

**Institution:** University of the West of Scotland

**Unit of Assessment:** 11: Computer Science and Informatics

## 1. Unit context and structure, research and impact strategy

### 1.1 Structure of research

With 25 academic staff, 19 post-doctoral researchers and 40 projects with the total value of around GBP35,000,000 (UWS share approximately GBP5,000,000) in this REF period, Computing at UWS represents the strongest Division within the School of Computing, Engineering and Physical Sciences (CEPS). The Division is recognised for its pioneering research, knowledge transfer and innovation, led by the Artificial Intelligence, Visual Communications and Networks (AVCN) research centre, comprising two major research groups: (1) Beyond 5G Research Group and (2) Affective and Human Computing for Smart Environments (AHCSE) Research Group. Collectively, each group focuses on a specific sub-discipline and provides the focus needed to develop world-class research. The leadership of the groupings is internationally recognised and responsible for the ongoing strategy development and management of resources.

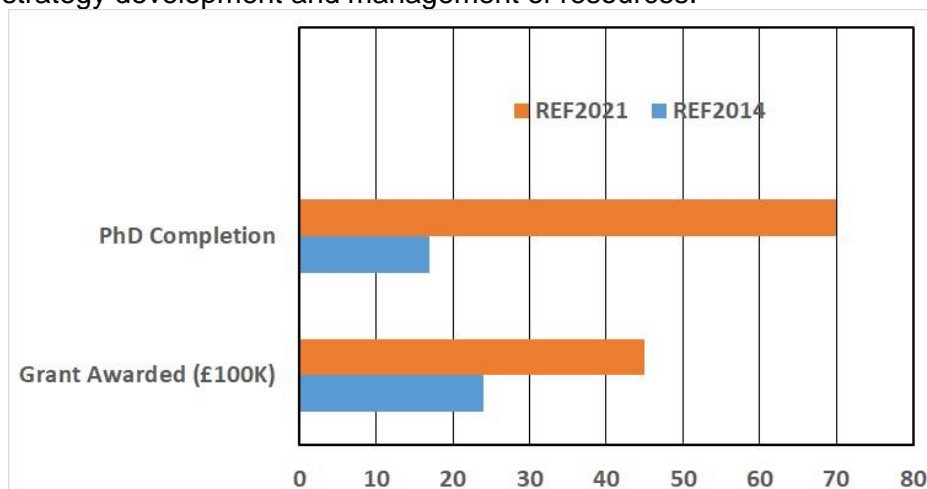


Figure 1: Doubling awarded grants and quadrupling PhD completions are a testament to the unit's world-class standing.

**Artificial Intelligent, Visual Communications and Networks (AVCN)** research centre led by **Dahal** is one of UWS's strongest research centres in terms of research outputs, intellectual property (IP), and income generation. AVCN has grown into a centre internationally known for cutting-edge research for Artificial Intelligence, Big Data, Deep Learning, IoT, Blockchain, and Cyber and network security. AVCN has a proven track record of leading national and international projects from European Commission, EPSRC, Research Councils UK, Innovate UK, Scottish Funding Council (SFC), Scottish Innovation Centres and industries. Since 2014, AVCN has hosted 34 small and large funded projects, including coordinating a large consortium of EU EM SmartLink (total project value EUR3,000,000) project with 20 international partners. It has been a partner of EU gLINK (total project value EUR3,000,000), SunSPace (total project value EUR1,000,000), eACCESS (total project value €1m), Police Scotland/CENSIS (Scotland's Innovation Centre for sensing, imaging and Internet of Things (IoT) technologies) projects. The research contributions of the centre in this REF period have been officially recognised through over 250 peer-reviewed research publications, a number of research & enterprise awards, and best paper awards. While AVCN covers an enormous breadth of research interests, it actively supports interdisciplinarity as the key for its success. The research centre has been working with more than 30 international academic and technology partners around the world. One of the aims of research at UWS is to be an internationally renowned knowledge hub for societally important applied research to meet the UN Sustainable Development Goals (SDGs) in Smart, Connected, Secure & Sustainable Environments. The AVCN research activities promote the position of UWS at this point. More specifically, its two research groups are:

**The Beyond5G Research Group (Beyond5GHub):** the group is led by **Alcaraz-Calero** and **Wang** and is one of the foremost research groups of this kind in the UK. The team have developed a complete mid-sized data centre and a unique 5G testbed designed specifically to conduct

cutting-edge research in the field of 5G, Network Function Virtualisation, Network Slicing, Software-Defined Networks (SDN) and AI. It features specialised hardware equipment for 5G, UAV, AR/VR etc., and is an integrated platform where a collection of industry-grade open source networking systems including OpenStack, Juju, MaaS, OpenDayLight SDN controller, Open vSwitch and other supporting tools are installed, to provide an industry-relevant operational testbed. The Beyond5G team has grown significantly since REF2014 primarily based on the external funding, complemented by the significant institutional internal funding in excess of GBP450,000 (reinvestment in equipment, PhD studentships and space). Their research has been primarily funded by several large EU Horizon 2020 projects with a total project budget of EUR27,000,000 including SELFNET (total budget EUR7,000,000), SliceNet (EUR8,000,000), 5G-INDUCE (EUR6,000,000) and 6G-BRAINS (EUR6,000,000). This world-class research group has produced over 100 high-quality publications over the assessment period including over 40 journal publications and over 70 conference publications. The group has won a number of research and innovation awards including the Innovation Award 2002 from Scottish national body, the Centre for Engineering Education and Development (Ceed) - NATO Scientific Achievement Award 2018, Winner for Times Higher Education (THE) Awards 2020 - Knowledge Exchange/Transfer Initiative of the Year category, Best Paper Award Winner for SOFTNET-WORKING 2017 and IEEE ICCE (International Conference on Consumer Electronics) 2014, as reported by BBC and other media.

**Affective and Human Computing for Smart Environments (AHCSE) Research Group:** led by Ramzan, the research group brings together the complementary expertise of social science, computing and engineering, and humanities. In total, over the assessment period, the group has published in excess of 100 publications including more than 50 journal papers and received Best Paper Award 2017 of the IEEE Transactions on Circuits and Systems for Video Technology and a paper selected for cover page of the IEEE Journal of Biomedical and Health Informatics 2018 first issue and released the world's first open-source dataset for Emotion Recognition by Physiological signals. As a result of the translation of world-class research into innovations, Ramzan received the Scottish Knowledge Exchange Champion of the Year 2020 award. The AHCSE has secured more than GBP4,000,000 external research and knowledge exchange funding and received significant internal institutional investment in excess of GBP250,000. Since 2014, the research group has built an unrivalled portfolio of 14 new Knowledge Transfer Partnerships (KTP) with a total value of more than GBP2,800,000. The quality of their work is exemplified by the recently completed KTP with MODO, which achieved "Outstanding" rating by Innovate UK. The other main research funding is secured by EU projects including ATHIKA (EUR945,000) and SAFE-Rural (EUR648,000). The principal expertise of the team lies in emotion recognition, signal processing, emotional language and cyber-psychology, e-learning, digital games, social media, personality and social media, system thinking and practice, and Independent living. Emotions perform a significant function in personal or social interactions and can be conveyed verbally by words or expressed by non-verbal signs such as facial expressions and gestures. The main intention of AHCSE is to construct the next generation smart environment that contains systems of sensors, actuators, objects and software to analyse and drive affective states in health and sport applications.

## 1.2 Research Objectives

### 1.2.1 Current REF Period: Review of REF2014 Objectives

In REF2014 we have committed ourselves to supporting a vibrant research and knowledge exchange environment across all of our subject disciplines, underpinning student experience, providing a stimulating environment in which staff can work and develop. The University has committed to supporting the development of our communities and regional economies through the exchange of leading-edge knowledge into industry, commerce, government and the professions as we aspire to deliver world-class outputs across its research portfolio. The current submission clearly demonstrates that we have achieved this key objective.

Furthermore, the University operates an annual planning cycle that includes a review of progress against a wide range of key performance indicators, and the production of strategic and operational plans within Schools. In Computer Science, strategic and operational plans are developed iteratively by the leadership team in consultation with research group leaders. A review of progress against these plans and objectives is a standing item on School leadership team agendas, so the progress and the effectiveness of agreed actions is monitored regularly.

Specific objectives are monitored within the framework of the annual operational plan for the Division of Computing, indicating how these support our vision, and providing evidence of progress since REF2014. The objectives are:

*Research objective: to value research excellence for its own sake.* This is in line with our vision to carry out *pioneering* research in computer science, which encompasses different models of intra- and inter-disciplinary research. Evidence of progress: To ensure that our strongest research is highly visible, staff have been encouraged to publish outputs of the highest quality (e.g. 72% ERA A and A\* Conferences and Journals).

*Research objective: to attract critical mass of world-leading & early career researchers.* In computer science, the aim has been to recruit and retain academics of the international standing via reinvestment by offering attractive package. Evidence of progress: 11 research active staff recruited during this REF period and 6 promotions.

*Research objective: to transform itself into an engine for commercialisation of research, knowledge exchange and serving our communities.* In computer science, to enable engagement in larger scale projects with the resources to conduct pioneering research, and to strengthen outward looking collaborations, we have had three primary associated objectives: To increase participation in EU projects, we have established a role for an EU Coordinator, increased engagement in EU events, and run training on EU funding. Evidence of progress: total expenditure per annum on EU projects increased by 70% from 2014 to 2020; To increase industrial income, to ensure close engagement with industrially relevant problems, and to enable the direct application of research results. Evidence of progress: annual expenditure on industrial projects increased by 60% from 2014 to 2020; To increase involvement in knowledge transfer projects. Evidence of progress: during the REF period, we have been involved in 14 Knowledge Transfer Partnership (KTP) projects with a range of partners, including the Codeplay, Police Scotland and VMS.

### 1.2.2 Strategy: Next Five Years

Following from our successes in this REF period, we aim to be among leaders in academic activity contributing digital solutions and skills to tackle global challenges. The objectives to secure this position are:

- We support fundamental computer science research and interdisciplinarity to develop high Technology Readiness Levels (TRLs) solutions focused on the UN SDGs;
- We stimulate curiosity-led, world-class research with purpose, through knowledge exchange and commercialisation, in support of the economy and society everywhere;
- We attract world-leading and early career researchers to develop signature research and areas of strength, complementing high-quality international collaborations;
- Our world-class research translates into research-informed education programmes to contribute to the upskilling, reskilling and shared prosperity goals.

To achieve our objectives, our strategy has been to sustain a balanced portfolio of fundamental curiosity-driven and applied problem-driven research relevant to UWS's strategic themes related to the UN SDGs. This strategy is realised through a focus on emerging research challenges in core Computer Science and increased interdisciplinary research by collaborating internally and externally. Focusing on large interdisciplinary grants has been at the heart of our success and this will also be of vital importance in the future. Whilst the strategy itself is reviewed annually, its implementation will be enriched through: (1) targeted studentships; (2) continued embeddedness in collaborative alliances (e.g., SICSA); (3) engagement with the members of our industry board; (4) sabbaticals and extended visits; (5) expanded dissemination (software,

standardisation, online educational materials, public engagement), and (6) proactive engagement with funders. In addition, our curriculum revision processes will continue to integrate new research content to deliver leading edge and exciting education to our next generation of scientists and engineers.

### **1.3 Achievement of impact**

Institutional Business Innovation unit is involved in the development of all research proposals with impact being at the forefront of staff, who also receive central support in intellectual property discovery, protection, and exploitation. This includes working with industry, KTP and commercialisation. UWS maintains the open-door-to-industry approach, which has been critical for creating a welcoming innovative environment.

#### **1.3.1 Impact Case Studies and Impact Approach**

Focusing on impact at the outset is at the heart of our strategy to develop signature research. The submitted impact case studies (ICS) are a testament of this approach [(a) 5G Innovations, (b) Data Driven Intelligent and Autonomous Systems and (3) Signal/Image Processing and Machine Learning].

While we did not have 5G research capabilities back in 2014, focusing on our niche contribution to the development of 5G services since then has led to a rapid development of industry-focused high-TRL research activity that delivered benefits almost immediately to industry. For example, UWS contributed technically to one of the first commercial launches of 5G networks and to the development of International Telecommunication Union (ITU) and European Telecommunications Standards Institute (ETSI) standards. In addition, the Signal/Image Processing and Machine Learning ICS shows how UWS research has led to new care home solutions, a pioneering open-source database, healthcare solutions, as well as significant financial impact for the businesses we work with. The Data driven intelligent and autonomous systems ICS has achieved comparable impacts; and the benefits to include developments in smart farming practices in Nepal, Bhutan, and Thailand, t13Q smart trolley in 19 Chinese airports, and award-winning drone technology for use by Police Scotland in search and rescue operations.

### **1.4 Interdisciplinary Research**

Interdisciplinarity is key to achieving high-TRL solutions and our research has benefitted from an institutionally-driven focus on developing innovative solutions. For example, AVCN research centre has a strong international base with over 30 interdisciplinary teams having coordinated the large SmartLink project and participated in projects like gLINK, SunSPACE and eACCESS) with many international partners. The SmartLink project focus was smart technologies in a wide range of applications areas including data management, education and disaster management. gLINK focused on ICT for green technology. The SunSpace project is looking at smart farming practice and the eACCESS project at smart power systems. Within the research groupings, AHCSE has developed robust interdisciplinary collaboration with industries and research institutions (Income for this REF period is over GBP5,000,000). The group has strong collaboration with health and healthcare providers especially for emotion recognition by physiological signals. They have developed and deployed the emotional gym in Loretto Care and developed a long-term partnership with Wheatley Group. This interdisciplinary area has been supported through two joint research projects funded by the Scottish Funding Council (SFC), 14 KTP awards, and Ramzan awarded Scottish Knowledge Exchange Champion of the Year 2020 award. Within this REF period, the Beyond5G Hub team has closely collaborated with over 40 European/international partners and stakeholders, including network operators (e.g., Orange France, Orange Romania, Portugal Telecom, OTE), equipment vendors (e.g., Ericsson, InnoRoute), technology providers (e.g., IBM, DellEMC, Thales UK), vertical businesses (e.g., EFACEC, PROEF), public sectors (e.g., Police Scotland, Swedish Drone Rescue), standardisation organisations (e.g., ITU, ETSI), SMEs (e.g., Nextworks in Italy, CSE in Greece, Intebloc in UK), academia (universities and research centres in Spain, Germany, France, UK etc.). The prestigious Times Higher Education Award for Knowledge Exchange/Transfer Initiative of the year, designed to save lives of missing people,



could only have been achieved with the interdisciplinary research partnership between UWS, industrial partner Thales and Police Scotland and funding from the “CENSIS”, Scottish Innovation Centre.

Staff in the unit have sought to apply their knowledge to help support the national effort to deal with the first COVID-19 lockdown and in rapid response mode towards the end of the REF2021 5a period, were in the late stages to arrange funding from Scottish Government and Comic Relief (NSI funding) to develop a mobile phone app to help reduce the disproportional number of ethnic minority people affected by COVID-19.

### **1.5 Open Research Environment**

In computing, open-source has been in existence for decades and we use modern technologies to improve access to research, transparency in the research process, reproducibility of results, and to promote efficient methods of scholarly communication. This is further underpinned by the University and funders support for a growing culture of Open research to increase the quality, integrity and accessibility of our research.

For example, to serve the open-source research community, we pioneered the first publicly available dataset (DREAMER) for emotion recognition using wireless portable electroencephalography (EEG) and electrocardiography (ECG) devices. After its publication, the dataset has attracted a significant attention from international professional audience (e.g., Facebook/Oculus). Up until 21/08/2020, 3,757 requests for access to the dataset had been made via the “zenodo.org” platform, 5,000 full text views of the publication via the “IEEE Xplore” platform. Another new open access dataset for Biometric EEG dataset namely BED has been developed since then and will be published in IEEE IoT Journal.

We have developed the open source software "Open vSwitch (OVS)-based 5G traffic" for the industry de-facto open standard Open vSwitch, to enable traffic classification and control in 5G/LTE networks and "5G Topology Manager" for leading global 5G infrastructure platform OpenAirInterface (OAI), to enable topology management in 5G networks.

In addition, UWS are committed to the use of the research networking system PURE for research knowledge management. This has enabled us to go above and beyond the REF open access policy requirements, as we aim at making a version all of our research outputs publicly available through the UWS institutional repository. Alongside with the Green open access route, an increasing number of outputs is being published Gold open access, thanks to the transformative agreements the UWS Library has signed with numerous publishers.

### **1.6 Research Integrity**

The UWS is committed to maintaining the highest standards of research integrity in all aspects of its research. The University and School Ethics Committees are thus custodians of research integrity, from developing guidance to monitoring all research projects at all levels. The School of Computing, Engineering, and Physical Sciences Ethics Committee has members from Computing, ensuring appropriate representation and dissemination of guidance and standards. Staff in Computing work with staff in Support Services to ensure highest standards of scholarly and scientific research integrity. They adhere to the university Code of Ethics, which is in place to ensure that all researchers are aware of ethical issues, as well as fairness and integrity.

## 2. People

### 2.1 Staff Development Strategy

We have a wide range of formal and informal mechanisms for staff development and career progression. The annual MyContribution process provides an appraisal and self-reflection opportunity: it assesses each year's performance, rewards exceptional contribution, and importantly it includes a goal setting and development component. We operate a "Workload Allocation Model" which records measurable activity and effort under three headings: Research, Teaching, and Administration, to prevent individuals from being overloaded. This allows reduced loads to be given to our star performers in research, and we also support academics targeting prestigious grants having far reaching impact, globally and in the immediate communities we serve. Part-time staff benefit from sabbaticals and pro-rata loads. We have developed a systematic approach to support grant writing at four distinct levels: generic, mechanism-specific, subject-specific, and proposal-specific. We provide: workshops aimed at generic training in computer science grant writing, largely aimed at ECRs and those joining us from non-UK HEIs; regular tutorials and Q/A sessions on specific mechanisms for funding (e.g., Horizon 2020, programme grants, KTPs, etc.); subject-specific mentoring and review through the research groups; and regular proposal-specific reviews for each proposal itself through our internal grant review process. This internal review process tries to simulate the real review process with independent and constructive feedback. In addition, the institutional support mechanisms (see REF5a for more details) have been in place during this assessment period to support staff development. They include: PhD studentships (Internally funded; requiring ECRs and experienced supervisors); GBP1,000,000 VP Fund for research and enterprise activities; and infrastructure grants.

### 2.2 Staffing and Recruitment

During this assessment period, we appointed 11 research active staff: one Senior Lecturer (Ndzi; AI and Autonomous Systems) and nine Lecturers: (Olszewska; Algorithms and Software for Intelligent Vision Systems), (Riordan; AI and robotics), (Marco and Siddiqui; Cybersecurity), (Shakir; 5G), (Gilardi; AR/VR), (Keir; Software Engineering), (Matalonga; Blockchain), (Truslove; Music Technology) and (Katsigiannis; AI and Affective Computation). Two of these staff members have subsequently been promoted to Reader.

Our Strategy for academic appointments reflects our interest in both core computer science and its application. We are committed to appointing and retaining leading international researchers at all stages of their careers. Our strategic investments (11 new staff) were focused on expanding our expertise in AI, Next Generation of Networks (5G/6G and beyond), and Data Analytics. Staff retention is deep-rooted in our staff development; despite an atmosphere of intense recruitment between British institutions, only three research active academics (Lou, Casaseca and Wang) have left UWS for personal reasons. Our recruitment process aims to attract the best researchers, in line with the School's strategic objectives. When advertising posts, the School encourages excellent researchers, usually from cognate areas of Computing. Academics with relevant and complementary expertise, are invited to review the applications and contribute to the selection process. An appointments committee, which includes elected representation, creates the final shortlist. Candidates are invited for interview and spend at least a day in the School to give a seminar, have individual sessions with potential colleagues and with students, as well as a formal interview. All academics are invited to attend the seminars and add to the feedback from the one-to-one sessions. In order to sustain research in the longer term, the emphasis has been on recruiting junior staff, with the potential to become future research leaders.

### 2.3 Support for Early Career Researchers

Welcoming new staff and early involvement is key to our success with ECRs, including their engagement with industry partners. Our standard support packages for all new members of staff include: (1) being immediately introduced to key people, policies and resources through a School induction pack and initial trainings with UWS systems; (2) having assigned a personal mentor to provide further support and guidance; (3) monthly informal meet-ups with the Head of Division (HoD) to provide an opportunity to talk through research, teaching or university issue that may be pertinent to their careers.

In addition, the University provides training courses for new staff, in a range of topics, including "proposal writing", "research supervision", and "research project management". At UWS Early Career Researchers (ECR) benefit from a range of approaches, including: (1) ensuring ECR representation on main research committees; (2) Early Career Researchers' Forum; (3) dedicated professional development opportunities (e.g., UWS Crucible, PROPEL, UWS Research Mentoring Scheme); (4) participating in Scottish research pools and innovation centres – e.g., the Scottish Informatics and Computer Science Alliance (SICSA); and (5) requiring ECR involvement as standard for all UWS-supported research projects. Throughout the REF period, this highly inclusive approach has enabled us to retain 4 ECRs. Their achievements are celebrated and acknowledged through career progression and incentives (e.g., PhD studentships, research time allocation, equipment support, research space development for larger projects). During this REF period, one ECR was promoted to Reader, and later to a Full Professor.

#### **2.4 Academia – Industry Exchange**

Staff in the Division of Computing have had an excellent relationship with industry and more than 50 organisations (local, national, international) are on its Industrial Advisory Board. Working with industry is at the heart of our research projects and the staff thus regularly host or visit industry professionals. The Division has produced more than 100 joint publications with industry including INTEL, SAMSUNG, HUAWEI and BBC among others. A number of research projects are carried out in collaboration with industries who provide funding and PhD studentships. In addition, all our industry match-funded PhD projects include industry supervisors (e.g., Dr Navid from Lumen Research Ltd. and Dr Majid from MODO Ltd.). The Division supports industry exchange and ECRs in particular have benefitted from early exposure to industry partners (e.g., Marco spent three months in VMware Research Group, USA).

The School facilitation of academia-industry exchange is further enhanced through our central support teams (*i.e.*, Business Innovation), who include a dedicated UWS KTP Centre, Continuous Professional Development (CPD) Centre and commercialisation support, all helping to facilitate partnerships between academic staff and industry, as well as helping with commercialization, consultancy, CPD development, and knowledge transfer. A total of 7 KTP projects were successfully delivered during this REF period. In addition, over 7 new KTP were established related to this UOA.

#### **2.5 Research & Impact Rewards**

Several frameworks for incentives and rewards are in place to support the development of research including: (1) Salary recognition and reward procedure (6 staff benefited on research basis); (2) Staff Appreciation and Recognition (STARS) Award (8 awards on research basis; highest in the whole University); (3) Additional annual leave purchase procedure; (4) UWS reinvestment in research excellence through Vice-Principal's Research Fund (3 research projects funded internally of worth more than GBP300,000 along with 7 PhD studentships). The Dean of the School allocates 10% of additional research time for live projects and offers competitive PhD studentships as reinvestment for projects over two years in length. For each KTP award, the knowledge base supervisor is awarded GBP3,000 per year to enable further professional development, meetings with potential industry partners, addressing small equipment needs and further supporting their doctoral students.

#### **2.6 Research Students**

**Postgraduate research community:** Our computing postgraduate research community is among our key strengths as we are contributing to the vibrancy of the discipline, developing excellent scientists and leaders of tomorrow. There are presently 104 postgraduate research students in the School, of which 30 students are associated with Computing: Within the review period, 80 PhD students have been recruited to Computing. There have been 70 PhD completions (34.5 submitted to REF4a) within this period, following strenuous institutional efforts to ensure students complete within the maximum period of registration. The strategy for the next few years is to increase the recruitment of high-quality research students to 20 annually through UWS studentships calls, industry match funding and other sources as appropriate. In the assessment period, five prestigious

externally funded studentships have been awarded by Scottish Innovation Centres (The Datalab, CENSIS). Ten students have also been funded through competitive internal studentship calls (15% success rate). Recently in Computing, eight KTP Associates have been recruited who have enrolled as PhD students due to UWS's strategic approach in support of KTPs. Approximately half of our research students are self-funded, with an increasing number in recent years, via our MSc Advanced Computing programme.

**Recruitment and Progress Monitoring:** We have consistently recruited excellent PhD students nationally and internationally (*i.e.*, receiving ~100 applications per year from qualified candidates, and recruit between 20 and 30 PhD students), and awarded a significant number of highly-competitive scholarships to cover 50% to 100% full tuition fees and stipend. Applicants submit a research statement for an initial review and allocation of potential supervisors who interview the applicant before a place can be offered. Upon joining UWS, PhD students attend an induction meeting where they meet members of the Doctoral College and supervisory team. Each student is provided with dedicated office accommodation, a new high-end computer and appropriate laboratory access. Students are provided with a budget of GBP1,000 for professional development, and research groupings often provide additional funding for resources, access to grant-funded specialised equipment, and travel/visits. Our original target of having each research active member supervise at least 2 PhD students during this period has been exceeded with on average 2.8 PhD students per research active staff. We have introduced comprehensive monitoring and progress reviewing procedures overseen by the School PGR Coordinator who, compliant with Doctoral College requirements via an online MyPGR platform, ensure students complete their PhD studies within the maximum period of registration. In the first year, there is a 6-week, six month and first year review, where students present a literature survey and thesis outline. Annual panel reviews represent important progress monitoring milestones with an independent assessor recommending progress continuation or termination in consultation with the supervisory team. Transfer event is another key milestone the students need to achieve to become PhD candidates. At the end of the second year the independent assessor evaluates the status of the thesis plan (*i.e.*, completed and outstanding work). This rigorous approach has been beneficial and we have increased completions by 412% when compared to the REF2014 period. The success of our approach is evidenced by the fact that in the current REF period the average time to submission of the thesis from the initial registration was 3.5 years. We now maintain a sector-leading position of 90% of students complete their PhD degree within a maximum period of registration (4 years for full-time students). The awarded PhD degrees during this assessment period has increased four-fold compared to REF2014. 47% of our PhD students now have an RA or Lectureship position at universities and research institutions worldwide. Our research students have won many scholarships and prizes (Best Paper award in ICDAMT2017; Best Student Paper Award Winner for SIGMAP2014 and IEEE ICCE2014). Our PhD students are an integral part of research advancements, contribute to our research strength and publish at highly competitive venues.

**Training:** As standard, our PhD students join a vibrant research environment. Upon starting their studies, they immediately join strong, award-winning research teams, benefit from co-location with staff working on major externally funded projects and through the Doctoral College interact with PhD students from other Schools. While this forms the basis for students to develop their skills, we offer bi-weekly research seminars at which PhD students present their research in addition to individual research groupings organising their own research meetings where each student presents their research once each term. While the institutional support is exemplified in REF5a, it is worth emphasising that the Doctoral College jointly with the UWS Academy provides skills training courses, and students are required to take at least four of these. There is a wide range of courses, the most popular of which are Research Management, Personal Effectiveness, Communication and Presentation, Networking, and Team-working and Career Management. The Doctoral College promotes a collegial and interdisciplinary research environment, facilitating communication between students from different schools by hosting events, including research symposia, poster competitions, annual research conference and lectures by prominent figures from the international research community. Further, by bringing together Scottish HEIs, SICSA offers a number of training and development opportunities for our PhD students: (1) PhD Peer Support Group run by PhD



students for PhD students, (2) Annual PhD conference, (3) Demofest to show case research work to industry, and (4) SICSA Summer School.

### **2.7 Equality & Diversity**

UWS' HR policies provide a framework for achieving our aims of progressing equality. The Equality, Diversity and Inclusion (EDI) team provides advice on best practice. In REF2021, we have adopted a Code of Practice to appropriately recognise that not every member of staff has significant responsibility for research. The Code of Practice ensures that EDI is mainstreamed within REF processes. The University has demonstrated its commitment to equality and diversity through attainment of: (1) Athena SWAN Bronze award; (2) HR Excellence in Research award; (3) UWS are Stonewall Diversity Champions; (4) Disability Confident employer.

The setting up of Academic Life, a fully integrated and co-located unit to support all academic activities, has been instrumental in developing and offering career-enriching opportunities to engage in research, access internal funds and receive support for submission of funding applications. Research and Business Innovation teams within Academic Life have, since REF2014, developed numerous support mechanisms targeting under-represented groups, as defined by the Equality Act 2010, within the University. These include PROPEL, Grant Accelerator, REF Accelerator, UWS Crucible, and Masterclasses. There are also a number of staff support networks that provide peer support, advice and guidance. These include a UWS HighER ( staff female network, UWS Liberty (staff LGBT+ network) BME Staff Network and a disabled staff network has recently been launched.

The School has an EDI champion who attends a University wide forum to share good practice in EDI and take forward activities to progress EDI, The Dean is represented at the EDI Committee. This ensures that EDI information and activity can be shared at all levels in the School. In addition all staff complete unconscious bias and inclusion essentials training.

In Computing, we operate within School and University policies and procedures which ensure that we work towards the promotion of equality, diversity and inclusion. We operate a family-friendly flexible working environment, to allow staff to achieve an appropriate work-life balance, and, for example, to accommodate caring responsibilities. All staff are entitled to request part-time or reduced hours, compressed working, job sharing, annualized hours, and home working. Staff who return from periods of leave are supported in accordance with the university policy, starting with a return-to-work interview, and applying a phased return as necessary and this scheme is highly appreciated by staff returning after COVID-19 infection. Staff who have been off work for a longer period of time through e.g ill health or pregnancy and maternity can apply for our Returner's Scheme. This provides funding to support staff to get their research career back on track.

The university has a dedicated Occupational Health Manager, who works closely with staff, in the People and Occupational Development (Human Resources). There is an employee assistance programme that provides a range of support including counselling.

In terms of gender balance, all committees have female members including committees related to recruitment. In student recruitment, we are actively seeking to increase ethnic minority representation and gender balance. Within the School, female staff have completed the Women's Leadership Programme and the Aurora Programme. Staff in the School, including female staff in Computing have taken part in the UWS Crucible, to support their development as researchers.

Our School is seen to be fair and open to all, resulting in a diverse international department in terms of gender, race, religion and age. We have five female academics in this submission, which represents 20% of total REF returned staff. Our academics originate from over eight different countries on four continents.

### **3. Income, infrastructure and facilities**

### 3.1 Research Income and Funding Strategy

Our income strategy has been to focus on large (>GBP3,000,000 total project size), industry-focused, and high-TRL grants (>TRL6) while simultaneously supporting developmental smaller grants to support ECRs. We have significantly expanded our research portfolio during this REF period by leading or partnering in approximately GBP35,000,000 of total research project funding through a number of national and international projects. This represents a 200% increase in the external income generation when compared to the last REF. The increased resources allowed us to recruit and host >200% more researchers and research staff in comparison with previous REF period. In addition, we have the most improved KTP portfolio in the UK, recruiting 100% more KTP associates.

The increase in research income (REF4c) from GBP2,409,000 in REF2014 to GBP8,476,674 in REF2021 is also fuelled by unprecedented success in projects funded by the European Commission. Just recently, we have secured approximately EUR19,000,000 in three Horizon 2020 projects and this provides a strong foundation for the next REF period. In addition, 7 KTP projects are on-going apart from seven completed KTPs that also demonstrates sustainability of our approach to work with businesses and deliver economic, technological and societal impact.

The table below includes projects with total award values in excess of EUR500,000 which have contributed to grant size and grant income since REF2014.

PI/Co-PI	Project Short Title	Total Award Value EUR
Dahal, K	Erasmus Mundus SmartLink	EUR 3,049,600
Dahal, K	Erasmus Mundus gLINK	EUR 3,036,625
Alacaraz-Calero,J, Wang,Q	Horizon 2020 Selfnet-5G	EUR 6,886,496
Wang,Q, Alacaraz-Calero,J	Horizon 2020 Slicenet-5G Smart Grid	EUR 7,979,030
Dahal,K	Erasmus+ Collaboration (eACCESS)	EUR 997,820
Dahal,K	Erasmus+ Sunspace	EUR 869,676
Ramzan,N	Erasmus+ ATHIKA	EUR 945,060
Riordan,J	H2020 Risk Aware Autonomous Port Inspection Drones (RAPID)	EUR 4,997,134

Our staffing strategy (Section 2) supports our income strategy. It has been implemented in order to increase our research income. In Computing, over the assessment period, we have promoted three lecturers to Professors with respect to the thematic areas of AI, and 5G networks, and appointed ECRs in areas of strategic importance (Cyber security, IoT and Robotics) with high grant-earning potential. A number of appointments have been made within the past three years in Computer Science. These appointments are part of a longer-term strategy and are expected to bear fruit at the next REF exercise.

### 3.2 Organisational Investment

REF5a includes the overall picture of the substantial institutional investment in new research facilities and it is worth mentioning that a whole suite of laboratories (ALMADA Centre) has been dedicated at our new GBP110,000,000 Lanarkshire campus as a home for the flagship RAPID project (EUR4,997,133.75m; Riordan). Prior to this, soon after REF2014 submission, UWS invested GBP160,000 to build a complete large-scale data centre with unique capabilities in terms of security, softwarization and programmability. Recently, there has been significant university investment via GBP1,000,000 Vice-Principals fund. The Division of Computing has received the highest share of nearly GBP300,000 along with seven funded PhD studentships. The 20% unfunded research time is allocated to all research active staff including ECRs. The general-purpose labs of Computer Science and Networks (GBP200,000) are upgraded to latest PCs and networking hubs and switches. The new plans of refurbishing the lab spaces is approved as well that will

help to get sustainability for the next REF. Our research space has increased by approximately 60% by developing three new state-of-the-art research labs namely Beyond5G (GBP200,000); Affective lab (GBP100,000); and IoT and Robotics (GBP100,000).

### 3.3 Support Staffing and Infrastructure

Most of our research requires standard computing infrastructure, which is supported by ITDS services teams at university, and school level. A dedicated Network Support Analyst “Tom Caddell” provide support to Computing staff and students. In addition, each group trained their PhD students and Post-doc with the help of ITDS to maintain the dedicated equipment’s (like 5G test bed; HPC platform for AI; Brain Computer Interface framework, etc.).

A dedicated member of the Research & Business Innovation team provides hands-on support for financial planning and detailed administrative aspects of proposal writing. This level of support is critical to ensure funding requirements are met, scope appropriately determined and consortia activities are appropriately coordinated. We have a dedicated finance team, to help staff to manage the finances of awarded grants and a dedicated departmental HR manager, who oversees the process of recruiting research staff. This infrastructural support has been very successful as evidenced by our funding success over the assessment period.

### 3.4 Specialist Research Infrastructure for Impact

The School has its own cloud infrastructure, 5G network (including a mobile unit), and a complete mid-size data centre designed specifically to carry out computational experimentation in the field of Machine Learning, Big Data, Cloud Computing, Data Privacy, and Network performance & security. School facilities also include a world-class cloud testbed for mobile edge/fog computing, an Internet of Things (IoT) platform and a number of networking devices. The data centre and infrastructure greatly supports our research in the field of Cloud Computing, Network Function Virtualized and Software-Defined Networks. It is worthy to emphasize that this data centre is not a regular cloud computing platform but also a platform that enables the automatic installation and configuration of a complete cloud computing infrastructure in less than 10 minutes, enabling all the partners to enforce any configuration or setup they want to use for the experimentation towards the purposes of the project. It features specialised hardware equipment for 5G, UAV, AR/VR among others, and is an integrated platform where a collection of industry-grade open source networking systems including OpenStack, Juju, MaaS, OpenDayLight SDN controller, Open vSwitch and other supporting tools are installed. This setting provides an industry-level testbed for virtualization, comprising more than 250 cores and can emulate more than 80,000 Linux containers with speeds up to 100Gb/s, enabling highly complex networking infrastructures to emulate the real-world settings and to evaluate performances and analyse network issues in the realistic environment.

### 3.5 Cross-HEI Infrastructure Collaboration

UWS is part of EPSRC bid for “The ARCHIE-WeSt HPC Centre” with the University of Strathclyde. The computing PhD students and staff benefitted from the HPC platform by utilising 10,000 hours to conduct their training and testing of content-based image retrieval framework based on deep learning. Furthermore, cross-HEI infrastructure collaboration is enabled through SICSA where UWS takes active part in the Artificial Intelligence, Cyber-Physical Systems, Cyber Security, Data Science, Human Computer Interaction, and Networking and Systems. ECRs and PhD students benefit from SICSA activities (*i.e.*, PhD conference, Demofest, and themes’ workshops) but also from collaboration with staff and students from other 13 Scottish Universities who are members of SICSA. UWS regularly hosts thematic workshops for SICSA (*e.g.*, AI workshop in 2017 and Cyber Security in 2019).

### 3.6 In-kind Benefits

The main in-kind support we receive is in the form of additional support for industry co-funded PhD studentships. The support so far includes supervision time of one hour every fortnight (GBP72,000 in total). BT and NATS provide a test bed as in-kind support to test “Network flying platforms for 5G and beyond wireless communication” along with supervision time (GBP36,000). NVidia provided hardware platform to test “Multiple Deep CNNs for Content-based Image Retrieval”

(GBP18,000). Microsoft provided access to their full Azure stack through Microsoft Research programme (GBP14,000). In addition, we received GBP168,900 to setup beyond5G lab from different industrial partners. These in-kind supports contributed to our research portfolio not only in terms of time but also the expertise and infrastructure exploited is a unique experience for staff and students.

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

The School is committed to support a vibrant research and knowledge exchange environment across all of its subject disciplines. Our globally impactful research is a key contributor to enhancing student experience, providing a stimulating environment in which staff can work and develop, contributing to the development of each discipline, and supporting our communities and regional economies through the exchange of leading-edge knowledge into industry, commerce, government and the professions. Our research groupings aspire to deliver world-class research outputs across its research portfolio. Our research is interdisciplinary and of a highly collaborative nature with leading industry players nationally and internationally.

##### **4.1 Research Collaborations, Networks, Partnerships and Communities**

The School has a wide range of mechanisms to support and encourage collaborative research. These include: a visitor programme (56 visits of more than one month during the assessment period), a budget available to all researchers specifically for increasing engagement in EU programmes either by school or SICSA, and joint supervision for all research students. To encourage collaborations with industry, the school has established an industry advisory board with over 50 members (including IBM, Microsoft, CISCO, HP).

Staff are involved in large international collaborations. Staff have been the coordinators or partners of big national, International and European projects extending collaborations with more than 85 UK, European, Asian and African HEIs, enterprises and SMEs. This includes providing Leadership in International Flagship Collaborative Projects:

- Coordinator of EU H2020 project RAPID; EM SmartLink; and SAFE-Rural projects with 20 international partners from Europe and Asia.
- Partner of five EU gLINK, SunSpace, eACCESS, and ATHIKA projects involving over 35 international partners from Europe, Asia and Africa.
- Technical Manager for two EU 5G PPP SELFNET and SliceNet projects with 35 European HEIs and Enterprises, SMEs. UWS was the only Scottish university involved in this 5G-PPP programme, and one of the very few UK universities that technically led both 5G-PPP Phase-1 (SELFNET) and Phase-2 (SliceNet) projects.

The research environment has been significantly enhanced by our membership in the SICSA. It has involved close collaborative working with partner universities and Innovation centres, especially the universities of Glasgow, Strathclyde, Edinburgh Napier, and CENSIS. One distinctive feature of the Scottish research environment is the existence of “Research Pools” that encourage collaboration in particular disciplines across Scottish HEIs. The goal of the pools is to coordinate activities where relevant and to ease reaching critical mass by pooling across the different HEIs in Scotland.

The main areas of SICSA activity are Research Themes, Graduate Academy, Knowledge Transfer, and Education. The SICSA Research themes are: Artificial Intelligence, Cyber-Physical Systems, Cyber Security, Data Science, Human Computer Interaction, Networking and Systems and Theory, Modelling and Computation. These cover the main areas of work in Scotland and provide larger, active, open, supportive communities across all the Scottish HEIs. SICSA is pivotal for cross-institution collaboration in bidding for larger scale projects where the spread of expertise crosses institutional boundaries. The themes deliver a lively schedule of meetings, workshops and masterclasses on particular topics and SICSA provides support for travel, visiting speakers and event catering.

The Graduate Academy provides support for the whole PhD community across Scotland and encourages the development of a “Scottish Cohort Effect” through the PhD and SICSA conference,



an annual best thesis prize and other activities. More than 20 PhD students of computing has benefitted from PhD events. The Graduate Academy Distinguished Visiting Fellow (DVF) scheme provides a mechanism to facilitate collaborations between Scottish-based Computer Scientists and talented academics, researchers and/or leading professionals in industry or the public sector from across the globe (two leading academics invited by UWS). Our Postdoctoral and Early Career Researcher Exchanges (PECE) funding provide research training and development opportunities for the most able postdocs and early career researchers across SICSA by offering funding to collaborate and work with other institutions around the world (more than 10 ECRs from UWS). In Knowledge Exchange SICSA works closely with the SFC funded Innovation Centres (in particular: Data Lab, CENSIS, and the Digital Health and Care Institute) to develop routes to impact and exploitation of university research (UWS regular receive funding from these initiatives). Events such as DemoFest allow Scottish Researchers to showcase their work to industry and others as part of a programme of Knowledge Exchange work. SICSA thus provides a stable means for inter-institution and inter-discipline collaboration where appropriate, and sustains a broad inclusive research community in Scotland. The student and staff take an active part in SICSA activities (PhD conference committee, Theme leader, organising workshops, hosting DVF).

#### **4.2 Contribution to Economy and Society**

Our contribution to the economy is achieved by focusing on industry projects with immediate and globally impactful projects. 5G services market is valued at approximately GBP35,000,000,000 in 2020 and the compound annual growth rate (CAGR) is expected to be 46.2% from 2021 to 2028. The unprecedented academic success of being technical managers for two consecutive EU 5G PPP SELFNET and SliceNet projects with 35 European enterprises, SMEs and universities; demonstrates the global role we are playing in this market. Furthermore, our staff have contributed to the European's 5G vision, development and trials through direct involvement in 5G-PPP Working Groups on 5G Architecture, Software Networking, Network Management, QoS and Security, and Trials. Alcaraz-Calero and Wang have been serving as the EU 5G-PPP Technology Board members since 2015, overseeing all the 5G-PPP Working Groups and projects and actively contributing to 5G-PPP programme-level innovations and advising on key achievements and plans for next phases. Adding our involvement in KTP projects with Innovate UK assessment of GBP7.5 gross value added GVA for every GBP1 investment, so far we have directly contributed to the generation of >GBP2,100,000 GVA to the UK economy. Our collaborative projects (SmartLink, gLINK and SunSPace) have catalysed socio-economic development in middle and lower-income SAARC and ASEAN in Asia, including Afghanistan, Nepal, Bhutan, Bangladesh, Pakistan, India, Thailand and so on. Through the SmartLink and gLINK projects, UWS helped the HEIs in these countries in developing their research capacity and facilities. UWS's computing research played a significant role in the SunSPace project addressing socio-economic growth in three Asian countries (Thailand, Nepal, and Bhutan) by up-skilling conventional farmers to smart farming technologies across the entire sector as farm-to-fork. In addition, our outreach activities and contribution to computer science education and upskilling in the areas of social deprivation (>25% of students who are from the SIMD20 (Scottish Index of Multiple Deprivation, Quintile 1 or 20% most deprived) areas study at UWS, making it a sector leader in widening participation) is of particular importance in response to the UK Government Clean Growth agenda.

#### **4.3 Discipline, Interdisciplinarity, International Priorities and Wider Contributions**

**Discipline contributions:** Our wider contributions demonstrate global reach and influence through organisation of scientific conferences, editorial boards of highly impactful journals, developing standards, serving on a spectrum of external committees and bodies. We have provided Conference Leaderships by serving on more than 500 programme committees, including all the first-tier conferences in each of the research groups' sub-areas. Our staff have also provided general chairs and programme chairs, including IEEE Wireless Communications and Networking Conference; IEEE International Conference on Intelligent Robots and Systems; IEEE International Symposium on Robot and Human Interactive Communication; international conference on Software, Knowledge Management and Applications (SKIMA); IEEE International Conference on Computer and Information Technology; International Conference on Algorithms and Architectures for Parallel Processing; and International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage. Two staff members are on the organising committee of the

IEEE WCCI 2020. IEEE WCCI 2020, Glasgow - the world's largest technical event on computational intelligence of the IEEE Computational Intelligence Society (CIS). The contribution to the discipline also include a range of roles on committees and groups within specific research areas. Staff are contributing to the UKRI research councils: 6 staff have been members of the EPSRC college; 4 staff have acted as review members of the EU Horizon 2020 projects; 1 staff member is a project reviewer of Australian Research Council (ACR) and Natural Sciences and Engineering Research Council (NSERC) Canada.

**Interdisciplinarity:** Addressing global challenges is the key strategic position of our research, which is thus inherently interdisciplinary. All projects during this REF period involved expertise in other disciplines and we have contributed to delivering impacts in other UOAs (e.g., Smart Built Asset Management impact case study in UOA12, **Ramzan** and **Pervez**). Specifically, some of the particularly pertinent interdisciplinary areas include: (1) machine learning techniques to revolutionise medical diagnosis (R. Alzubi, N. Ramzan, H. Alzoubi and A. Amira, "A Hybrid Feature Selection Method for Complex Diseases SNPs," in IEEE Access, vol. PP, no. 99, pp. 1-1. doi: 10.1109/ACCESS.2017.2778268), (2) addressing urgent challenges in the health sector through the ATHIKA project involving academia, public health administration, health business, startups, consultants and entrepreneurs; and (3) 5G with novel self-healing algorithms running on the power distribution network to avoid power disruption caused by short-circuits, climatic phenomena and animals; as well as (4) 'Special Commendation' recipient in the Multiparty Collaboration category at the 2018 Scottish Knowledge Exchange Awards - Thales-Challenge AALART project. Finally, SICSA has worked closely with the other research pools to develop Research and Innovation Scotland (RIS) that combines all the pools to develop a cross-pool approach to multi-disciplinary, challenge-based research. Currently RIS is developing focused challenge workshops with KTNs and is working towards a presence at the COP26 climate conference.

**International priorities:** We have contributed to standardisations activities including to ITU-T FG-ML5G (Focus Group on Machine Learning for Future Networks including 5G) and SG13 (Study Group 13: Future networks, with focus on IMT-2020, cloud computing and trusted network infrastructures) with 2 official ITU-T Draft Recommendations approved, ETSI ENI ISG (Experiential Networked Intelligence Industry Specification Group) with 1 POC approved, and ETSI GANA with 1 ongoing specification being standardised; CoChair of VQEG HDTV; Co-Chair of VQEG PSYPHY; Member of BSI IST/37.

**Wider contributions:** During this assessment period, our staff have been serving on 37 different editorial boards, including Applied Soft Computing journal (Elsevier); Cognitive Computing (Springers); Signal Processing: Image Communication; International Journal of Cyber Security Technology; Frontiers in Wireless Communications and Networks; IEEE Communications Technology Newsletter; IEEE Communications Letters; Elsevier Physical Communications Journal; IEEE Communication Magazine; Elsevier Computer and Electrical Engineer; IET Wireless Sensor System; IARIA International Journal on Advances in Telecommunications; Cyber Journals: Multi-disciplinary Journals in Science and Technology; and International Journal of Trust Management in Computing and Communications. We have been invited to give 55 keynote/invited talks, including ACM Future Worlds Symposium 2020, IEEE IES Webinar, IEEE.tv (2020), IROS WS 2018, BMVA Symposium on Enabling Human-Level Understanding in Robots, IEEE ICC 2020 Workshop on Intelligent 5G Network Slicing, IEEE International Conference on Cybernetics, 7th International Conference on Cloud Computing, Data Science & Engineering, and IEEE sponsored Conference on Innovations in Mobile Computing.

Staff in this assessment period have won 33 Best Paper Prizes/Awards in total including Best paper award 2017 IEEE Transaction of Circuit and Systems for Video Technology; Best Journal paper award 2019 jointly presented by IEEE Communications Society and China Institute of Communications; Best Paper award at International Conference on Digital Arts, Media and Technology (ICDAMT2017); Best Paper Award Winner for SOFTNET WORKING 2017; Best Student Paper Award Winner for SIGMAP2014; and Best Student Paper Award Winner for IEEE ICCE2014; IEEE ICCE (International Conference on Consumer Electronics) 2014.

Our ten staff are Members or Senior Members of IEEE, and seven have served or are serving as the visiting research professors/academics at the following HEIs: Nanjing University of Information Science and Technology (China), Chiang Mai University (Thailand), Kantipur Engineering College (Nepal), University of Lyon 2 (France), Amity University (India), University of Lorraine, France, Capital University of Science and Technology, Pakistan, Polytechnic University of Valencia, Spain.

Staff have been recognised in winning several National and International Research and Innovation Awards for their research and research projects. Significant awards include:

- Winner of the Times Higher Education (THE) Awards 2020 -Knowledge Exchange/Transfer Initiative of the Year Award 2020
- Scottish Knowledge Exchange Champion award 2020
- Scotland Centre for Engineering Education and Development (CeeD) Innovation Awards – Best Innovation – 2020
- 2018 NATO Best Scientific Award – IST-118
- Special Commendation award in Scottish Knowledge Exchange Awards 2018.