: £132k**, 2017-19). This project concerned digital twin model development to aid TechnoCover Ltd. develop security solutions for complex engineering applications that sit outside of current security design standards. The KTP led to reducing the development time and cost of new security products through novel methods and inhouse testing (**Currie**, **Nelson**).

- **Development of 3D Printing Buildings for Constructing Sustainable Houses** (**The Royal Academy of Engineering: £50k**; 2018-2021), applies reconfigurable parallel robots in the development of 3D printing technology for constructing sustainable houses in developing countries. Proof of concept design and prototype have been accomplished, which indicates that the proposed approach is feasible for practical applications (**Wei**, with ASAR).

- **Construction theory and control strategy for programmable meta-material** (**NSFC: £320k**; 2021-25) focuses on the theory, design and control strategy investigation of a new type of

programmable meta-materials inspired by origami patterns and design. The aim is to present a systematic theory for origami-inspired devices and apply such theory to developing novel type soft-rigid hybrid programmable meta-material (**Wei**, with ASAR).

- **KTP with Autac Ltd.** (**Innovate UK; £140k**; January 2020-22) to design a new smart, foldable electrical connector with Cable Reel variants for the Electric Vehicle market, alongside a new product innovation process and development of a new Research and Development department. (**Babaie**, **Nasr**, **Nourian**)

Materials, Physics and Chemistry funding includes:

- **CHEOPS** (Production technology to achieve low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells; **EU H2020: €3.2m with £276k to Salford**; 2016-19). Salford was a key academic partner alongside Oxford University, Centre Suisse d'Electronique et de Microtechnique, École polytechnique fédérale de Lausanne and Tyndall National Institute (Ireland). The project concerned the efficiency of new solid state, thin film perovskite solar cells including tandem configurations with conventional silicon solar cells. Salford expertise led to the development of new electrodes and charge transfer layers that allowed for efficient perovskite single junction upscaling (**Yates**).

- **MultiscaleSolar** (Multiscale in Modelling and Validation for Solar Photovoltaics; **H2020: €580k with £89k to Salford**; 2015-19). The project established a network of over 80 institutes and industrial organisations across Europe, including: Imperial College London, Northumbria University and Silvaco semiconductor designers. The network's objectives were to bridge scales in experimental and theoretical research in optoelectronics, with a focus on photovoltaics and breakthroughs in solar cells technology for enhanced energy conversion efficiency. The activities succeeded in bridging fields between solar cell manufacturing SMEs and industrial partners and academics relying on the interdisciplinary nature of this exchange, facilitating future breakthroughs in the field (Tomic, *leaver*).

- **PLIANT** (Process Line Implementation for Applied Surface Nanotechnologies; **EU FP7: €13.5m with £140k to Salford**; 2013-17). This project included 20 academic and industrial partners managed by Fraunhofer IWS. The project focused on the fabrication of aligned carbon nanotubes on electrode surfaces in a roll-to-roll procedure. Salford's focus was on upscaling the processes. These surfaces are now the basis of future high-capacity lithium-sulphur batteries and efficient capacitors; industrial partners included VARTA and Airbus (**Yates**).

- **Electrical and picosecond optical control of transistor-type plasmonic antenna switches** (**EPSRC: £159k**; 2012-15) was concerned with miniaturising optical components for on-chip integration of electronic and photonic functionalities. A key development was the development of a nanoscale version of a radiowave antenna: the plasmonic nanoantenna. Such antennas are designed to overcome the diffraction limit of light and to focus light into a nanometer-sized antenna 'feed' gap. During the project, CVD process were developed to give a significant degree of control of film morphology (crystal phase) via introducing a nucleation layer. The work significantly enhanced the opto-electronic properties which is being taken further by the collaborator institute (Southampton University) through characterising and assessment for device integration (Sheel, leaver).

- **Erbium implanted silicon for solid state quantum electronics** (**EPSRC: £94k**; 2018-20) with partners including the National Physical Laboratory, Ionoptika Ltd., Queen Mary University of London and Saarland University, Germany. The project was concerned with exploring the feasibility of erbium atoms doped in silicon acting as quantum bits (qubits). Such a system would combine the telecommunication capability of erbium with the integrated circuit capability of silicon to make it valuable for both quantum computing and quantum communication applications. The project successfully demonstrated the control of the spin state of erbium using laser light. Refinement and robustness of control is further being studied by a School-funded PhD studentship (**Hughes**).

- **iCASE with AWE Ltd.** (**Innovate UK: £94k**; 2013-16): This industry funded PhD studentship investigated the diffusion of hydrogen and its isotopes in palladium in bulk and thin film form, with a view to isotope separation and containment applications. The project successfully undertook detailed characterisation of diffusion as a function of temperature; applications are now being developed by AWE using this information. The student (Steel) is now employed at the Culham Centre for Fusion Energy based on the expertise attained during the studentship (**Bull**, **Ross**).

Infrastructure and facilities

Engineering research occupies a number of dedicated laboratories located in the Newton, Cockcroft and Maxwell Buildings on Salford's Peel Park Campus. In 2017, the University embarked on developing a Campus Masterplan to ensure its presence as a civic and cultural gateway for the city. Within the Masterplan, the **new £65m SEE building**, due for completion in 2022/23, will provide **15,366m^2 of state-of-the-art collaborative workspace** including workshops and studios at the heart of the Peel campus, consolidating SEE from five buildings into one. The existing engineering laboratories will be co-housed in this new building. The co-location of research laboratories will enhance interdisciplinary research and lead to new innovative projects. Funding for NERIC has been secured from the European Regional Development Fund, Research England, and match-funding support from the University of Salford totalling £17.6m. Due for completion in in 2022/23, **NERIC will be a 2,000m^2 research facility providing laboratory and R&D space for industrial collaboration in healthcare robotics and rehabilitation** (e.g. exoskeleton development, 3D-sensing and mapping and force plates to measure movement and load), **manufacturing robotics and industry 4.0 and terrestrial and aeronautical autonomous system development**. The overall aim is to facilitate engineering research, primarily to enhance productivity and prosperity across multiple industrial sectors.

Projects in the robotics area have been enabled by robotics and autonomous systems laboratories hosting multiple industrial Kuka robots, conveyors and programmable logic controllers with associated sensors, actuators and I/O modules and manufacturing facilities for bespoke robotics equipment, in particular for soft robotics projects. In this REF period, the University has invested **£1m in a new Autonomous and Automotive Vehicle Technology (AAVT) laboratory**, that includes a purpose-built 12-seater Level 4 driverless shuttle (Navya) allowing us to explore research on connected and autonomous vehicles (CAVs). The shuttle is complemented by three further hybrid vehicles (Mercedes, Toyota) linked to a chassis dynamometer rolling road and emissions analysis equipment (Pegasor Mi3), suitable for Worldwide Harmonised Light Vehicles Test Procedures (WLTP) and Real Driving Emissions (RDE) measurements on multiple vehicles. The lab also features a medium-sized robotic development platform to bridge to robotics research. Our simulation facilities include the Siemens PreScan simulator to develop technology solutions for Advanced Driver Assistance Systems (ADAS) in CAVs. The AAVT facility is closely linked to vibro-acoustics facilities (including an anechoic chamber) for development of new components and measurement of acoustic properties of materials and components.

Autonomous Systems and Robotics research is also a major user of **OCTAVE**, a world class immersive virtual environment facility with dedicated expert technician support. OCTAVE has been used as a tool for remote robotics applications related to the nuclear industry. 3D tracking facilities have also been used extensively for prosthetics research, enabling an advanced understanding of human movement.

Materials and physics research is supported by bespoke materials analysis laboratories including RAMAN spectroscopy and unique polarisation microscopy equipment (through a University spin-out company, Optimum Imaging). **A laser laboratory** houses a range of spectroscopy facilities including bespoke systems for the in-situ studies of materials under high pressure. Salford Analytical Services, a linked commercial research unit, contains scanning and transmission electron microscopes, x-ray diffraction, Nuclear Magnetic Resonance and thermal deposition. These facilities are managed by expert technical managers and used both internally for research and for external commercial work. **CVD laboratories** house a range of test rigs allowing

environmental control (thermal, plasma, gas flow) to explore deposition operating conditions before upscaling towards industrial processing. The laboratories also offer a range of other thin film deposition, including magnetron sputtering and physical vapour deposition system to complement the CVD deposition facilities.

The research leading to the development of the Salford Eco-valve was undertaken within our **specialist spray and gas laboratories** housing advanced spray characterisation equipment, including: Phase Doppler Anemometry, pulse photonics, Particle Image Velocimetry, and high-speed cameras coupled with spray coating and flow control systems. The petroleum technology laboratories house facilities for understanding gas and fluid flow in porous media and carrying out measurements for x-ray tomography, unsteady state gas permeameter and porosimeter, rock compressibility and *in-situ* acoustic velocity.

The **Engineering laboratories** facilitate research across the engineering group and include 3 supersonic wind tunnels. These experimental facilities have been utilised for benchmarking of CFD research. Civil engineering uses the strengthened floored laboratory for design, testing and demolishing of large structures (e.g. masonry bridges) with dedicated technical support.

Facilities for rapid prototyping are provided through the **Morson Maker Space**, an additive manufacturing and digital fabrication facility managed by expert technical staff who support both digital design and operation. The facility was **funded by £500k of industrial investment** from the Morson group and a further £250k from the University. Manufacturing and analysis facilities include: 3D Printing Technologies – Fused Filament Fabrication (FFF) and Stereolithography (SLA) printing, large format printing and metal additive manufacturing; Waterjet cutting – Omax Maxiem 1515 5 Axis waterjet to machine a wide range and thickness of materials from metals and composites to glass and plastics; Laser cutting - Gravograph LS 900 and Epilog Fusion Pro and Epilog Zing; 5 Axis machining – Haas UMC-500; CMM – Nikon Altera 10.10.8; Digital and Optical microscopy – Zeiss Smartzoom 5 and a Zeiss Axio Zoom V16; and a laser scanner (Nikon MCAx).

4. Collaboration and contribution to the research base, economy and society

Engineering research at Salford is diverse and interdisciplinary in nature and engages with a wide range of industry stakeholders at national and international levels. The vast majority of our research and training activity is undertaken in collaboration with academic and industry partners and we have worked with over 300 companies. Many researchers hold leadership positions in European and UK expert academic and industry networks and our staff offer expertise in a range of areas linked to engineering academic discourse.

Evidence of effective academic collaborations and networks

ASAR has long-term and extensive collaborations with globally leading robotics institutes, with which it has collaborated for more than 20 years on projects funded by EU Framework Programmes for RTD 5, 6 and 7. These include the Technical University of Munich, Scuola Superiore Sant'Anna, the University of Zurich, the Italian Institute for Technology and the Advanced Manufacturing Research Centre at Sheffield University (for example the SMART-E FP7 ITN Doctoral training network which hosted and developed training and research programme for 17 doctoral students and researchers), together with 8 industrial partners including Airbus and BAE Systems. ASAR has a partnership with the École Supérieure des Technologies Industrielles Avancées (ESTIA) to develop a collaborative approach to research and training around robotics, automation and manufacturing.

The EPSRC FAIRSPACE Hub is a collaboration of 6 UK universities: Surrey, Salford, Edinburgh, Warwick, Liverpool and Imperial College London, with each partner bringing complementary, but unique skills to enable space robots to perform more complex tasks on long-duration missions with minimal dependence on ground crew. In recognition of its research, Salford has been invited to co-organise the Shangh'AI Lectures (http://shanghailectures.org), whose creators include prestigious universities recognised globally in the area of Artificial Intelligence and Robotics, such

as Osaka, Shanghai Jiao Tong and University College Dublin. These lectures take the form of real-time interactions between researchers across continents to make education and knowledge on cutting-edge scientific topics accessible to everyone.

Howard is co-lead of the Human Movement Technologies group (jointly with Prof Lawrence Kenney, School of Health and Society). The group collaborates extensively with other universities, medical practitioners and manufacturers in the prosthetics and orthotics sector and leads an EPSRC Centre for Doctoral Training in Prosthetics and Orthotics (2019-24). As an example, through the Fit for Purpose Prosthetics project, the Salford team collaborates with groups at UCL, the Universities of Southampton and Portsmouth, the University of Jordan and Makerere University, and is funded by the EPSRC and the National Institute for Health Research Global Challenges fund. In the international context, the group's research investigates cultural constraints, and clinical and manufacturing resources in Uganda and Jordan to improve prosthesis in the two countries.

In MPC, **Yates** works on thin film photovoltaics with an extensive list of UK and EU partners through CHEOPS and PLIANT (section 3). The EPSRC-funded quantum technology project (**Hughes**) was based on significant collaboration with academic collaborators at Surrey, Southampton and Surrey Universities, as well as the National Physical Laboratory. **Proctor** collaborates with Edinburgh, Manchester and Queen Mary University of London in the area of high-pressure physics.

In Engineering for Sustainability, **Scholz** leads a European network in the area of sustainability in the built environment and is a key contributor to the WATER-AGRI EU H2020 project consortium which consists of a group of 23 partners from 12 European countries, including Lund University (Sweden), prominent European water and soil research institutions and centres such as VTT Technical research Centre of Finland, Universities of Debrecen, Bologna, TU Delft and Universite de Neuchatel, as well as international experts on stakeholder engagement and communication.

Collaboration and innovation with industry

Our research contributes to the overarching University industrial collaboration strategy priority areas that include Robotics and Smart and Sustainable Living. Research which positively impacts UK and global prosperity is at the core of all our activity and Engineering has a breadth of external research links with industry and third-sector partners to deliver this.

Engagement with SMEs and industry representative organisations

With two members of staff involved in leading Salford spin-out companies (**Nasr** as non-Executive Director of the Salford Valve Company Ltd. and **Shirley** as co-Founder and Director at Salsa Sound Ltd.), our expertise extends beyond academic research to direct understanding of the needs of SMEs within these sectors. As 99% of businesses are classed as SMEs, all areas of Engineering prioritise building strong partnerships with these organisations to translate research into business solutions supporting economic growth within the North West region and UK. Through 8 projects (both KTP and iCASE) each of the four Engineering themes have partnered with individual companies to ensure commercial value arises from our work within a variety of sectors (Section 3).

Our influence and involvement extends beyond working with individual companies through our participation in industry networks. This ensures our research and expertise contributes to regional and national agendas and we understand and respond effectively to changing sector needs. ASAR is actively engaged with the National Robotics Network (NRN) and the Food Manufacturing Engineering Group (FMEG) and provided expert robotics advice to the Aerospace Supply Chain Excellence Programme ('ASCE2', led by the NWAA, which engaged 250 SMEs). **Davis** and **Nefti-Meziani** contributed to the GAMMA programme, a three-year Regional Growth Fund project with eight partners to develop software for unmanned vehicles and drones, with ~250 SMEs.

Into the future, NERIC will expand on our support for the food manufacturing and healthcare technology sectors by contributing to the creation of an ecosystem for collaborative R&D in the

Greater Manchester city-region and beyond. The facility has been designed to complement and strengthen the Made Smarter National Adoption Programme piloted in the North West and to provide an increased volume of industry engaging with the High Value Manufacturing Catapult national network, generating true impact for our private sector partners. NERIC will host expert staff and cutting-edge robotics and automation facilities to support 60 SMEs with piloting, testing and experimenting with robotics and AI innovation to assist them with embedding industry 4.0 technologies into their business processes.

Our expertise is recognised through leadership roles in industry and government affording us influence to help shape the future of sectors of importance to the UK and global economies, especially in a post-COVID world. **Nefti-Meziani** is Co-founder and Executive Board Member of the *UK's National Robotics Network* and a member of the UK Government's (BEIS) *Robotics Growth Partnership*. She is a member of UK-RAS and contributed to the network's White Paper *Agricultural Robotics: The Future of Robotic Agriculture* (2018). She is also an advisory board member for the Chamber of Commerce for Bayonne Region (France) and the Asian Council. We contribute to industry developments in infrastructure engineering through **Currie's** role on the British Standards Institute CB/2 Committee for developing new standards to reflect innovation and sustainability in construction. In MPC, **Morrison** is a member of the IEA Hydrogen Task 40: a collaboration of international academic and industry experts (e.g. Toyota, Daimler) to develop reversible or regenerative hydrogen storage materials. **Nasr** engages with politicians and industry around the reduction of VOCs in aerosol technology to steer policy change, for example through DEFRA and aerosol associations (in the UK and USA). He has served as an expert witness in the USA for a number of cases in relation to aerosol inhalation.

Partnerships with large enterprises, multinationals and the public sector
We develop and maintain relationships with key major businesses to deliver impact across various sectors. ASAR partners with a range of companies within robotics and automation development, for example, Siemens, (the largest industrial manufacturing company in Europe). Other prominent industry partners work with us to address engineering issues impacting on the environment, for example, around nuclear decommissioning where we have developed a new flexible gripper demonstrator (with Sellafield, National Nuclear Laboratory and Wood Group Plc) and we also work with United Utilities to create ecologically protective engineering solutions. The group's involvement in healthcare applications requires development of collaborations linking public and private sector and we work with various NHS Trusts, for example, Grampian in Scotland, Salisbury and Manchester University NHS Trust, together with Chas A Blatchford & Sons Ltd., to deliver rehabilitation solutions and new lower limb prosthetics for children.

In the area of spray research, we have collaborated with over 120 multi-national companies relating to indoor and outdoor air quality for new product development and construction of the supply chain to deliver this. Examples of these are: Carlisle Fluid Technology (UK), VAX (UK), Hughes Safety Showers (UK), AWI Ltd. (Europe and China), Colep (Poland and Asia), XDC (Taiwan) and Derjjn Group (China). The end goal is a reduction in Volatile Organic Compounds for cleaner environments within homes, schools, homecare and hospitals has resulted in timely contributions to environmental policies, particularly to the DEFRA Clean Air Strategy 2019.

Patents awarded
Cultivating an environment of creativity and innovation in research has resulted in the award of 10 patents (plus another pending for **Scholz**):

- **Davis** - 'Robot Gripper Comprising a Slippage Sensor and Operating Method of a Robot Gripper', patent WO2019243781 (A1), 2019.
- **Howard** - 'A system for performing functional electrical therapy', GB2545712, 2017.
- **Nasr**, **Burby** - Liquid dispensing apparatus', patents US8820588B2 and US8820589B2, both 2014.
- **Nasr**, **Burby** - 'Aerosol spray device', patent US8752737B2, 2014.
- **Shen** - 'Measuring polarisation via a gating frequency', patent US10228287B2, 2019.

- **Shirley** - 'Assistive mixing system and method of assembling a synchronised spatial sound stage', patent US9979499B2, 2018.
- **Wei** - 'A reconfigurable Quadrotor Based on Sarrus-linkage', patent CN109592026A, 2019.
- **Yates** - 'Quantum Dots Made Using Phosphine', patents US20140370690 A1, 2014 and US9343301, 2016.

Contribution to the sustainability of the discipline

Engineering has supported the organisation and delivery of the work of international professional societies and learned journals, and our expertise and involvement has been frequently sought by peers and external organisations.

Selected keynotes, plenaries and invited talks

- **Arrigo** (Invited) - The Science and Technology of Materials, Interfaces, and Processing (AVS) 63rd International Symposium, 2016, Nashville, USA.
- **Arrigo** (Invited) - Ambient-pressure x-ray photoemission spectroscopy (APXPS) Workshop, 2015, Berkeley.
- **Chadwick** (Keynote) - 16th Annual International Conference on Boundary Element and Meshless Techniques (BETeq 2017), Romania, 2017.
- **Currie** (Invited) presentation at the Henderson Colloquium organised by International Association for Bridge and Structural Engineering (Cambridge 2017).
- **Howard** (Keynote) - BioMedEng19, Imperial College, London.
- **Hughes** (Invited) lecture at the University of Strathclyde's John Anderson Research Colloquia, 2019.
- **Nasr** (Plenary) - Advances in Plastic Technology: 2019, Chorzów, Poland, audience of 250.
- **Nasr** (Plenary) - ADF (Association Dentaire Francaise) Congress, Paris 2016; an annual international congress with over 400 participants.
- **Nefti-Meziani** – (Invited) ShanghAI Lectures, University of Zürich (Dec 2014) and Robotics; AI for health and social care, Turing Institute, University of Manchester (2019).
- **Wei** (Invited) - 27th IFToMM PC-A, Working Meeting on Standardization of Terminology & Advanced Symposium on Mechanism and Machine Science, 2018, Fuzhou University, China.
- **Yates** (Keynote) - 16th International Conference on Plasma Surface Engineering, Garmisch-Partenkirchen, Germany, 2018.

Organisation of major conferences

Over 500 attended the *14th International Symposium on Metal-Hydrogen Systems* hosted by Salford in 2014 and Chaired by Ross (leaver), with organisation by **Bull, Morrison** and **Proctor**. **Scholz** was on the organising committee for the International Conference on Water Microbiology & Novel Technologies (2016), Chicago, USA. **Hughes** was on the organising committee for the IoP Photon conference, 2018 and chaired the Waveguide and fibre optic devices and sensors session. **Nefti-Meziani** chaired a session at the 2018 POLIS conference on Innovation in Transport for Sustainable Cities and Regions. **Yates** is chair of the 16th conference on Photovoltaic Science, Applications and Technology to be hosted in Salford in 2021 (delayed from 2020) and organised by the (UK) Solar Energy Society affiliated to the International Solar Energy Society (ISES).

Roles within funding bodies

Davis and **Howard** are full members of the EPSRC peer review college whilst **Hughes** and **Nefti-Meziani** are associate college members. **Nefti-Meziani** has reviewed for the Netherlands research funding body, and for the EC on FET and COST programmes. She also served on the Advisory Board for the EPSRC Centre for Innovative Manufacturing in Intelligent Automation (2011-2017) at Loughborough and Cranfield Universities. **Scholz** is a reviewer for the Israeli Ministry of Science and Technology.

Selected leadership roles in learned societies

- **Arrigo** serves on the user group committee for the Diamond Light Source.
- **Chadwick** was Chair of the North-West Branch of the Institute of Mathematics and its Applications and Chair of Maths In Action outreach at University of Salford and University of Warwick.
- **Currie** was chairman of IStructE Branch for the northwest region.
- **Nasr** is a member of CPD committee of the Institution of Gas Engineers and Managers and Fellow member of IGEM and IMechE.
- **Nefti-Meziani** is former Vice-Chair of IEEE Robotics and Automation Society UK.
- **Proctor** was Secretary for the IoP Shock Wave & Extreme Conditions group.
- **Wei** is Vice-Chair, Youth Commission of International Society of Bionic Engineering.

Selected journal Editorships

- **Davis** is a Guest Editor for *Frontiers Robotics and AI*.
- **Howard** serves on the Editorial Boards of the *International Journal of Bionics Engineering* and the *International Journal of MultiPhysics*.
- **Mei** serves as an Associate Editor for *IET Electronics Letters*.
- **Nefti-Meziani** serves as Associate Editor of *IEEE Transactions on Fuzzy Systems* and the robotics conferences IEEE IROS.
- **Scholz** is on the editorial board of *Petroleum and Chemical Industry International*.
- **Uzomah** serves on the editorial board of journals including MDPI – Sustainability; IJERPH; Agronomy; *Water* journal and *Applied Science* Journal.
- **Wei** serves as Associate Editor, *Journal of Mechanical Engineering Science* (Proc. IMechE Part C).

Overseas visiting positions

- **Arrigo** is an honorary visiting scientist at the Diamond Light Source and at the Polytechnical University of Milan.
- **Mei** is a Visiting Professor at Tongji University
- **Wei** is an Adjunct Professor at Jilin University, China

Media engagement

Both **Davis** and **Theodoridis** have appeared on the BBC; **Davis** in a robotics feature on BBC Northwest Tonight and **Theodoridis'** home service robot 'Carebot' featured on the BBC documentary 'Six Robots & Us', attracting 32.5 million views (2018). **Whittleston** appeared on Sky News giving expert opinion on the Grenfell tower fire. In online media, **Arrigo** featured in 'Take a Tour of the Diamond Light Source' in Chemistry World and authored 'Thinking Big to See Small Things' in Chemistry (Nature Portfolio 2018) and **Proctor** authored 'Liquid Mysteries' in Physics World (2018).