

Institution: University of Dundee
Unit of Assessment: UoA12 Engineering
1. Unit context and structure, research and impact strategy

1.1 Unit context and structure

UoA12 at the University of Dundee (UoD) comprises 48 Category-A staff with a diverse range of backgrounds delivering solutions to major global challenges including: demographic changes (population growth, urbanisation, ageing society), healthcare, challenges in the use of science in fair justice decisions, climate change, natural disasters, resource depletion and environmental change.

Research within UoA12 is undertaken principally within the School of Science and Engineering (SSEN), one of ten academic Schools within UoD. SSEN supports research across UoA10, UoA11 and UoA12 and its research strategy aligns with the University's mission of **transforming lives locally and globally** in terms of societal and economic impact. Fundamental to this is the strategic aim of embedding interdisciplinarity, leading to impact across four institutional themes (IT):

- IT1: Understanding and improving health and wellbeing;
- IT2: Life-enhancing creativity and design;
- IT3: Innovating technological solutions to tomorrow's problems;
- IT4: Promoting social change to enhance diversity, justice and socio-economic prosperity.

The institutional strategy prioritises excellence and research at disciplinary interfaces. To focus research activity on priority areas of strength, SSEN has created four **Themes**, within each of which there are multiple **Research Clusters**. Clusters provide critical mass in areas of excellence while nurturing innovative interdisciplinary research. Each cluster has a lead academic and every researcher is a member of at least one cluster; some join multiple clusters facilitating inter-cluster working and staff from other Schools are drawn-in for interdisciplinary research. This has facilitated long-term sustainable collaborations with the Schools of Life Sciences, Medicine, Social Sciences and the Duncan of Jordanstone College of Art & Design (DJCAD). 52% of outputs submitted for UoA12 have been flagged as interdisciplinary. Staff returned in UoA12 contribute to the following clusters (*indicates a member of multiple clusters):

- **Biomedical Imaging & Technology (BIT)** [IT1, IT3] – This cluster works closely with the Schools of Life Sciences and Medicine to develop medical devices and optical, ultrasonic and elastographic imaging techniques utilising approaches ranging from fundamental physics investigations to translational application in clinical medical practice. Led by **MacDonald**, it comprises 15 Category-A members from two Schools (**Campbell, Cuschieri, Homaeigohar*, Huang, Joseph, Krstajic, MacDonald, Murphy, Manfredi, Melzer, Nabi, Nylk, Vettenburg, Vorstius*, Zolotovskaya***) including biomedical engineers, physicists and clinical practitioners based at the UoD teaching hospital (Ninewells).
- **Materials Science & Engineering (MSE)** [IT1, IT3] – This cluster invents, produces and exploits advanced materials with improved functional properties for applications ranging from (small to industrial scale) coating and manufacturing processes to highly specialist

materials for high-energy physics research at the European Organisation for Nuclear Research (CERN). Led by **Abdolvand**, it comprises 13 Category-A members principally drawn from the disciplines of Mechanical & Electrical Engineering and Physics (**Abdolvand, Cochard, Homaeigohar*, TJones, Keatch, Keeble, Menard*, McKenzie*, Mohammadi, Vorstius*, Wilcox, Zhao, Zolotovskaya***).

- **Concrete Technology & Structural Engineering (CTSE)** [IT3, IT2] – This cluster develops more sustainable and functionally-improved cementitious materials for use in the design and rehabilitation of infrastructure. This includes the re-use of waste products (e.g. fly ash, demolition waste) and optimisation of structural forms through innovations in reinforcement, formwork design and digital technology to produce a durable, resilient, low-cost, low-carbon, future built environment. Led by **RJones**, it comprises eight Category-A members (**Chernin, Dyer, Knappett*, McCarthy, Newlands, RJones, Spadea, Zheng**) including civil engineers and material scientists and collaborates with the School of Social Sciences (Architecture and Urban Planning).
- **Geotechnical Engineering & Fluid Mechanics (GEFM)** [IT3, IT2] – This cluster focusses on understanding the influence of natural and anthropomorphic processes on the terrestrial and marine environment and development of sustainable and resilient methods to adapt these environments to anthropogenic activities. Led by **Cuthbertson**, it comprises ten Category-A members (**Bengough, Brennan, Brown, Ciantia, Cuthbertson, Davies, Eaves, Guha, Hayatdavoodi, Knappett***) including civil engineers and applied mathematicians; it collaborates with the School of Social Sciences (Geography and Environmental Science) and with the James Hutton Institute for land, crop and natural-resource management (e.g. through the shared appointment of **Bengough**).
- **Science and Justice (SJ)** [IT4, IT3] – This grouping overarches work in Forensic Science, Science Communication & Policy and Anatomy & Anthropology. Led by **NicDaeid**, SJ develops robust scientific solutions to the current vulnerabilities associated with forensic evidence used in the criminal, civil and family courts, both nationally and internationally. This has involved an interdisciplinary approach, leveraging assets across SSEN and UoD – e.g. development of novel nanoparticle detectors for drugs (SJ; **Adegoke, NicDaeid / MSE; Zolotovskaya, Abdolvand**). It comprises eight Category-A researchers (**Adegoke, Cole, Garcia-Donas, Gray, Hackman, McKenzie*, Menard*, NicDaeid**) including material scientists, forensic scientists, chemists and data scientists and collaborates with the Schools of Life Sciences, Medicine, Dentistry, Social Sciences, Humanities, Social Work & Education and DJCAD.

UoA12 incorporates a cross-institutional centre, the **Leverhulme Research Centre for Forensic Science (LRCFS)** which supports work in SJ. Led by **NicDaeid**, LRCFS was established in 2016 and is a £10M, ten-year research centre, one of seven disruptive centres across the UK funded by the Leverhulme Trust. LRCFS brings together stakeholders from across the forensic science and justice ecosystems to collaboratively articulate operational challenges and co-create research-led solutions, enabling the Unit to lead change within the UK forensic science community.

1.2 Implementation of REF2014 strategy

UoA12 brings together researchers submitted across UoA14 and UoA15 of REF2014. Over the current period the Themes and Clusters approach of SSEN enhanced cohesion and integrated strategies under the following priorities:

(i) Deepen integration between engineering, physical science & biomedicine

In BIT, the €3.7M European Training Network PHOQUS contributed to establishing the **PaLS (Physics and Life Sciences) Laboratory**, bringing technology developers in UoA12 and life scientists together, enabling benchmarking of developing technologies against the currently available gold standard and translation from engineering concept to imaging solutions available to facility users. **MacDonald** and **Zhao** are members of the Centre for Antimicrobial Resistance at UoD, which enables integration with biomedicine. The **Dundee Institute for Healthcare Simulation**, established within the School of Medicine, provides a custom-built facility at Ninewells Hospital incorporating the Cuschieri Surgical Skills Centre and the Image Guided Therapy Research Facility. UoA12 researchers have utilised this facility to clinically evaluate new surgical technologies as part of the Unit's ISO13485 certification, allowing CE marking for devices developed in-house. The surgical technology group under **Cuschieri** has developed 16 CE marked products in a collaboration with Karl Storz GMBH, including 5 patent families developed during the period (e.g. EP-3-527-150-B1 (UK); DE-60-2015-048-431.2 (Germany); US-8882799-B2 (USA)).

(ii) Establish internationally competitive computational modelling and analysis

Expertise in computational modelling and simulation has been embedded within clusters to complement the physical and experimental expertise and infrastructure that were a hallmark of the 2014 submissions. This has provided computational modellers with high-quality data for calibration and validation, with subsequent validated approaches providing a development pipeline of higher capacity towards greater impact. Recruitment in GEFM and CTSE has focussed on staff with expertise in modelling of particulate materials (**Ciantia**) and fluids (**Guha**), and optimisation techniques (**Spadea**). Within SJ, expertise in data analytics (**Cole**) and data-management systems (**NicDaeid**) has enabled the development of deep-learning solutions for pattern matching in biological/chemical (DNA, drugs, toxicology) and physical (fingerprints/footwear/ballistics) data. To support this growth, SSEN has invested in High-Performance Computing resources across UoA12, UoA11 & UoA10 (see Section 3).

(iii) Grow materials science and engineering research

Materials-based research is embedded within all clusters. In MSE, novel metal alloys have been developed through continuous casting technology, alongside laser surface and in-volume processing to create materials with optimal properties for specific applications. The latter has expanded by the Unit joining the Compact Muon Solenoid (CMS) Collaboration at CERN, including a student-exchange programme. This has resulted in the development of an automated laser-treatment technique for eliminating residual electron clouds in the Large Hadron Collider (LHC) that will result in considerable future financial savings for CERN and its member states (**Abdolvand**).

The Unit's strong track record in electronic engineering, with historical achievements recognised in 2018 by a milestone plaque from the Institute of Electrical and Electronics Engineers commemorating the invention of the thin film transistor, has continued in the Unit's work in novel materials for Memristors (**Cochard**) and satellite data communications (**Parkes**) (see Impact Case Study).

CTSE and GEFM have created low-carbon composite materials for sustainable infrastructure incorporating re-use of waste materials. This includes high-performance concretes using recycled aggregates from demolition waste as part of a \$7M international consortium (**RJones**), and

innovative processing of stockpile fly ash to reduce cement use (**McCarthy, RJones**). Demolition waste and vegetation have been used to develop engineered cover soil for the protection of embankments and retaining structures within the EPSRC-funded CACTUS project (**Bengough, Knappett**), alongside a suite of validated modelling tools across multiple projects facilitating the practical implementation of green infrastructure solutions.

SJ is addressing the fundamental principles of the transfer of traces of materials (fibres, glass, DNA, firearms discharge residue) and their persistence once transferred. This is building an open-source database for use by forensic practitioners worldwide (**Menard, Gray, Cole, NicDaeid**). Developments in functionalised nanoparticles and quantum dots for specific drugs, explosives and body fluids (SJ; **Adegoke, NicDaeid** and MSE; **Zolotovskaya, Abdolvand**) have demonstrated potential for low-cost, selective and sensitive field-deployable testing kits that can deliver point-of-response confirmatory testing beyond the current state-of-the-art.

(iv) Make a difference in global-challenge-based interdisciplinary research

UoA12 has increased impact generation towards achieving the UN Sustainable Development Goals (UNSDG); examples include:

- UNSDG#3 Good Health and Wellbeing: Development of datasets characterising Novel Psychoactive Substances, street benzodiazepines and synthetic cannabinoids in collaboration with Police Scotland and the Scottish Prison Service, providing early warning information to the United Nations and World Health Organisation (see Impact Case Study – SJ; **McKenzie, NicDaeid, Cole**).
- UNSDG#7 Affordable and Clean Energy: Development of low-cost screw-pile foundation technology for solar/wind energy that is resilient to natural hazards for deployment in India as a SPARC-funded collaboration with Indian Institute of Technology Bhubaneswar (GEFM; **Brown, Knappett**).
- UNSDG#9 Industry, Innovation and Infrastructure: Use of wastepaper sludge within the manufacture of cementitious products in Africa (CTSE; **Spadea, Dyer, Ciantia, McCarthy**).

(v) Link engineering with social sciences and the arts to increase societal and cultural impact

In CTSE, synergies between engineering performance and architectural appearance of the built environment are being realised. Examples include: (i) the addition of hydrophobic waste printer toner to colour concrete and improve durability (**Newlands**) in conjunction with Architecture and Urban Planning – winning the Scottish Knowledge Exchange Award 2018 (Social and Environmental Impact Category); and (ii) the evaluation of historic cementitious materials for conservancy, rehabilitation, repair, and therefore protection of culturally significant structures, funded by AHRC in collaboration with Historic Scotland (**Dyer**). In SJ, the production of comics for the effective communication of science and the use of virtual and augmented reality for crime-scene investigation and hypothesis scenario testing has been advanced with the School of Humanities and DJCAD (**NicDaeid**).

(vi) Increase impact and translation of research outside academia

To deliver this, the Unit has:

Increased industrial collaboration: A Knowledge Transfer Partnership with Rautomead (see Impact Case Study; **Abdolvand**) has developed continuous casting processes and materials for specialist applications in the aerospace, marine, automobile and energy sectors. Unit involvement in the Transforming Construction Network Plus programme has developed benchmarks to drive improved performance in construction projects in conjunction with the Department of Transport and Whole Life Consultants Ltd. (CTSE; **Newlands, RJones**) and resulted in the Unit's involvement in the InnovateUK-funded Transport Infrastructure Efficiency Strategy Living Lab with 22 industry partners.

Built on existing relationships with national and international sectoral bodies: work in cement replacement using fly ash has directly influenced industry guidance on the specification of sustainable concretes using BS8500 (CTSE; **McCarthy**). Work in ultrasound elastography has directly influenced international guidelines for clinical use within both World and European Federations for Ultrasound in Medicine and Biology and is in use for breast and prostate cancer screening in NHS-Tayside (BIT; **Nabi, Huang**).

Engaged with the SFC Innovation Centres: work to improve the health of farmed salmon in aquaculture, particularly related to sea-lice infestation, has been funded by the Scottish Aquaculture Innovation Centre (SAIC) and industry. This has included the development of ultrasonic based treatments (BIT; **Campbell**) for inshore use and resilient anchoring solutions to enable siting further offshore where lice do not thrive (GEFM; **Brown, Knappett**).

1.3 Future research and impact strategy

The creation of research clusters and substantial investment in facilities (Section 3) and people (Section 2) have provided a platform to enable the Unit to tackle complex interdisciplinary problems in areas including energy, the environment, healthcare, infrastructure and the justice system. The Unit's strategic aims for the next 5 years (linked to institutional themes [IT1–IT4]) are:

(i) Establish hubs for innovation and translation of medical technologies [IT1]

The BioDundee partnership between UoD, NHS-Tayside and regional partners is poised to undergo a step change in harnessing the Unit's research innovation and become the medical-technologies innovation driver for the local region with global impact, enabled by a direct contribution through the **Tay Cities Deal** (Section 3). A proposed **MedTech Pipeline Hub (£5M)** will augment existing facilities to create an innovative space for the Unit (alongside clinicians) to develop, test and drive the adoption of emerging medical technologies proximal to ongoing clinical care. This will be supported by a proposed £0.9M-extension to the Unit's Thiel-cadaver facility to increase capacity and by recent appointments within the Unit (**Homaeigohar, Joseph, Krstajic, Manfredi, Murphy, Nylk, Vettenburg, Zolotovskaya**). Solutions developed by the Unit will feed a proposed translational **Innovation Hub (£20M)** providing estate and business support to attract investment to grow successful spin-out and spin-in companies and drive the regional economy. This will increase the number of strategic partnerships between the Unit, healthcare and industry and strengthen the articulation of BIT with the School of Medicine, Ninewells Hospital Medical Physics, Photobiology (Dermatology) and the Clinical Research Centre. The Unit will use these strategic developments to support establishment of an industrial collaboration with Neusoft (China)

focussed on diagnostic imaging systems as part of a £25M 10-year Joint Educational Programme (JEP) with Northeastern University, China (led by **Huang**). This will provide new pathways to impact for new medical devices developed within UoA12 for personalised healthcare.

(ii) Establish JustTech – Institute for Innovation in Forensic Science [IT4]

The Unit aims to establish the World's first **Institute for Innovation for Forensic Science (JustTech; £15M)**, supported by Tay Cities Deal investment, enabling a step-change in global leadership in forensic science to generate, transform and translate existing and future research within UoA12 into bespoke tools that address the challenges faced by current and future forensic practitioners serving justice in countries across the World. This investment will be supported by recent appointments (e.g. in novel sensing technologies), including Baxter-Fellow **Adegoke**.

(iii) Grow materials science and engineering research [IT3]

The Unit will continue to develop robust research streams, focussing both on advanced manufacturing and harnessing fundamental physical science to develop novel functionally enhanced and composite materials, processes and instruments that will translate into the industrial sphere. Technologies will be supported for which the Unit possess the required depth of research expertise and entrepreneurial capability to develop and exploit, specifically focussed on materials that will have new or improved structural/functional properties with applications across a wide range of sectors, including photonics, electronics, pharmaceuticals, aerospace, automotive, security, energy and infrastructure. This aligns to the UK's Industrial Strategy priorities of advanced technologies in processing and engineering of functional materials, improved standards and low-cost production methods. This will be enabled by redefining the Unit's research infrastructure in this area, with CERN and Rautomead partnerships providing new living laboratories for research at an industrial scale. This will be supported by recent appointments specialised in manufacturing processes, materials physics and materials for energy (**TJones, Cochard, Mohammadi**). The Unit will seek collaborative opportunities through the recently established strategic partnership between UoD and the **Michelin Scotland Innovation Parc (MSIP)**, co-led by **Newlands**, providing access to the MSIP Skills Academy and Accelerator Programme to accelerate the translation of new technologies to industry.

(iv) Innovate and translate solutions to societal grand challenges [IT2]

Recent investment in physical infrastructure (see Section 3) and expertise within UoA12 have aligned the Unit with the **Future Mobility, Clean Growth** and **Ageing Society** Grand Challenges of the UK Industrial Strategy, providing future industry collaboration opportunities. To deliver against these the Unit will:

- **Develop enabling technologies for commercially-viable deep-water marine renewable energy (MRE) and aquaculture**, with opportunities around the development of innovative construction techniques and composite materials, substructures and anchoring technologies. These will unlock the full potential of the UK and further afield (beyond existing shallow-water developments) allowing the Unit to take a global lead towards meeting 2050 Climate-Change targets and facilitate growth of global aquaculture to provide low-carbon protein for an expanding World population. The Unit will modify the operational model for the Scottish Marine and Renewables Test (SMART) Centre to increase the Unit's agility in responding to industry demands and support increased activity with a focus on translation and impact generation (see Section 3).

- **Advance environmentally-sustainable construction, repair and rehabilitation technologies for the built and natural environments** through growth in developing low carbon materials and design approaches towards a net-zero future. Opportunities include (i) increasing re-use of waste products for engineering purposes; (ii) translating sustainable 'green' infrastructure solutions (which sequester carbon) into industry; and (iii) developing solutions for the environmentally-responsible decommissioning of fossil fuel infrastructure. New interdisciplinary links will be forged within UoD (e.g. the UNESCO Centre for Water Law, Policy & Science) and externally (e.g. the UK Collaboratorium for Research in Infrastructure), where the Unit's unique combination of facilities and expertise is complementary.
- **Develop minimally-invasive diagnostic and interventional medical techniques** including image-guided therapies building on existing work with the Unit's dedicated Insightec Exablate system and expanding into neurological treatments with a new Magnetic Resonance Guided Focussed Ultrasound (MRgFUS) system. Research will aim to improve the complete patient journey – diagnostics, prognostics, treatment planning, novel minimally-invasive therapies, robotic surgeries and infection control – using ultrasonic, optical and materials-based approaches. In parallel, at-home and point-of-care healthcare technology will be advanced, particularly for ageing populations. These will be operationalised through the MedTech Pipeline and Innovation Hubs (Section 1.3(i)).

(v) Maximising impact

The Unit will increase its impact generation activities across all of its activities, capitalising on recent investments in infrastructure (Section 3) and investment secured through the Tay Cities Deal. The operation of key research facilities will be restructured to facilitate greater interaction with industry, alongside raising the profile of the Unit's activities and building strategic industrial-academic partnerships.

1.4 Fostering an open-research environment

Significant progress towards an open-research environment has been made, leveraging the University's Library and Learning Centre (LLC) and Discovery Portal to ensure compliance with the Concordat for Open Research Data. Standard practice for all staff and research students in UoA12 is to deposit all research outputs, datasets and theses in Discovery as open access and to maintain this as the definitive record of their research output. The institution is a member of the Datacite scheme to assign Digital Object Identifiers (DOIs) to research outputs. LLC advises on data-management planning and compliance with funders' open-data policies. Datasets and programme code arising from UoA12 research have been published with DOIs as open data using CC-BY licenses, facilitating re-use (including **Abdolvand, Brennan, Brown, Bengough, Knappett, MacDonald** (first UoD minted DOI: 10.15132.10000100), **Nabi, NicDaeid**). Publication in open access publications is encouraged and Unit staff serve on the editorial boards of 28 journals, of which 7 (25%) are open access (see Section 4.2).

1.5 Research Integrity

UoA12 staff provide leadership in this area School-wide, with the Research Integrity Lead (**Wilcox**) and Deputy Lead (**Abdolvand**) providing: (i) an independent point of contact for staff and research students outside their immediate research environment; (ii) impartial advice on responsible conduct of research; and (iii) advice on making misconduct allegations. Research staff and students are provided with online video-based training in Responsible and Ethical Practice in Research and

Publication. The Director of Postgraduate Research Studies (DRPS; **Wilcox**) oversees rigorous procedures that ensure all postgraduate research students benefit from the appropriate research integrity training and all data created for PhD theses and publications are archived in an appropriate form.

2. People

2.1 Staffing strategy and staff development

The REF 2014 strategy aimed to grow research excellence in areas of strength while increasing opportunities for interdisciplinary research through the creation of research themes and clusters. To achieve this, the Unit's staffing strategy aims to attract outstanding researchers with established track records of independent post-doctoral research achievement. The Unit's guiding principles in the present context are:

- (i) to recruit individuals internationally with track records of excellence, achievement and potential to become leading researchers, to continually reinvigorate the Unit's activities;
- (ii) to appoint in coherent research areas of existing strength, critical mass and long-term potential to underpin technologies of the future (particularly in interdisciplinary areas) and fully exploit the investment the Unit has made in physical and digital infrastructure (Section 3);
- (iii) to recruit staff with expertise that optimises complementarity within and between clusters to ensure that clusters remain agile and responsive;
- (iv) to maintain a balance between Early Career Researchers (ECRs) and established researchers to ensure a rich pool of future Unit leaders while maintaining sufficient mentoring support and established research income streams (29% of Category A staff are ECRs);
- (v) to foster the ambition of all staff by appointing to permanent contracts wherever possible, and providing targeted resources, access to professional development and networking opportunities, enabling them to become leaders in their field.

The School's Associate Dean Research is a member of all shortlisting and appointment panels for roles that include significant research responsibilities. The appointment process usually runs over two days to ensure that candidates interact with relevant cluster staff and become familiar with the Unit's research structure before interview. Success of this recruitment strategy at early-career level, and for the new cluster-level peer support for applications, has been demonstrated through the award of a £1.4M UKRI Future Leaders Fellowship to **Vettenburg** (2019; appointed 2018).

In 2013, UoD introduced **Dundee Fellowships** across the Institution with the long-term aim of attracting research leaders of the future while providing a catalyst for strategic growth within the current period. These staff were given protected research time over a five-year period (through limited teaching and administrative duties). The Unit benefitted from three Fellows out of eight appointments, including **Wilcox**, who held an EPSRC Early Career Fellowship during the period and provides leadership in research within the Unit as the current Director of Research Postgraduate Studies. The programme was renewed in 2019, with four **Baxter Fellows** being appointed in UoA12 (**Homaeigohar**, tissue engineering and biomechanics, BIT/MSE interface; **TJones**, casting technology for renewables, MSE; **Adegoke**, analytical chemistry and sensors, SJ; **Manfredi**, surgical technology, BIT). Their appointment was made by a cross-cluster panel to maximise impact in key strategic research areas.

The creation of LRCFS in 2016 attracted Category A appointments with new expertise to the Unit including data analytics and science communication (**Cole, NicDaeid**). Additional Category A appointments across all clusters included: **Ciantia, Cochard, Cuthbertson, Hayatdavoodi, Joseph, Krstajic, Guha, Murphy, Mohammadi, Nylk, Spadea, Vettenburg, Eaves**, in addition to appointments at cluster interfaces to strengthen interdisciplinary research – **Zolotovskaya** (BIT/MSE), **Menard** (SJ/MSE) and **McKenzie** (SJ/MSE). Across all new appointments in the period, 20% were Baxter Fellows, 60% were non-Baxter ECRs and 20% were established researchers. This approach resulted in an age demographic across Category A staff at census of 27% under 40 years of age, 40% between 40-49, 21% between 50-59 and 12% over 60, ensuring that the Unit has an age profile that can ensure long-term sustainability with a strong pipeline of new talent.

International appointments and recruitment

Recruitment within the period has seen 27% of new appointees from overseas institutions, 8% internal and the remainder from UK institutions. Overseas appointments were: **Eaves** (University of British Columbia, Canada), **Hayatdavoodi** (Texas A&M University, USA), **Homaeighar** (Aalto University, Finland), **Guha** (IIT Kanpur, India), **Menard** (Sasol – industry, South Africa), **Mohammadi** (University of Waterloo, Canada). Appointments from UK institutions included: **Ciantia** (Imperial College), **Cochard** (Queen's University Belfast), **Joseph** (University of Cambridge), **Krstajic** (University of Edinburgh), **Nylk** (University of St Andrews), **Spadea** (University of Bath), **Vettenburg** (University of Exeter) and **Zolotovskaya** (Lancaster University).

Career development

A supportive environment is provided, aligned with the institution's strategic aims to **enable staff to flourish** and maintain a **high-performance community** and with the Concordat to Support the Career Development of Early Career Researchers. All staff benefit from annual individual reviews of their research progress at Unit level by their line manager, as part of the institutional Objective-Setting and Review (OSaR) process, which supports a culture of continual improvement. This is complemented by an institutional **Workload Allocation Model (WAM)**, managed at Unit level, and an **Annual Research Review (ARR)** conducted across all clusters to identify interdisciplinary opportunities. The Cluster Lead role, supervision of research students, external research projects, impact-generation (e.g. consultancy/service work) and public engagement activities are recognised in the WAM in addition to a protected research-time allocation to all research-active staff. The ARR provides peer feed-forward to maximise the impact and visibility of research, guidance in developing future plans for securing resources and career-development support using discipline-specific benchmarks in line with the Declaration on Research Assessment (DORA).

All newly appointed staff are guided by a mentor (a senior colleague within the cluster) to formulate and achieve personal performance goals and deliver the Unit's objectives. Additional support is provided through a cross-institutional Teaching, Research and Academic Mentoring scheme (see Institutional Statement), which is open to all staff, including ECRs and postdoctoral research associates (PDRAs). Newly appointed staff enjoy reduced teaching load to provide time to establish sustainable research activities and access to start-up funding from the School to support network establishment, dissemination activities and establishment of specialist equipment. ECRs are preferentially allocated PhD studentships (at Unit and Institutional level) to assist in establishing their research profile. Academic staff can transition between Teaching & Scholarship and Teaching & Research contracts (and vice-versa) to support career development, a process which has been utilised by the Unit within the period.

Cross-cluster capital investment (£125k) was obtained from EPSRC to enhance integration of newly appointed ECRs into the existing laboratory ecosystem. Further support was obtained through the Northern and Scottish Research Partnerships in Engineering through the PEER (Pool Engagement in European Research) & PECRE (Postgraduate and Early Career Researcher Awards) schemes to facilitate European and International networking and research visits (six awards within the period).

Clusters run active seminar programmes (either individually or cross-cluster) with external and internal speakers. The former promote interaction with visiting speakers who are leaders in their area, exposing Unit staff to current and new (inter)national research developments, increasing the visibility of the Unit's work and establishing new external collaborations. The latter provides academic staff, PDRAs and research students with critical input to their research, promotes new interdisciplinary activities and develops communication skills. The Unit encourages industry-academia interactions in either direction, an example being the visit of Mr H. Matsui (Taisei Corporation, Japan) working on installation of undersea cables aligned with the Unit's work on enabling technologies for marine renewable energy which has strategic future importance as outlined in Section 1.3(iv) (12 month visit; GEFM, hosted by **Brown**).

Excellence in research is recognised through the institutional Annual Review and Promotions Procedure, informed by ARR via OSaR, where research, impact generation and public engagement can all be used as supporting evidence across all academic levels. The effectiveness of Unit-level support outlined above is reflected in the promotion of three members of staff to Lecturer-8 grade, eight to Senior Lecturer, six to Reader and six to Professor within the period.

2.2 Research students

The Unit has graduated 132.8 FTE PhD students within the period with 93 current research students at census, showing a healthy and growing community. Research students are supported at institutional level by the **Doctoral Academy**, providing specialist support and research development training for students, bespoke training for supervisors and embedding an interdisciplinary research ethos. At Unit level, the DRPS coordinates student support and development activities including quality assurance and mentoring of research staff in supervision (particularly for ECRs). Students have a minimum of two supervisors to provide resilience in provision and enhance mentoring. A Thesis Monitoring Committee (TMC) meets biannually, individual TMC meetings being held with two non-supervisory research-active staff (assigned for the duration of study to ensure continuity of oversight) to which both student and supervisor provide independent progress reports and can identify any issues confidentially; the TMC feed-forward suggestions and guidance to the supervisory team and DRPS. A small cohort of students are located in Ninewells Hospital, supervised by Unit staff and NHS-Tayside Medical Physics; their TMC is administered by the UoD Medical School and committee membership includes Unit staff (**MacDonald, Huang, Zhao, Melzer**).

Research students are provided with full access to the Unit's physical, digital and human infrastructure and can access the full academic and transferrable skills training programme offered by UoD Organisational and Professional Development. Funding support is available for all students to attend international conferences to disseminate their research. An annual Postgraduate Research Symposium provides opportunities for dissemination across all SSSEN clusters, facilitating identification of interdisciplinary opportunities and complementing the Unit's seminar programmes. A student from CTSE working at the interface of civil engineering and marine biology was a semi-finalist in the national Three-Minute Thesis competition and a finalist in

the national FameLab competition, highlighting the importance of the initiative. Students (and PDRAs) have access to external training in advanced and applied physics provided by the Scottish Universities Physics Alliance (SUPA) Graduate School. Students studying within LRCFS have the option of undertaking a Postgraduate Certificate in Researcher Development encompassing modules in research development, statistics and programming, leadership, public engagement and science communication. Roll-out of this pilot initiative Unit-wide is currently under development.

Future growth in the Unit's activities (see Section 1.3) will require significant growth in research students and this underpins the Unit's future strategy in this area. UoA12 is already engaging with institutional initiatives to **increase its visibility** for postgraduate research (e.g. *100 Projects* initiative). **Increased capacity** will be provided by pursuing Doctoral Training Centre opportunities in strategic areas, increased direct industrial funding of research through the impact strategy (Section 1.3(v)), and growing new international collaborations e.g. through the JEP identified in Section 1.3(i).

2.3 Equality, Diversity and Inclusion (EDI)

The Unit is committed to maintaining an inclusive culture and collegiate working practices and its composition includes academic staff, PDRAs and Research students across a diverse range of nationalities and ethnic groups. All staff (including PDRAs) undertake training on EDI, including modules on *Diversity in the Workplace*, *Disability*, *Diversity in Learning and Teaching*, *Stress in the Workplace* and *A Manager's Guide to Stress*. A module on *Recruitment and Selection* is additionally taken by staff with such a role. Completion is monitored centrally, and its importance is emphasised to staff by all levels of leadership within the Unit. SSEN has an EDI standing committee, including representation from UoA12 (**Spadea, Zolotovskaya**), facilitating sharing of best practice across Units. **Hackman** and **NicDaeid** are both trained as investigators in discrimination, harassment and bullying cases.

In addition to the institution's Athena SWAN Bronze award, SSEN holds a departmental Bronze Award and is developing a Silver Award submission for 2022. The Unit appoints staff on merit alone and is committed to equality and diversity. All staff appointment panels are gender balanced. Of the 22 new appointments within the period, 18% were female and the proportion of female staff being promoted was at or above the underlying gender balance at census of 87.5% male, 12.5% female, at all levels. 25% of promotions to Reader or Professor were female.

It is part of the University strategy to minimise the number of fixed-term contracts. All of the 22 new appointments were made on permanent contracts, with 89% of Category A staff in the Unit being on permanent contracts at census.

UoA12 is supported by a range of institutional flexible-working practices covering changed circumstances, compassionate leave, parental leave, adoption/fostering leave, carer's leave and fertility treatment leave. These include mechanisms for short periods of special leave that can be locally implemented by the Dean of School in emergency situations. Discussions related to return to work, including requests for reductions in FTE, are held prior to return in line with UoD's Flexible Working Policy. The Unit can be flexible in transitioning staff to/from part-time working; job sharing and flexible/phased retirement are also supported. Flexible-working considerations are embedded at Unit level within the ARR and OSaR processes when reviewing performance and establishing individualised development plans. Voluntary declaration of any mitigating circumstances is part of the Annual Review and Promotions Procedure.

2.4 Construction of REF submission

Outputs have been selected and attributed to individual staff by the Unit's Planning Group following rigorous internal and external review aiming to maximise the overall quality profile for the submission, consistent with the UoD REF Code of Practice. All Unit Planning Group members completed unconscious bias training prior to output selection in addition to EDI and information security awareness training undertaken by all staff. Of the outputs submitted, 89% are attributed to male staff and 11% to female staff, consistent with the UoA12 gender balance at census and the proportion attributed to staff from different ethnic groups is consistent with the proportion of staff identifying with those groups. The proportion of outputs attributable to each cluster is also approximately proportional to cluster size.

All staff were invited to submit Impact Case Studies and the four submitted case studies reflected the strongest impacts arising over the REF period, with authorship which is 75% male and 25% female.

3. Income, infrastructure and facilities

The REF 2014 strategy aimed to grow income and activity across the Unit's activities and invest in physical and human infrastructure to provide a sustainable foundation for its activities moving forward.

3.1 Income

The Unit's portfolio encompasses Research Grants and Contract (RGC) income from UKRI, EU, charitable and industrial sources, totalling £21.3M. This has increased by 10% compared to £19.3M in REF 2014 (General and Civil Engineering submissions combined). Additional major external-capital and operational investment has been secured including:

- £10M over 10 years from the Leverhulme Trust to establish the **Leverhulme Research Centre for Forensic Science** (in 2016), enabling the development of the SJ cluster, £2.7M of which has been invested within the period.
- £2M to establish the **SMART Laboratory** (in 2014), a cross-cluster initiative between CTSE and GEFM. This was funded through the European Regional Development Fund (ERDF) with matched University funding and was facilitated by the Offshore Renewables Institute (ORI), a collaborative alliance established in 2013 funded for a five-year period by UoD, University of Aberdeen and Robert Gordon University.
- £1.25M capital investment in BIT (in 2019) through the JEP with Northeastern University and Neusoft, China, enabling significant expansion of BIT facilities.

The majority of RGC funding supports a critical mass of continuous activity. Examples include:

- Biofouling – from fundamental understanding of formation and structure in conjunction with the School of Life Sciences (BBSRC, £2.04M; **Campbell**) to applications in developing anti-fouling nanocomposite biomaterials for urinary catheters (EPSRC £501k; **Zhao, Keatch Nabi, Campbell, Vorstius, Wilcox**) and engineering concrete marine structures to limit biofouling by invasive species (Leverhulme Trust £60K; **Dyer**).

- Engineering with light through the application of photonics and nanotechnology, including development of: (i) novel imaging devices for quantitative multi-scale investigation of biological processes through the PHOQUS project coordinated by the Unit (EU €3.28M; **MacDonald, Cuschieri**); (ii) optical and ultrasonic micromanipulation devices for bio-processing (EPSRC £165k; **MacDonald**), leading to a Breakthrough-of-the-Year Award from the Institute of Physics (2014); and (iii) a robotic device for mitigating electron clouds through laser surface processing for the LHC (STFC £535k, match-funded by CERN at CHF680k and a further £1.07M STFC funding through the High Luminosity LHC (HL-LHC) second phase; **Abdolvand**).
- Development of bio-mediated techniques to adapt infrastructure to the effects of climate change while effecting climate improvement. Funding totalling £1.24M has included the use of vegetation within embankments led by the Unit (EPSRC £1.23M, £640k to Dundee; **Bengough, Knappett**), and identification of breeding strategies to select for root traits that engineer soil (BBSRC, £79k; **Bengough**). Global Challenge applications included fieldwork in Thailand (Royal Society, £71k; **Knappett, Bengough**) and protecting infrastructure in seismic zones (Leverhulme Trust £168k; **Brennan, Knappett, Bengough**). This platform was leveraged in ongoing work developing engineered vegetated capillary-breaks layers to protect linear infrastructure (EPSRC £1.76M, £280k to Dundee; **Bengough, Knappett**).
- Development of enabling technology for the expansion of marine renewable energy. Funding totalling £1.67m included work led by the Unit on screw piling for fixed platforms at deep-water locations (EPSRC £1.0M; **Brown, Brennan, Knappett**). Subsequent work (EU £170k; **Knappett, Brown**) extended this as a next-generation anchor for floating systems. In parallel, other work has improved installation techniques for buried offshore cables (EPSRC £470k, £180k to Dundee; **Brown, Brennan**), and developed new approaches to wave energy generation (Energy Technology Partnership (ETP)/Industry £322k; **Hayatdavoodi**). The Unit is also part of the Blade Access System and Working Environment project (InnovateUK; **Chernin**).

Supporting income generation

Clusters support research-income generation through the open discussion of ideas, sharing of information and best practice, and providing expert peer-review of grant funding applications. Additional cross-cluster review is actively encouraged. PhD studentship support is provided for staff winning external funding, who are encouraged to use this to leverage co-funding from industry or other bodies such as the Scottish cross-HEI research pools, including the Scottish Research Partnership in Engineering (SRPe) and ETP. The Research Administrative Lead (Section 3.2) continually reviews available funding opportunities and the Unit is also supported by a dedicated **Technology Transfer Manager** to assist in establishing new links with industry. These complement institutional awareness raising and network-building activities (see Human infrastructure, below).

3.2 Infrastructure & facilities

Physical infrastructure is grouped by the areas of excellence and critical mass represented by clusters; in addition to developing these within the period, additional interdisciplinary infrastructure has been established which integrates and complements cluster facilities. Digital and human infrastructure are shared across SSEN.

Specialist physical infrastructure

In addition to access to the Dundee Institute for Healthcare Simulation mentioned in Section 1.2(i), BIT research laboratories include the **Clinical Research Imaging Facility**, housing a 1.5T research MRI machine (part of the GE European Centre of Excellence for MRI-guided Interventions and Surgery) with an adjoining interventional suite incorporating an ExAblate focussed ultrasound surgery device (all located on the Dundee MediPark), plus a PET/CT scanner with its own interventional suite at Ninewells Hospital. An **Ultrasound Development Suite** is available for equipment fabrication, testing and characterisation. All laboratories are equipped to handle cadavers prepared in the UK-leading **Thiel-Cadaver Facility** within SSEN, allowing new techniques to be evaluated on tissue that is as realistic as currently possible. The **Cell and Tissue Culture Laboratory** provides a facility to grow, maintain and engineer live tissues under controlled physiochemical conditions. A TRI-SPIM Fluorescence Light-sheet Microscope (unique as a commercial platform) was established within the PaLS Laboratory using £0.6M from BBSRC (**MacDonald**) in partnership with 3i Intelligent Imaging.

The research laboratories for MSE contain state-of-the-art photonics infrastructure, and associated measurement and characterisation equipment. The **Laser Technology Laboratory** provides high-power pulsed laser systems for surface and in-volume structuring of materials (metals, glass and polymers) and has facilitated impact generation through the work at CERN outlined in Section 1.2(iii). The **Materials Testing Laboratory** provides advanced characterisation via scanning and transmission electron microscopes with in-built chemical analysis, atomic force microscopy, scanning capacitance devices, digital microscopy, optical spectroscopy and nanomaterials printing/analysis and has underpinned advanced materials characterisation work with Rautomead (see Impact Case Study) A **cleanroom suite** provides wet chemistry infrastructure.

GEFM maintains the **Centrifuge Laboratory** which was refitted within the period through ERDF funding to add in-flight robotic actuation, high-speed imaging, and a new flight-control system. Together with earthquake and fault-rupture simulators, the facility provides a unique combination of capabilities in Europe, particularly for modelling natural hazards, and contributed to the award of eight EPSRC/EU grants worth £2.5M to UoD and £5.5M to the wider project consortia; it has been utilised by international academic partners including the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, National Technical University of Athens and University of Auckland, and in partnerships with industry that have generated impact (see Section 4.3). The **Geotechnical Laboratory** provides advanced element-test facilities supporting the capabilities of the centrifuge. The **Fluid Mechanics Laboratory** has been recently refurbished and contains five bespoke facilities for studying environmental flows at reduced scale, including a 14m long wave-flume for fluid-structure interaction analyses, a multipurpose channel-basin for estuarine flow dynamics, and a tsunami simulator. The Unit also has access to the Ocean Basin at Harbin University of Science and Technology (**Hayatdavoodi**).

CTSE has invested heavily in specialised equipment for multi-scale microstructural and chemical analysis (including x-ray diffraction/fluorescence, thermo-gravimetric analysis, laser-diffraction particle-size analysis) alongside facilities for environmental exposure simulation within the **Concrete Technology Unit (CTU)**. This has generated impact by facilitating bespoke testing for the next generation of UK nuclear power stations as outlined in Section 4.3 and complements facilities within the Materials Testing and Geotechnical Laboratories. The **Structures Laboratory** has recently been enhanced by bespoke multi-axis servo-controlled static/cyclic test equipment that has been integrated with the reconfigurable 150m² strong floor, and non-contact image-based measurement systems (£96k; **Spadea**); this provides a unique facility for multiscale testing from

1:1 structural elements to reduced-scale modelling of structural systems through recent advancements made by the Unit in reduced-scale modelling of reinforced concrete (**Knappett**).

SJ benefits from a bespoke analytical-chemistry facility housed in the **Fleming Laboratory**, providing access to separation techniques including spectroscopic methods and chromatography as well as PCR- and DNA-quantification capabilities. Advanced spectrometers are accessible through collaboration with the School of Life Sciences. Specialist equipment within **LRCFS** includes cyanoacrylate fuming for fingerprint enhancement, Video Spectral Comparison, Electrostatic document deposition analysis, alternative light sources, comparison microscopy, a muffle furnace for time-temperature studies, virtual and augmented reality capability, 360-degree Matterport photography, and LIDAR.

Cross-cluster physical infrastructure

New investment within the period has established new physical infrastructure which enables interdisciplinary working either directly or by linking specialist cluster facilities:

- At the interface between Physics and Life Sciences, the **PaLS laboratory** (Section 1.2(i)) was funded through institutional investment and SUPA and sits adjacent to the **Dundee Imaging Facility (DIF)**. The DIF provides facilities and support including state-of-the-art commercial microscopy and expertise in imaging software and analysis; BIT (**MacDonald**) and MSE (**Keeble**) are represented on DIF's steering group. Equipment investment in the PaLS Laboratory of approximately £850k, leveraging additional external funding of £250k, principally supported ECRs to build bespoke research instruments, including: a super-resolution 3D-stimulated emission-depletion (STED) microscope, tissue-specific optical tweezer systems, and a Raman spectrometer. This also facilitated installation of a femtosecond laser, and a Dektak surface-characterisation system. In collaboration with the School of Medicine, point-of-care diagnostic platforms and endoscopic microscopy have and are being developed including:
 - Generation of ligand-free metallic nanoparticles fluorescence and surface-enhanced Raman-spectroscopy platforms for sensitive diagnostic assays;
 - Generation of molecularly imprinted polymers (plastic antibodies) for cheap manufacture of antibody-like labels for a wide range of biological and non-biological targets.
- The **SMART Laboratory** was established to support decarbonisation of the UK's energy infrastructure (including decommissioning and environmental restoration) and provide access for industry to advanced facilities including the centrifuge and CTU (see Section 4.3). An x-ray micro-CT imaging facility for non-destructive material evaluation is incorporated (**RJones/Newlands**) that complements the DIF. SMART Laboratory facilities form a component part of the Scottish Energy Laboratory (Scottish Enterprise) providing access for industry and other HEIs. The combination of accessible facilities makes it a nationally unique facility for the delivery of subsea engineering, complementary to other national facilities (e.g. ORE Catapult). An example of interdisciplinary working is the non-destructive forensic evaluation of friable evidence from fires and characterisation of the thermal capabilities of representative concrete mixes in fire (see Impact Case Study).

Digital infrastructure

High-Performance Computing requirements across UoA12 are supported via scalable infrastructure. SSEN has established (since 2014) a local cluster with 640 cores that is principally used by UoA12 and UoA10. A larger institutional cluster is based in the School of Life Sciences and is comprised of 186 nodes (3780 CPU cores; 206720 GPU cores; 21 TB RAM), which includes a dedicated UoA12 resource consisting of 38 nodes (1152 CPU cores; 150720 GPU cores; 4.6 TB RAM). This dedicated Unit capability is larger than the institutional capacity in 2014 and has more than doubled in the period using UoA12 resources. These facilities support the genesis, development and up-scaling of large numerical simulations prior to accessing shared national resources (e.g. ARCHER).

Human infrastructure

The majority of senior research leadership roles within SSEN are held by UoA12 staff. The **Associate Dean Research (ADR; Abdolvand)** provides strategic leadership and chairs the School Research and Knowledge Exchange Committee (RKEC) comprising cluster leads, and the **Director of Research Postgraduate Studies (DRPS; Wilcox)**. RKEC allocates funding supporting staff development, networking and other expenses (e.g. pump-priming activities), with priority given to ECRs and maintaining research continuity (e.g. retaining key PDRA expertise). The **Associate Dean Industrial Engagement (ADIE; Newlands)** provides additional leadership around engagement with industrial partners and external organisations. This includes creating and nurturing partnerships with regional enterprises, developing opportunities for industry-led research and supporting knowledge exchange (KE), impact and commercialisation. The ADR, ADIE and DRPS are supported by the Research Integrity Lead (Section 1.5) and a Research Administrative Lead (RAL) in sustaining a research-driven culture. The RAL collates and analyses data relevant to research reviews and other Unit activity, supporting staff in developing a culture of Open Access and Open Data (see also Section 1.4), disseminating funding opportunities from Research Connect and liaising with institutional support services – **Research Finance Services (RFS)**, providing pre- and post-award management of non-commercial grant applications and awards; and **Research and Innovation Services (RIS)**, providing support for collaborative bid development, intellectual property, licensing, contracts and KE. A recently-appointed **Director of Public Engagement (DPE)** supports the translation of research to non-academic audiences.

The ADIE, alongside the DPE, supports KE and public engagement (PE) activities at project, cluster and Unit level and researcher development in these areas (for all staff, including PDRAs). All clusters include senior staff who are experienced in KE and impact generation, providing mentoring to staff with less experience. Unit-level support complements institutional resources available through Organisational and Professional Development (OPD) and the Centre for Entrepreneurship – one of three hubs of Elevator UK – for support in commercialisation. Recent successful KE examples include the spin-outs **ActiveNeedle** – for use in ultrasound-guided anaesthesia and biopsy – and **Softech** – for developing a low-cost soft robot for colorectal cancer screening and treatment (Scottish Enterprise High Growth Spin-out Programme £80k; **Manfredi**). SSEN established a Graduate Apprenticeship Programme in 2017, which has increased the School's industrial network by over 100 local, national and international organisations, and funded two dedicated **Industrial Liaison Officers**.

Significant regular opportunities for PE are provided via the Café Science programme at the Dundee Science Centre and Bright Club Dundee; all clusters have access to a PE lead who is part of the SSEN Public Engagement Committee. Researchers from the Unit have appeared on The

One Show (BBC One; **Knappett**), Inside Science and The Today Programme (BBC Radio 4; **NicDaeid**) and local, national and international radio. Since its establishment, LRCFS has developed significant international PE collaborations, including with the Alan Alda Centre for Communicating Science at Stony Brook (USA) and the Winton Centre for Risk and Evidence Communication at Cambridge (UK). LRCFS enjoys a high media profile through participation at science, arts and book festivals and a unique 'Crime Café' developed in Dundee.

Opportunities for cross-cluster working are actively encouraged where these can form a stronger team for addressing challenging problems. The institutional **Dundee Interdisciplinary and Innovation Forum (DIIF)** facilitates challenge-led events bringing together researchers from UoA12 with those from across the institution and industrial stakeholders. Examples of cross-cluster working include:

- Solving infrastructural challenges related to the operation of the CMS detector at CERN, one of four detectors of the LHC. This includes new technical solutions for aligning the detector to critical tolerances during maintenance cycles (GEFM; **Knappett** / MSE; **Abdolvand**).
- Addressing increased morbidity and mortality relating to catheter-associated urinary tract infection (EPSRC-funded) through the development of anti-infective Ag-PTFE coated catheters which can extend the mean life of a silicone catheter by a factor of six (MSE; **Zhao, Keatch** / BIT; **Nabi, Campbell, Vorstius**).

3.3 Future income, infrastructure and impact strategy

Tay Cities Deal investment will provide focussed investment in infrastructure of £20.2M supporting Unit activities, principally in BIT and SJ clusters, to support delivery of the strategy items outlined in Section 1.3(i) and 1.3(ii), with Heads of terms signed in 2018 for investment within the next REF period.

Growth in income and opportunities supporting strategic items in Sections 1.3(iii) and 1.3(iv) will be achieved through:

- **Restructuring the operation of key research facilities**, including new business models and a professional services review with the aim of providing dedicated technical and research staff to increase capacity to undertake industrially funded work alongside support for core research activities. This will enable strategic relationship-building with industry partners and increase opportunities to accelerate innovative research to market. Initial pilot studies (Section 4.3) indicate that this can be an effective and sustainable model long-term.
- Establishing a series of **targeted industrial 'Discovery Days'** for specific sectors aligned to raise awareness of the Unit's unique facilities and expertise.
- Supporting staff in **increasing industrially funded PhD research** to assist in growing the cohort of research students within the Unit. This will be supported through additional resources generated from increased industrial work and increased engagement with funding schemes operating on a cost-sharing model between funder and industry.

To support delivery of increased impact (Section 1.3(v)) the ADIE will establish and lead an Industrial Engagement Committee with **Impact Champions** from each cluster to provide a network

for sharing, across the Unit, best practice from clusters with the strongest track records of generating impact (see Impact Case Studies) and develop metrics for measuring impact and KE.

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

4.1 Research Collaborations, networks and partnerships

The Unit has been involved with more than thirty research collaborations, three international networks and two partnerships. Exemplars of successful international collaborations are:

- Partnership with CERN, whereby research students are embedded within CMS to conduct translational work in advanced materials and infrastructure asset management (MSE, CTSE; **Abdolvand, Knappett**). This has produced deliverables which will generate impact in the next period (Section 1.2(iii)) and resulted in the Unit being invited to join the HL-LHC Collaboration Board alongside other international laboratories, expanding international links and laying a platform for future growth (Section 1.3(iii)).
- A series of collaborative EU projects around advanced surgical and non-invasive medical technologies, including the development of surgical robots for minimally invasive procedures (SARAS project, **Huang, Nabi, Melzer**; and CARPE project, **Cuschieri, Manfredi**) and for non-invasive use of focussed ultrasound (FUTURA project, **Huang, Nabi, Melzer**). The success of these collaborations contributed to the Unit's track record, supporting the attraction of Tay Cities Deal investment to establish medical technology hubs in the next period (Section 1.3(i)).
- Collaborative working on EU-Hydralab projects for pan-European facilities access, most recently on morphodynamics of estuaries and sea straights as part of Hydralab+ (**Cuthbertson**). These collaborations have expanded Unit links that will support growth in the environmentally-responsible use of marine resources for energy and aquaculture (Section 1.3(iv)).
- EU-funding to develop profiling methods for ignitable liquids led by the Netherlands Forensic Institute with eighteen other partners (**NicDaeid**) and a Churchill Fellowship (**Hackman**), fostering collaboration between LRCFS and the Australian and Canadian Judiciary. Networks built through these collaborations will be exploited by JustTech moving forward (Section 1.3(ii)).

The Unit is highly collaborative with other UK Universities, research institutes and industry, examples being:

- EPSRC-funded Automating Concrete Construction consortium (£1.24M) collaborating with the Universities of Bath and Cambridge and multiple industrial partners, including the Building Research Establishment (**Spadea**), contributing to work outlined in Section 1.2(iii).
- EPSRC-funded Screw piles for wind energy foundation systems consortium (£1M) led by the Unit, collaborating with the Universities of Southampton and Durham and industrial partners including Soil Machine Dynamics UK and Roger Bullivant Ltd (**Brown, Knappett, Brennan**). This has provided a foundation for supporting future strategy outlined in Section 1.3(iv).

- EU-funded H-Unique project, developing robust hand biometrics for combatting child sexual abuse (€2.5M), in collaboration with the University of Lancaster (**Hackman**). This built networks supporting future development of JustTech (Section 1.3(ii)).

SFC-funded research pools have contributed to Unit growth across multiple clusters as outlined in examples in Sections 1-3, including though SUPA, the National Telford Institute, SRPe and ETP. These embed collaboration with other Scottish universities and industry at their core. Within the SFC Innovation Centre (IC) programme the Unit has received project funding from the Construction Scotland IC (**Newlands**), Datalab (**Cole**), Oil and Gas IC (**Brennan**), Sensor and Detection IC (CENSIS; **NicDaeid**), and Scottish Aquaculture IC (**Campbell, Brown**).

The Unit has hosted external academic and industrial visitors, including:

- Professor G N Ivey (University of Western Australia) on a Distinguished Visiting Fellow Award from the Royal Academy of Engineering, working on internal solitary waves (two months; GEFM, hosted by **Davies**);
- Professors Bo Zhao and Bingbing Wang (Northeast Electric Power University, China) and Professor Yongwei Cai (Chongqing University of Technology), each on Visiting Scholar Awards from the China Scholarship Council, working on anti-biofouling materials (each for 12 months; BIT, hosted by **Zhao**);

The Unit also hosted the EuroCoalAsh2019 International Conference, co-organised with the European Coal Combustion Products Association (**McCarthy, Newlands**). This provided Unit visibility and industrial network-building around work in sustainable construction materials (Sections 1.2(iii) and 1.3(iii)).

4.2 Contribution to the research base

Editorships of international journals include:

- Surgical Technology & Other Interventional Techniques (**Cuschieri**, 2014-2018)
- Int. J. Physical Modelling in Geotechnics (**Knappett**, 2014-2018)
- Proceedings of the ICE: Engineering & Computational Mechanics (**Davies**, 2014-2018)
- Proceedings of the ICE: Geotechnical Engineering (**Brown**, to end of 2014)

Unit staff serving on editorial boards include (OA = open access journal):

Géotechnique (**Brown, Brennan**); Soils & Foundations – Japanese Geotechnical Society (**Brown**); Proc. ICE: Geotechnical Engineering (**Ciantia**); Surgical Innovation, Intl J. of Medical Robotics and Computer-assisted Surgery (**Cuschieri**); Proc. ICE: Water Management (**Cuthbertson**); Environmental Fluid Mechanics, J. Marine Science & Engineering (OA), J. Hydraulics Research (**Davies**); J. Waterway, Port, Coastal & Ocean Engineering, J. Offshore Mechanics & Arctic Engineering, J. Ocean Engineering & Marine Energy (**Hayatdavoodi**); Int. J. of Sustainable Built Environment (OA), Coal Combustion & Gasification Products (OA) (**TJones**); Frontiers in Bioengineering and Biotechnology (OA), Frontiers in Robotics and AI (OA), Actuator (**Manfredi**); Minimally Invasive Therapies and Allied Technologies (**Melzer**); J. Composites for Construction, Frontiers in Built Environment (OA) (**Spadea**); Wiley Wires Forensic Science, Forensic Chemistry (**NicDaeid**); Surface Innovations, Frontiers in Microbiology (OA) (**Zhao**).

Keynote lectures given include:

8th Int. Conf. on Plant Biomechanics, 2015 (**Bengough**); 1st Indian Symp. on Offshore Geotechnics, 2019 (**Brown**); Int. Congress on Ultrasonics, 2019 (**Campbell**); 8th Int. Symp. on Environmental Hydraulics, 2018 (**Davies**); 9th Int. Conf. on Physical Modelling in Geotechnics, 2018, 7th Int. Conf. on Earthquake Geotechnical Engineering 2019 (**Knappett**); 17th European Conf. on Soil Mechanics and Geotechnical Engineering 2019 (**Ciantia**); 3rd Int. Ashtrans Conf, 2015 (**McCarthy**); World Science Festival 2019, Gordon Research Conference USA 2018, Daniel Lecture 2018, European Academy of Forensic Science 2015 (**Nic Daeid**).

Fellowships of Learned and Professional Societies include:

Royal Society of Edinburgh (**Cuschieri, Davies, NicDaeid**); Royal Statistical Society (**NicDaeid, Cole**); Royal Anthropological Institute (**Hackman**); Royal Society of Chemistry (**NicDaeid**); Royal College of Surgeons (**Cuschieri**); Institution of Civil Engineers (**RJones**); Institute of Materials, Minerals & Mining (**RJones**); Institution of Engineering & Technology (**Huang**); Institute of Physics (**Abdolvand, Campbell, Keeble**); Optical Society (**Abdolvand**); Chartered Society for Forensic Science (**NicDaeid**); UK Association of Fire Investigators (**NicDaeid**); Institute of Chemistry of Ireland (**NicDaeid**); Norwegian Academy of Science & Letters (**Davies**); International Society for Medical Innovation and Technology iSMIT (General Secretary **Melzer**); European Society for Focused Ultrasound (**Melzer**); German Society for Biomedical Engineering (**Melzer**); American College of Surgeons (**Cuschieri**).

Brown is a member of the EPSRC Supergen Offshore Renewable Energy Research Alignment Group and the ETP Oil & Gas Theme Steering Group. Staff elected to the EPSRC Peer Review College include **Abdolvand, Brennan, Campbell, Cuthbertson, Wilcox, Zhao, Davies, RJones, NicDaeid**.

Notable national and international awards include:

- Telford Premium Prize, ICE Publishing Awards (**Chernin**, 2020)
- International Society of Soil Mechanics & Geotechnical Engineering (ISSMGE) Bright Spark Award (**Ciantia**, 2019)
- ISSMGE TC203 Young Researcher Award (**Knappett**, 2018)
- Distinguished Forensic Scientist Award, European Network of Forensic Science Institutes (**NicDaeid**, 2018)
- Young Thousand Talents Plan of China Award (**Hayatdavoodi**, 2018)
- Best Research Paper Award, Japanese Geotechnical Society (**Brown**, 2018)
- British Geotechnical Association 13th Géotechnique Lecture (**Knappett**, 2017)
- Thanyarak Award for Research, Thailand (**NicDaeid**, 2017)
- Damehood (**Black** – Category B staff, 2016)
- National Research Council of Thailand Innovation award (**NicDaeid**, 2016 and 2017)
- Geneva Inventions Silver Medal (**NicDaeid**, 2016)
- SAGES Emerging Technology Award (runner-up; **Manfredi**, 2016)
- Pete Ganci Award 2016, UK Assoc. Fire Investigators (**NicDaeid**, 2016)
- PW Allen Award (**NicDaeid**, 2015)

Overseas appointments of Unit staff:

In BIT, **Melzer** was appointed as Visiting Professor in Image-guided Therapy at the Korean National Cancer Centre, Seoul (2018-2022), Visiting Professor in Interventional MRI at the Children's National Medical Centre, Washington DC (2014-) and Visiting Professor at the Brigham & Women's Hospital, Harvard Medical School, Boston MA (2014-). In GEFM, **Knappett** and **Brown** were appointed as Visiting Professors in Foundation Design at IIT Bhubaneswar, India (2019-2021).

4.3 Contributions to economy and society

Consultancy and professional services

Consultancy and service work is actively promoted as a means for generating industrial linkages to support both generation and exploitation of larger-scale grant-funded research.

CTSE provides service testing for major infrastructural projects, including creep testing of High-Performance Concrete for the BYLOR Joint Venture delivering the £2.8B Hinkley Point C nuclear power station (Phase 1 £127k and Phase 2 £50k; **Newlands, RJones**). In GEFM, EPSRC-funded work on offshore screw piles generated follow-on service work (£93k) with Heerema Marine Contractors (Netherlands) underpinning first stage statements of compliance (Det Norske Veritas) and the development of commercially-viable offshore silent piling (**Brown**). Separate EPSRC-funded work on seabed pipeline installation generated service work (£80k) with Oceaneering Intl. Services Ltd. to optimise a new commercial plough design (**Brown**). All of these projects have been enabled by the SMART laboratory.

SJ undertakes forensic casework for the defence and Crown in criminal and civil proceedings across the UK and internationally; **Hackman** and **NicDaeid** are registered experts with the National Crime Agency, resulting in a yearly income of £60k-£80k. An example of such work is contribution to the Grenfell Tower Public Inquiry. Members also provide bespoke rapid response to police forces in distinguishing between human and non-human bones (**Virtual Anthropology Consultancy Service**), contribute to the identification of perpetrators from digital images (leading to convictions for paedophilic activities resulting in more than 300 years in prison and over 30 life sentences (**Hackman, Black**), and are involved in the rapid chemical analysis and identification of drugs in prisons (Impact Case Study; **McKenzie, NicDaeid**).

Wider contribution

The Unit has significantly contributed to society in a wider professional capacity, including:

- In BIT, **Cuschieri** is an advisor to the International Federation of Surgical Endoscopic Societies. **MacDonald** is a member of the Light Microscopy group of the Royal Microscopy Society, promoting microscopy in both academia and industry and providing educational kits to primary schools. **MacDonald** and **Krstajic** have sat on the steering committee of BioDundee, a partnership between public, private, academic and third-sector organisations in Tayside.
- GEFM provides UK representation across multiple Technical Committees of the ISSMGE, including: TC104 – Physical Modelling (**Knappett**); TC105 – Geomechanics (**Ciantia**); TC203 – Earthquake Engineering (**Knappett**); TC211 – Ground Improvement (**Ciantia**);

TC212 – Deep Foundations (**Brown**). **Brown** is also a member of the Society for Underwater Technology Offshore Site Investigation and Geotechnics Committee and the International Press-in Association (TC4). **Cuthbertson** is a member of the Leadership Team of the International Association for Hydro-Environment Engineering and Research. **Davies** was appointed to the Scottish Ministerial Advisory Sub-group on Containment in Aquaculture, leading to formulation of a Technical Standard for Scottish Finfish Aquaculture (2015) that is now enshrined in legislation. **Knappett** currently serves on the Improved Containment Working Group, a body with governmental, industrial and academic representation, that oversees development and maintenance of this standard. In 2014, **Davies, Knappett** and **Brennan** served on the Scottish Government Ministerial Group for Sustainable Aquaculture (MGSA) Research Working Group, producing a comprehensive research strategy supporting sustainable growth of Scotland's aquaculture industry.

- In SJ, **NicDaeid** is vice-chair of the International Criminal Court Scientific Advisory Board, and a forensic expert for the United Nations Office of Drugs and Crime. She was an appointed commissioner for the Dundee Drugs Death Commission, provided expert evidence to the House of Lords Science and Technology Select Committee's inquiry on Forensic Science, was appointed as an expert witness for the Grenfell Tower Public Enquiry and developed the UK Judicial Primers in collaboration with the Royal Society and Royal Society of Edinburgh. **Hackman** chairs the Forensic Anthropology Committee of the Royal Anthropological Institute and is the highest certified forensic anthropology practitioner in Scotland. **McKenzie** sits on the Advisory Council for the Misuse of Drugs Working Group for Novel Psychoactive Substances, Scotland. **Menard, McKenzie** and **NicDaeid** are members of the European Network of Forensic Science Paint & Glass, Drugs, and Fire & Explosion Working Groups, respectively.
- The Unit has influenced national and international codes and standards. **Newlands** is Secretary and **RJones** a UK representative on CEN TC 51 (CEN TC 104)/WG 12/TG5 – Corrosion of Concrete Reinforcement (CTSE). **Brown** convenes CEN TC 341/WG 7 – Non-static Tests on Piles and is a corresponding member of BSi B/526/03 – Site Investigation and Ground Testing, providing UK input to Eurocode 7 and testing standards including ISO/TC 182/SC 1 (GEFM). **Keeble** is a member of the ISO/TC 229/JWG 2 – Measurement and Characterization eCommittee and directly involved with ISO/PWI 23878 Nanotechnologies – Positron Annihilation Lifetime Measurement for Nanopore Evaluation in Materials (MSE). **NicDaeid** led and **Hackman** contributed to the development of the European Best Practice Manual for Fire Investigation (SJ).
- LRCFS has collaborative relationships with production and theatre companies resulting in the development of a new crime series shown on the BBC (*Traces*, Red production company; **NicDaeid, Hackman**) and a new participatory play supported by Arts Council England (*The Evidence Chamber*, Fast Familiar; **NicDaeid**) where research outputs are generated through citizen science-based activities. Public engagement with science has been a key mission of LRCFS since its inception, leading to the first award of a Gold Watermark to a research centre by the National Co-ordinating Centre for Public Engagement (2019). Research into the failure of smoke alarms to wake children (SJ; **NicDaeid**), supported by EI electronics and utilising large-scale citizen science, was widely reported in the National media.

These activities provide pathways to impact for the Unit's activities and increase its visibility nationally and internationally.