

Institution: University of Northumbria at Newcastle

Unit of Assessment: UoA 11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

1.1. Overview

Northumbria's UoA 11 is based in the Department of Computer and Information Sciences. The unit consists of 66 staff members (64.4 FTE), a number that reflects a fivefold growth from REF2014 (Figure 1). This substantial growth derives from the University strategy set in 2013 (REF5a section 2) to significantly increase the number of staff performing high-quality research. Through the cultivation of strong leadership, increased university investment, ambitious recruitment, and the promotion of a pervasive research culture, the unit has created a sustainable and forward-looking environment for research. Overall, this approach has led to a radical transformation in the unit's research capability.

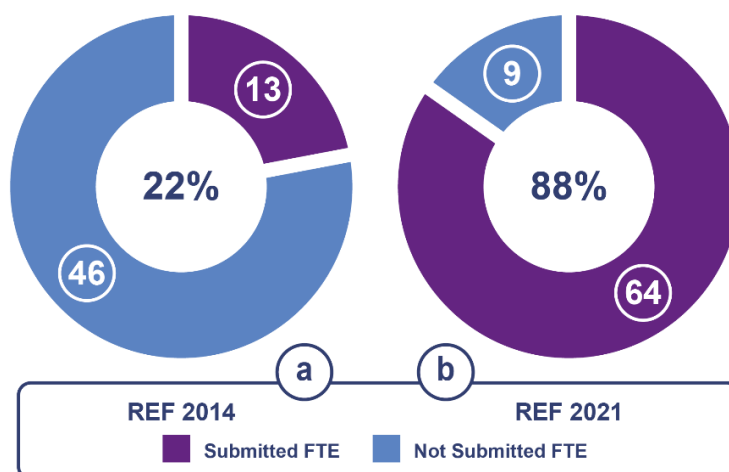


Figure 1. (a) and (b) Number of REF-eligible staff in REF2014 and REF2021, with percentage of staff submitted to REF.

Since REF2014, our unit embarked on an ambitious programme of investment and growth across distinctive areas of research and established six research groups that work on diverse but interconnected themes: **Social Computing**, **Digital Health**, **Computer Vision**, **Digital Learning**, **Cyber Security** and **Networks Systems**. Our research environment demonstrates a strong commitment to the development of our community of scholars at every career stage and an integrated approach to using our research so as to address real-world challenges to the benefit of local, national and international communities.

Our long-term vision for achieving research excellence has been to transform, from an exceptional teaching community with islands of research excellence, into a unit with a pervasive research

culture. To achieve this vision, we have employed a multipronged strategy driven by four main goals:

- 1) growing the size, diversity, and quality of our staff base through a range of strategic mechanisms that focus on research-quality enhancement (section 2). This goal was pursued in the complementary areas of human computing and interaction design, artificial intelligence (AI), and digital technologies as well as driving new research agendas in digital health and well-being, cybersecurity and future networks;
- 2) investing in strategic infrastructure and capital in order to create sustainable and vibrant state-of-the-art research facilities that should meet the demands of a dynamic, evolving, multi- and interdisciplinary nature of UoA11 research (section 3);
- 3) newly tailored processes, internal research support systems, and incentives capable of sustaining an ambitious and engaged research community (sections 2 and 3);
- 4) prioritising knowledge co-creation with stakeholders in order to make a positive difference across areas of strategic importance (section 4).

Particularly noteworthy evidence for the success of the unit's strategy, its development of intellectual capital, and its investment in state-of-the art facilities is presented below.

Evidence:

- The relevance of our research to UKRI and other funders has resulted in research awards in excess of £6.4M. (RGCI - £3.4M, a substantial increase from £217k in REF2014).
- We have been successful in establishing larger research centres – the EPSRC Centre for Digital Citizens (CDC) in 2020 (EP/T022582/1, £3.7M, Cols: *Montague, Lawson*) and the EPSRC Digital Economy Research Centre in 2015 (EP/M023001/1, £4M, Col: *Lawson*).
- Our investment in, and prioritisation of, building research capacity and developing future research leaders have led to a substantial rise in postgraduate completion, from 6 during REF2014 to 79 during the current REF cycle, while three staff members have secured EPSRC First Grant.
- Our expertise and sustained success in cybersecurity research are acknowledged in the form of the Academic Centre of Excellence (ACE) status awarded to us by the National Cyber Security Centre, which recognises the leading-edge quality of this research. Nationally, only 19 universities hold this status.
- Our growth in research quality and reputation is reflected in a large increase in the number of outputs published in the top 10% journals in our discipline and substantial increase in the number of citations (more than 10k since 2014).
- The unit is now ranked among the top 400 in computer science worldwide, and is the 18th most cited in the UK in the field of computer science (*Times Higher Education*, 2020).

1.2. Current research position with reference to REF2014

After REF2014, our strategy has been to expand high-quality research in the unit by consolidating the existing strengths, improving the size and impact of our research groups, generating a

sustainable research income, and developing a supportive research environment. The unit's successes in the areas of the strategic objectives set out in REF 2014 (here in italics) are as follows:

- i. *Growth in research capacity and academic staff base.* Our academic staff base (FTE) has grown from 59 in 2013 to 73 in 2020; this was accompanied by an approximately fivefold increase in the number of category-A submitted staff, from 13 in REF2014 to 64.4 in REF2021.
- ii. *Strategic infrastructure investment.* A new £7M building for the unit was purposely designed for the alignment of research with teaching; it has state-of-the-art laboratories and equipment that support our key research areas (section 3.3).
- iii. *Investment in existing fields of strength and creation of complementary research themes.* The unit's research base has been transformed through a strategic concentration on two research clusters with complementary research themes. The number of research groups has grown from two to six in REF2021 (section 1.3).
- iv. *Building capacity and capability via collaborative research.* Utilising our national and international research collaborations, we have integrated impact into our funded research and provided internal support designed to increase the diversity and significance of our impact case studies (section 4.1, 4.2).
- v. *Investment in staff sabbaticals, PhD studentships, and staff development; capital investment in the development of novel technologies.* Since 2014, 18 sabbaticals have been taken, 79 PhD students have graduated, and a laboratory and capital investment of £1.8M+ has been made.

1.3. Unit structure and key achievements

The unit's distinctive research spans two 'signature' research clusters: **Human-Centred Computing (HCC)** and **Artificial Intelligence and Digital Technologies (AIDT)** (Figure 2). These clusters offer overarching support to our six research groups, enabling cross-collaborations as well as target research challenges and priorities of local, national and global significance. In order to develop progressive, productive and engaged research communities with a strong sense of identity and with freedom to innovate and evolve, research groups have fluid boundaries, which encourage peer-to-peer staff support and collaborations. The establishment of such research groups reflects a dynamic and agile strategy of exploiting new research opportunities and 'grand challenges'.

1.3.1. HCC

The HCC research cluster consists of three groups that pursue research in diverse but connected areas related to social computing, impacts of contemporary computing systems on human lives, interaction design, digital learning, digital health and well-being.

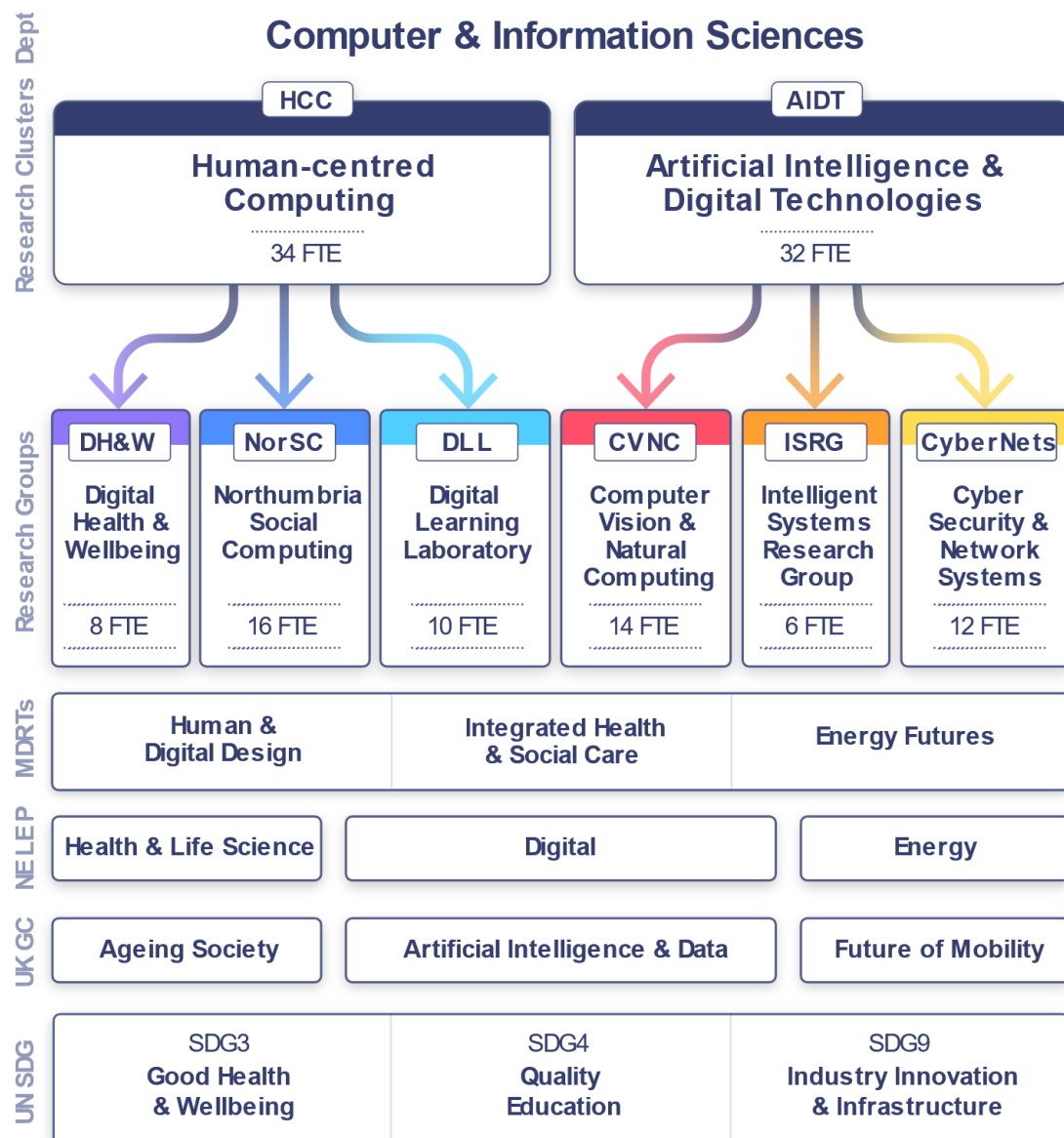


Figure 2. UoA11's organisational structure and alignment to the university's structure. The acronyms are: MDRTs = multidisciplinary research themes (cross university themes); NELEP = the North East Local Enterprise Partnership Strategic Economic Plan; UK GC = the UK Industrial Strategy Grand Challenges; UN SDG = the United Nations Sustainable Development Goals.

The **Northumbria Social Computing (NorSC)** group undertakes critical, participatory and place-based research in order to understand and explore the design of socially engaged and responsible digital technologies. We have a strong focus on the design, implementation and evaluation of new social platforms, applications and services, as well as on understanding the impact of everyday technology such as social media on citizens' lives. Our interdisciplinary and collaborative projects with regional partners and local communities have focused on innovative civic technologies that support citizen participation (Lawson, Kirk, Montague, Dow, Clear), the functional assessment and evaluation of human factors in the built environment (Amos, Rogage, Li) and the design of novel

interactions in virtual and mixed-reality interactive spaces (*Dalton, Vickers*). **NorSC** has contributed empirical studies on the future of work and on work–life balance interventions (*Cecchinato, Newbold, Vasiliou*); proposed radical community-based approaches with a view to providing protection from online harm for vulnerable and marginalised populations (*Nicholson, Lawson*); and developed user-centred design approaches to safeguarding data security in mobile and wearable technologies (*van der Linden, Conniss*).

The **Digital Learning Laboratory (DLL)** group explores computer science and digital technologies and user behaviour in relation to education. A key area is digital citizenship, with strands that focus on how to ensure that everyone can be a digital citizen regardless of background and environment. Digital citizenship has included working within the north-east region, with families and hard-to-reach communities, but also further afield, for instance in Vietnam and Nigeria (*Dele-Ajayi, Pickard, Sanderson, Strachan*). A further strand focuses on physical, cognitive, and affective access to information and on the ethical and regulatory management of information and records by means such as storage, retrieval, retention and disposal (*Casselden, McLeod*). Other avenues of research explore how we can provide an effective and supportive educational experience for computer and information science students in higher education (*Anderson, Keogh, Prickett, Walters, Watson*).

The **Digital Health and Wellbeing (DH&W)** group focuses on developing human-centred and accessible digital solutions in order to address unmet healthcare needs. A particular emphasis is on algorithm development and digital biomarkers that use wearable technologies and mobile computing to understand mechanistic (e.g. cognitive) as well as lifestyle factors in ageing (*Godfrey, Alshabrawy, Rooksby, Pointon*). Recognising the societal importance of this human-centric approach, staff members (*Akhtar, Warner, Anwar, Sice, Elvin*) research digital health challenges pertaining to vulnerable groups and information retrieval for decision support systems.

HCC's global research leadership role is evidenced by its staff's leading significant externally funded research projects and successful awards of over £3M during the REF period, more than 70% of them from UK research councils.

Examples of funding successes and partnerships:

- ESRC-ES/M003574/2, 2015: 'CuRAtOR: Challenging online feaR And OtheRing' – on social computing;
- EPSRC-EP/M000206/2, 2015: 'Social Computing and Mental Health Research Network' – on loneliness in the digital age;
- EPSRC-EP/P025544/2, 2017: 'Playing Out with IoT';
- AHRC-AH/S005773/1, 2019: 'Learning from the Past to Create a Sustainable Society' – on sustainable society, with international partners from Ethiopia, Kenya and Malawi.

1.3.2. AIDT

The **AIDT** research cluster supports interdisciplinary research in AI, machine learning, intelligent systems and digital technologies to solve real-world problems.

The **Computer Vision and Natural Computing (CVNC)** group's research ranges from the mathematical foundations of machine learning and AI (*Shang*) to computing algorithms (*Woo, Zeng, Mao, Rook*) and their applications to computer vision, computer graphics, visual activity and motion recognition (*Bo, Ho, Hu*). There is contemporary research on evolutionary computation and fuzzy systems and their applications in facial emotion recognition and video processing (*Yang, Mistry, Ellman*). The **CVNC** group continues to provide fundamental research on multiagent systems (*Zeng*), audio computation (*Mao, Bo*) and complex networks (*Shang*).

The **Intelligent Systems Research Group (ISRG)** focuses on developing intelligent algorithms for biometric security, digital multimedia security, modelling and analysis of complex systems. A particular strand addresses research challenges in the pattern analysis of human biometrics, image and video forensics (*Bouridane, Khelifi*). Other activities include developing smart systems for the detection of stock market manipulation (*Belatreche*), modelling and analysing swarm motion (*Eliot*), activity recognition in monitored environments, and smart homes and buildings (*Wonders*).

Examples of funding successes and partnerships:

- EPSRC-EP/M002632/1, 2014: 'Temporal Forensic Analysis of Digital Camera Sensor Imperfections for Picture Dating' – on digital forensics;
- EPSRC-EP/M002632/1, 2015: 'Interaction-Based Human Motion Analysis' – on motion based on the interaction with the surrounding environment;
- EPSRC- EP/M000206/2, 2015: 'Privacy-Protected Human Identification in Encrypted/Transformed Domains' – on digital security;
- Qatar Science Foundation Grants, NPRP7-442-1-082, 2014, 2015: 'Intelligent System to Digitally Support Paleographic Analysis of Ancient Manuscripts in Qatar'; NPRP8-140-2-065, 2016: 'A Biologically Inspired Multi-Sensor and Multi-Modal System for Public Security'; and NPRP12S-0312-190332, 2020: 'Video Forensics for Source Smartphone Identification, Video Content Authentication, and Forgery Detection' – all on digital security and forensics;
- KTP-10596: To develop a new and innovative middleware capability that can address the complex multivariate connectivity required for example by the IoT domain.

Cybersecurity and Network Systems (CyberNets) focuses on technical and theoretical aspects of communication and security in network systems. A particular emphasis is on developing efficient protocols for current wireless technologies, resource allocation, edge computing, Internet of Things (IoT) and software-defined networks (*Fehringner, Issac, Khan, Mehrabidavoodabadi,*

Moon, Tuysuz; Wang, Yuan). We are strategically developing our strengths in emerging areas such as unmanned aerial vehicles, intelligent reflective surfaces and communication for electric vehicles in intelligent transportation systems (*Aslam, Wang, Mehrabidavoodabadi*). Recognising the strategic importance of cybersecurity in communication networks, staff members (*Aslam, Chen, Issac, Anderson*) are addressing key research challenges in intrusion detection related to botnets, malware classification, the security of online payment systems, and differential privacy.

1.4. Multidisciplinary and Interdisciplinary research

Multi- and interdisciplinary research has been integral to the unit's current successes and will be the cornerstone of future research growth allowing staff to develop new areas of impact after REF2021. Strategic investment in university-wide multidisciplinary research themes (MDRTs; REF5a, section 2.3) designed to address key regional, national and global societal challenges (Figure 1) has partly enabled this growth. Our MDRTs specifically aim to enhance the interdisciplinarity of our research, while strengthening our core research groups through the development and strategic recruitment of staff. Staff from our unit are central to the Human & Digital Design MDRT, tackling regional digital challenges, the national AI and data challenge, and the global industrial innovation and infrastructure challenge. Thus *Lawson, Montague, Strachan, McLeod, Clear, Vickers, Rogage, Li and Rooksby*, who are involved in this MDRT, look at human aspects of computing. The unit also works centrally within the Integrated Health & Social Care MDRT, tackling the regional health and life science challenge and the national aging society challenge. Staff in this MDRT include *Godfrey, Shum, Khelifi, Ho, Bouridane, Mistry, Woo, and Alshabrawy*, who work on the use of AI in health and care applications. We also work within the Energy Futures MDRT, tackling the regional energy challenge and the national future of mobility challenge. Staff in this MDRT include *Aslam, Chen, Wang, and Isaac*, who focus on security and communication networks in various applications linked to IoT, unmanned aerial vehicles (UAVs) and electric vehicles.

Examples of interdisciplinary MDRT-led recruitment:

- *Rogage* (building information modelling), appointed through the Human and Digital Design MDRT, contributes to research on the interoperability of building models in the **NorSC** research group.
- *Godfrey* (data analytics in healthcare), appointed through the Integrated Health and Social Care MDRT, is leading the **DH&W** research group.

1.5. Impact Strategy

The unit's strategy for research impact aims to drive significant beneficial changes that endure and grow, through meaningful and effective working relationships with research beneficiaries. Building lasting collaborations with our external partners, research users and stakeholders has

been a central feature of our pathways to impact. This general policy has been supported through targeted investment in people and processes that focuses on three strands:

- i. the consolidation, development, and expansion of partnerships with non-academic users at local, national, and international levels;
- ii. the embedding of our research within large national and international organisations to stimulate and facilitate innovative partnerships that support smart homes, cities, and industries of the future;
- iii. the championing of research in human-centred computing and smart digital technologies.

Many of our impacts have been built on research that crosses disciplinary boundaries and reflects our approach of building interdisciplinary communities of researchers. Our REF impact case studies (ICS) exemplify our focus on these three strands:

STRAND I: Northumbria's research on digital literacy engagement positively impacted the educational practices and the aspirations of young people – both regionally, across the north-east, and internationally. Interactive workshops were delivered to some 95k children and 18k families, carers, and teachers in 34 primary schools from less affluent areas in the north-east. This led to improved knowledge of STEM subjects and broadened children's educational aspirations (ICS *Strachan, Pickard*). At the international level we have contributed to changing educational practices in Nigeria by developing innovative computer science tools. A lasting impact of this initiative has been to transform education through digital learning, as demonstrated in the work we carried out with the Nigerian Ministry of Education, Science and Technology (DIGISTEM project funded by the World Bank; ICS *Dele-Ajayi*).

STRAND II: Our research in data analytics, AI and the integration of network systems has contributed to solving real-world problems faced by businesses and industries supporting their transition to the smart industries of the future. Research on the integration of multiprotocol IoT solutions (ICS *Jin and Ferhringer*) contributed to the core functionality of ADLINK EDGE, a flagship product that was launched to the market in 2018, allowing the company **ADLINK** to gain valuable new business.

STRAND III: Our research on human-centred approaches to cybersecurity (ICS *Nicholson*) impacted policies and practices for protecting vulnerable populations. Northumbria's research has informed cybersecurity policy in the UK and in the European Union. Through collaboration with industry, our research has developed novel, award-winning cybersecurity training products and used them with staff at the Tesco Bank and the London Borough of Camden Council. Our research on complex system modelling (ICS *Sice*) has yielded a new concept of trauma-informed care (TIC) – an integrated health and social care approach, which has been adopted by the Tees, Esk and Wear Valley (TEWV) NHS Foundation Trust. National guidelines for TIC were developed, and the TIC approach was included in the national NHS Long Term Plan of 2019.

Our approach to impact has been supported by university-wide investment in a central support team (REF5a, section 2.3) and by the inclusion of impact activities into annual personal development objective setting and among the promotion criteria. Additionally, within the unit we created an academic lead for impact (*Amos*) who works with colleagues and the central support team; and we provided dedicated funds for impact development from our quality-related (QR) budgets.

Our submitted ICSs have been selected to reflect the diversity of impact that arises from our collaborations. Beyond REF2021, our approach ensures sustained support and focus on maintaining these research partnerships and developing new areas of impact intended to address key national and international challenges. Dedicated support for research impact will continue both locally, in the unit (through an academic impact coordinator), and centrally (through an impact support officer).

1.6. Research integrity, open research and open data

The unit builds on institutional policies (REF5a, section 2.5) to support the enhancement and impact of research outputs. As part of open-access publisher deals, we have no fees at the point of publication with eight major publishing houses. To enhance the reach and significance of selected outputs, members of staff are supported financially for gold open-access article-processing charges, which are resourced through central university funding.

Data and analytical codes are now available as part of outputs using discipline-relevant publication services. Furthermore, free-to-access code-sharing platforms such as GitHub are promoted, encouraged, and widely used by our research groups. Consequently, we proactively and routinely provide access to published data and analytical codes, thereby enhancing the reproducibility, robustness, and impact of our research outputs.

No research project can be undertaken in the unit unless an ethical audit has been conducted and approved. The university has developed a bespoke online research ethics system, which enables researchers to assess comprehensively the level of risk and the wider implications associated with their proposals. Researchers undergo ethics training every third year, a mandatory requirement to obtain permission to conduct research and to supervise doctoral students. By intentionally putting open, inclusive and ethical practice into formal training, research group discussion, mentoring and supervision processes we firmly embed good practice and all its associated benefits in the unit's identity and effective operation.

1.7. Future strategic aims and sustainability (2021–2028)

Building on, and consolidating, our current trajectory of expansion and enhancement of the staff base and investment in facilities and in innovative processes and policies, the unit is intent on

setting ambitious but realistic future development goals. We anticipate that global and national challenges such as ageing and health care, digital society, efficient and secure networks, AI and data will dominate our research agenda for the next period. Our objectives for the next REF period are as follows:

- i. to use our recent investments in both intellectual and infrastructure capital to carefully shape future research directions to: a) ensure sustainability, b) encourage continued growth in diversifying research income streams, c) develop new strategic research partnerships that target emerging grand challenges;
- ii. to enable and diversify the impact of our research by engaging and collaborating with industries related to digital products and services. We expect significant growth around the themes of social computing and interaction design, cybersecurity, future networks, intelligent systems, and digital health and well-being;
- iii. to nurture our large pool of early-career researchers (ECRs) in their transition into research leaders and to provide support and mentoring for our more junior staff, so that they may gain recognition and achieve (associate) professorships;
- iv. to continue promoting the participation of underrepresented groups to computer science and to develop a significant, creative and pervasive strategy of enhancing equality, diversity and inclusivity within the unit. We will pursue our Athena SWAN award towards Bronze (the first submission is due in late 2021) and continue our pioneering work of inspiring the next generation of digital citizens (e.g. NUSTEM: section 4.2.1);
- v. to enlarge our postgraduate base, moving towards a one-to-one student to staff member ratio and diversifying our portfolio of externally and collaboratively funded PhD programmes from industry and other external bodies (e.g. Marie Skłodowska-Curie Innovative Training Networks, DfE Commonwealth Scholarships).

2. People

2.1. Academic staff strategy and development

To sustain a structured growth in research capacity and capability, our unit has focused its staff development and recruitment strategy on promoting (1) a culture of support and inclusivity among our existing academic staff members and postgraduate researchers (PGRs) and (2) a policy of targeted recruitment of high-calibre ECRs and established researchers in areas aligned to our research ambitions. An overview of our staff base, by academic title and career stage, is shown in Figure 3; nearly one third of staff (29%) are Professor or Associate Professor and provide strategic research leadership. We have expanded and revitalised this base through the recruitment of 36 new members – both research leaders and ECRs with an intentionally multi- and interdisciplinary perspective.



Figure 3. Staffing base by academic title for REF2021.

Recruitments were strategically made to align with our target research areas in **HCC** and **AIDT**. Through targeted senior appointments (*Amos, Lawson, Woo, and Zeng*, appointed to professorships) and promotions, we have established an agenda-setting research culture with the capacity to support and mentor ECRs and other academic staff. The Vice-Chancellor's Fellow (VCF) positions (REF5a, Section 2.2) have been instrumental in the recruitment of researchers with distinctive potential (e.g. *Clear, Godfrey, Rogage*). This mixture of senior and early-career appointments gives our unit a balanced and diverse research profile.

Recruitment processes have been revised so that greater emphasis is now placed on the quality of current and future research. The extensive use of video conferencing and video screening has enabled a truly worldwide and diverse recruitment; thus 12 out of the 36 new members of staff come from outside the UK.

2.1.1. Recruitment, probation, mentoring and promotion

All new appointees to the unit follow the university's standardised selection, interview and probation processes (REF5a, section 3.2). All new entrants to higher education have a longer period of probation (up to 22 months rather than the standard 12 months), to allow time for research development and independence. The new starter and his or her head of department agree on a probation plan that links appropriate research objectives with the support mechanisms (funding, mentoring, guidance and additional non-teaching time in the workload) dedicated to achieving them. Progress against the plan is reviewed thereafter on a monthly basis, but individual circumstances (e.g. extended period of leave) and evolving situations (e.g. cover for other staff) may dictate when research objectives are assessed.

Each staff member is given a research mentor. We see the mentor's key responsibility as being to challenge the mentee's level of ambition and to help him or her to create a personalised route map for career development. The unit has used its rigorous and supportive processes to balance internal progression with the recruitment of exceptional external scholars. During the past REF cycle, eight senior lecturers have been promoted to associate professorships (*Shum, Yang, Zhang, Belatreche, Khelifi, Dalton, Walters, Issac*) and two associate professors have been promoted to professorships (*Aslam, Strachan*). To support staff with less research experience, (i) we created a Research Kick-Start Program, which offers targeted mentoring and funding to pump-prime an agreed research project with an experienced colleague, and (ii) we provided targeted support (time and a fee waiver) for staff members without a PhD to embark on a doctoral study (we supported six staff members - *Elliot, Wonders, Watson, Hanlon, Adams* and *Pointon* - all of whom have now completed their PhDs).

Examples of staff support via our Research Kickstart Programme:

- *Anderson* was supported to work on a personalised control system for robotic ankle exoskeleton through experience-based Adaptive Fuzzy Inference (published in *IEEE Access*);
- *Rook* was supported through targeted mentoring to develop an algorithm for multi-population automatic facial emotion recognition (published in *Proceedings of the International Joint Conference on Neural Networks (IJCNN) 20*);
- *Moon* was supported to research the optimisation model for the autonomous valet parking system (published in *IEEE Access*).

2.1.2. Early-career and postdoctoral researchers

In REF2014 we submitted 4 researchers who met the ECR definition. Since then, the unit has appointed 16 new ECRs and has significantly invested in the development of this cohort of researchers. The UoA lead (*Aslam*) organises ECR quarterly support ensuring that ECR voices can reach the unit's research committee. In addition, Cecchinato coordinates an ECR network for peer support, particularly focusing on research grant writing. ECRs receive collegiate support through having highly restricted administrative duties and lighter teaching loads; for example, VCFs start with 10 credits of teaching in their first year, 20 credits in the second and 30 in the third, rising gradually to a full teaching load in their fourth year. This pacing allows them the necessary development time as well as the physical resources, infrastructure, and guidance for building their research profile. Additionally, our ECRs, along with all new staff, are supported by a £2k flexible budget designed to kick-start various activities, enabling opportunities for research with external collaborators to build their network. Our work to foster ECRs' career progression towards independent research leadership is evidenced by grant success – a key metric among our

structured procedures, which are aimed at raising aspirations, enhancing research skills, and securing funds.

UKRI funding received by cohort of ECRs:

- BBSRC: BB/S014292/1 – Transforming food system relationships, by *Clear* (Col);
- EPSRC: *Clear* and *Cecchinato* Funded by EP/N027299/1 – Co-designing a mobile application with football fans to promote physical activity;
- AHRC: AH/R01037/1 – Memoryscapes: reimagining place through immersive and participatory experiences that recontextualise memory assets, by *Rogage* (Col).

The unit upholds the principles set out in the Concordat to Support the Career Development of Researchers and recognises the need to nurture and support our ECRs, along with all our staff, including our postdoctoral researchers (PDRAs). At the date of the census, the unit has 11 PDRAs, by comparison with 1 in 2013. We deliver 'independence' mentoring to PDRAs and allocate time for them to work towards personal research outcomes. We introduced mandatory training for principal investigators (PIs) to support an appropriate developmental culture for PDRAs on their projects. PDRAs are also part of our appraisal system (see section 2.1.3) and have access to the same training portfolio as our academics.

Our policy is to continue to develop and invest in our fixed-term staff. *Dele-Ajayi*, for example, received faculty funding to pursue a personal research project outside his PDRA funding, and subsequently transitioned from a PDRA position to a permanent lecturer post following a competitive recruitment process.

2.1.3. PDA, sabbaticals and promotion

A biannual performance and development appraisal system (PDA) is used to formulate and reflect on an individual Research and Innovation Plan, which runs alongside teaching and administrative objectives and sets out challenging but achievable aims related to research quality and impact delivery (REF5a section 3.4). Staff members are encouraged to specify objectives connected to publications, research grants, impact, knowledge exchange and public engagement. It is appreciated, however, that the rhythms of research activity rarely map directly onto annual cycles, and our researchers are encouraged to plan and prioritise over a three- to five-year period.

The unit facilitates an annual research sabbatical scheme. Sabbaticals are allocated via a competitive application process informed by applicants' track record of high-quality publications and external funding, plans for external engagement and impact, and strategic development of the unit. All staff members are encouraged to apply for sabbatical periods every seventh semester and are supported by their line manager and research mentor to do so, regardless of their FTE or fixed-term or permanent status. Incoming colleagues, once their probation is over, can access the scheme more quickly, and sabbatical opportunities are especially signposted for those who return

from career breaks or periods of leave. Examples of the range of activities that have been achieved through this scheme are the development of a successful proposal to the Leverhulme Trust (*Vickers*) and of a Knowledge Transfer Partnership (KTP) with Smyth Toys (*Zhang*), underpinning research and stakeholder activities dedicated to impacting the use of digital technology in education (*Strachan*), and the preparation of first outputs of staff members as independent researchers (*Watson, Casselden*).

2.1.4. Research support

In parallel with our growth in academic staff base, the unit has restructured its technical and administrative support staff to better facilitate research processes (both the bidding and the delivery of leading research quality). A core element has been enabling the professional development of technical staff, which incentivises professionalism in all research-related activities. The unit has now four permanent technicians supported by a technical manager. The technical team oversees health and safety in the laboratories, maintains the computer systems and provides training for researchers and PGRs on specialised equipment.

Dedicated grant development officers are involved in every external submission, supporting costings and other grant-relevant items so as to ensure compliance, while a unit-focused business development manager facilitates interactions and exchanges between academia and business, industry, public or third-sector bodies. To support the significant expansion of our staff base, we restructured the internal financial support for staff; the aim has been to grow a vibrant research culture by acting as an enabler in the process. For example, through a flexible unit fund, we invested over £282k as a research enabler. Such a fund did not exist in the REF2014 period.

Evidence:

We have used the unit's flexible fund as a research enabler and supported over 30 staff in the following activities:

- presenting research work at national and international conferences and delivering keynotes and invited and plenary speeches (e.g. *Zhang* at the International Conference on Pattern Recognition and Machine Learning (PRML), 2020), *Belatreche* at the 2nd International Conference of Forensic Medicine and Sciences, 2017);
- supporting our impact activities (e.g. *Fehringer, Dele-Ajayi* and *Nicholson* were allocated part-time researchers to gather and analyse data);
- developing international research collaborations (e.g. *Bouridane* with Qatar University and Al-Ahli Hospital in Qatar for joint funding bids with QSF, *Aslam* with TU Delft for EU Cost Action, *Godfrey* with the University of Waterloo for wearable gait analysis and with FDA offices in the USA for Digital Medicine Society networking).

2.2. PGRs

Within the current REF cycle the number of PhD awards increased to 79, from 6 in REF2014 (Figure 4a). We observe rigorous quality assurance in PhD recruitment, which is driven by the policies set by the Graduate School (REF5a, section 3.5), and international students make up 68% of our PGR population (Figure 4b). PGR funding within the unit is divided between (1) internal university-funded studentships (see strategy in REF5a, section 2.2); (2) external funded via industry, overseas governmental organisations or the European Regional Development Fund (EU ERDF), or EPSRC-funded projects; and self-funded (Figure 4c). We offer doctoral studentships as part of match funding where this goes towards supporting large research funding applications and integrating all our postgraduate students within strong, agenda-setting research groups and networks.

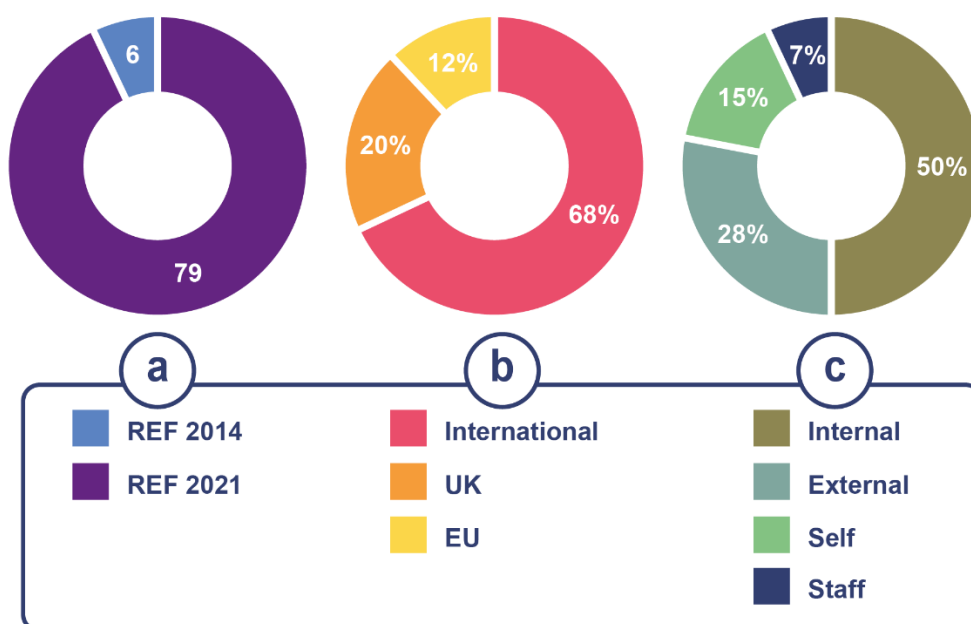


Figure 4. PGR population by (a) total number of PGRs in REF2014 and REF2021, (b) region of origin and (c) funding source of current PGRs.

2.2.1. Student progression, training and support

Processes and procedures for student progression are set out and overseen by the Graduate School (REF5a, section 3.2). Our regulations require monthly contact between supervisors and PGRs, normally via face-to-face meetings. These sessions must be formally documented, a synopsis of the discussion and agreed next steps being logged on to a central electronic system (eVision). Students must pass three progression 'milestones', which require submission of a structured report and internal viva with a nominated subject expert.

All PGRs enrol on the university's Professional Development and Researcher Training Programme (REF5a, section 3.5). The training offer combines mandatory and optional university

and unit-specific sessions, often delivered in the form of research group workshops or presentations, and via online interactive courses. We encourage our PGRs to attend a three-day course on introduction to teaching that enables them to get involved in academic activities with undergraduates, equipping them for careers beyond the successful completion of their thesis. Regular attendance at relevant research groups and research seminars is expected of all our PGRs, as it embeds them in the unit's research culture. Students are also encouraged to present their research at the faculty's postgraduate student conference, which provides a supportive and inclusive research culture and fosters cross-disciplinary research for staff members and PGRs. All students have access to the Graduate School's PGR bursary scheme and to a unit bursary (typically £3k over three years) designed to support bespoke additional research expenses and travel to conferences and workshops. Challenges faced by students throughout the COVID-19 pandemic have been acknowledged and responded to through the adaptation of research plans, extension of deadlines for internal reporting, and provision of a suite of mental health and well-being support measures including counselling.

2.2.2. PGR environment and engagement

Our PGR community is based in a PGR suite located adjacently to staff offices, giving access to common room spaces. The Postgraduate offices offer individual workstations with further hot-desking facilities within laboratories. Since 2018, our PGRs can also access dedicated areas within the new Research Commons space in the City Library, collaborative and networking space for digital and open scholarship with bookable rooms for reading, meetings and consultation and expert face-to-face support across the research cycle.

Students are encouraged to be proactive and organise their own training events and conferences, while supervisory teams advise them on how to access external research funding sources such as the Royal Academy of Engineering, or IEEE and conference travel grants. Outcomes are often successful; for example, our PGRs have won awards for best student talks at several conferences (e.g. CHI2014, UKCI 2016, UKCI2018, SKIMA2019). In addition, they engage with non-academic communities and charities in order to disseminate their research and share knowledge and best practices. For example, *S.Thirkle* participated in the Scholars' Programme organised by the Brilliant Club to deliver university-style tutorials in schools and sixth-form colleges to support pupils from underrepresented backgrounds to access university.

2.3. Equality, diversity and Inclusion (EDI)

The unit recognises that diversity, addressing inequality and creating vibrant and inclusive research environments is fundamental to our success and sustainability. We appreciate that the ability of colleagues to be productive researchers can be adversely impacted by a range of personal circumstances that pertain to health and well-being, maternity and paternity, caring

responsibilities, family location and commuting. The unit is strongly committed to an EDI agenda that fosters mutual respect and an inclusive and empowering culture for all. The unit's Athena SWAN self-assessment team, led by *Pickard*, works closely with the university's Athena SWAN team and EDI Committee to implement progressive policies and practices in line with the Athena SWAN Charter.

One of the defining elements throughout the unit's growth and development has been the drive to diversify the staff base into an inclusive community, where gender and equality are regarded as important. All adverts (staff, research fellow and PGRs) are checked for gender-coding words (<http://gender-decoder.katmatfield.com>); all interviews are conducted by mixed-gender panels – and, as far as possible, mixed-ethnicity, too; and all participants are required to undergo fair selection or unconscious bias training. In our recruitment process we take appropriate positive action, wherever possible, to address the under-representation of women within the unit. We advertise posts across a wide range of recruitment websites and promote options around flexible working arrangements and benefits to increase our appeal to a broader pool of candidates. If during the shortlisting process we end up with a single-gender shortlist, we take steps to rectify the situation, for example we readvertise the post or interview more candidates than initially planned.

Research seminars and committees are typically scheduled during core hours (10:00-16:00 hrs), to facilitate the attendance of staff with family and caring responsibilities; out-of-hours emails are discouraged. We are sensitive to the fact that work progresses faster when researchers can block out significant periods of time rather than making intermittent progress in between other commitments. Where institutional timetabling protocols allow, we aim to keep one day per week free of teaching for each member of staff, and possibly more than one day where timetable demands allow. A Wellbeing Hub provides a range of supporting materials, including carer support, access to a Health Advantage app with proactive well-being tools, and additional guidance for navigating the challenges of the COVID pandemic (e.g. guides to remote working). Mental health is supported by training programmes, and a parenting network constitutes a caring space in which members from across the university can meet, discuss and share ideas and experiences.

The unit supports the university's engagement with the Race Equality Charter and its Black, Asian and other Minority Ethnic (BAME) Staff Network (REF5a, section 3.6). Through our NUSTEM initiative, staff in the unit have been proactively working to reduce inequalities in the recruitment pipeline and to reverse the imbalance that affects young people from BAME and disadvantaged socio-economic backgrounds who choose computing and information sciences as a career (<https://nustem.uk/about>; section 4.2.1).

In 2014 we did not return any female academics as part of our submission. For REF2021, nearly a fifth of our submission consists of women. Our ability to recruit across geographic boundaries is reflected by more than 40% of our staff members holding non-UK citizenship (Figure 5a), further contributing to our growing multicultural environment (Figure 5b).

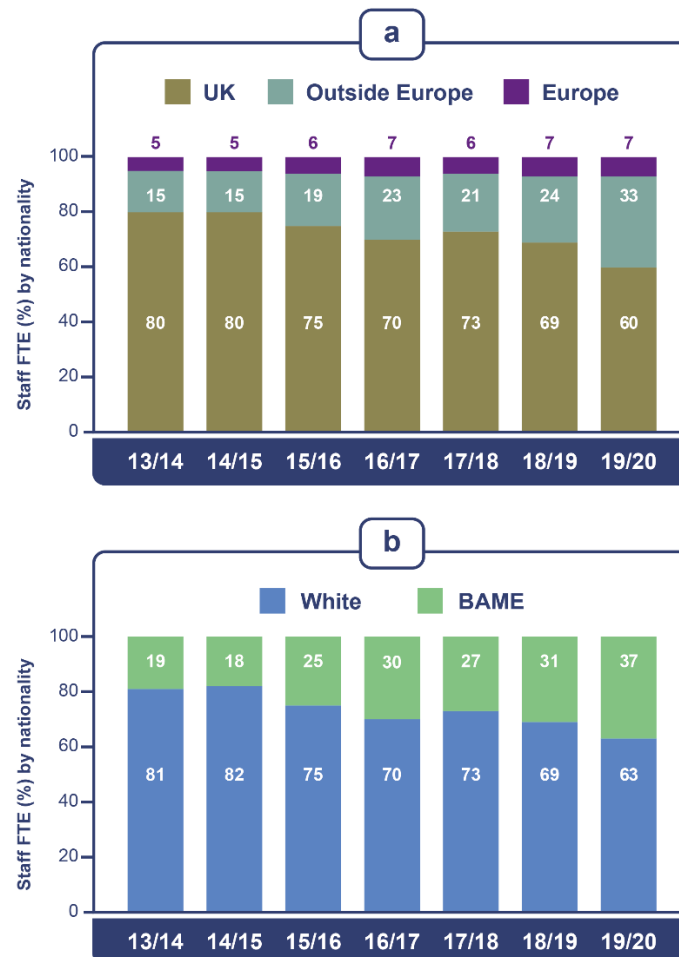


Figure 5. (a) Staff FTE (%) by nationality, (b) Staff FTE (%) by ethnicity.

The construction of our REF submission was compliant with all EDI principles and practices set out in our REF2021 Code of Practice: transparency, consistency, accountability, and inclusivity. The final output selection was made on the basis of quality, research groups, and male–female–BAME representation; to ensure, as far as possible, that the selected outputs were representative of the submitted staff. A diverse mix of staff members took part in the output review and calibration exercises, while the UoA lead (*Aslam*) acted as a moderator ensuring no conflicts of interest were present.

3. Income, infrastructure and facilities

Our unit's strategy of creating a critical mass of high-quality researchers working at the forefront of global challenges while investing in infrastructure and the professional development of staff has significantly increased the number and value of awards during the current REF period. By promoting a

pervasive culture of research and support for funding applications, our grant submissions rose from 27 a year in 2014 (from only 30% of the staff) to 79 a year in 2019 (from 90% of the staff;), see Figure. 6). During the current REF period we have successfully secured research grants in excess of £6.4M, and the overall size of research income (RGCI) has grown from £217k in REF2014 to £3.4M for REF2021 (Figure 6). The diversity of awards has also increased; this includes £3.1M from UKRI, £1.3M from the UK government, £550k from EU, £620k from charities, and £837k from industry and other sources. Furthermore, our dedicated team of business development managers has helped colleagues achieve a 100% success rate in KTP applications, securing eight KTPs in the current REF Cycle.

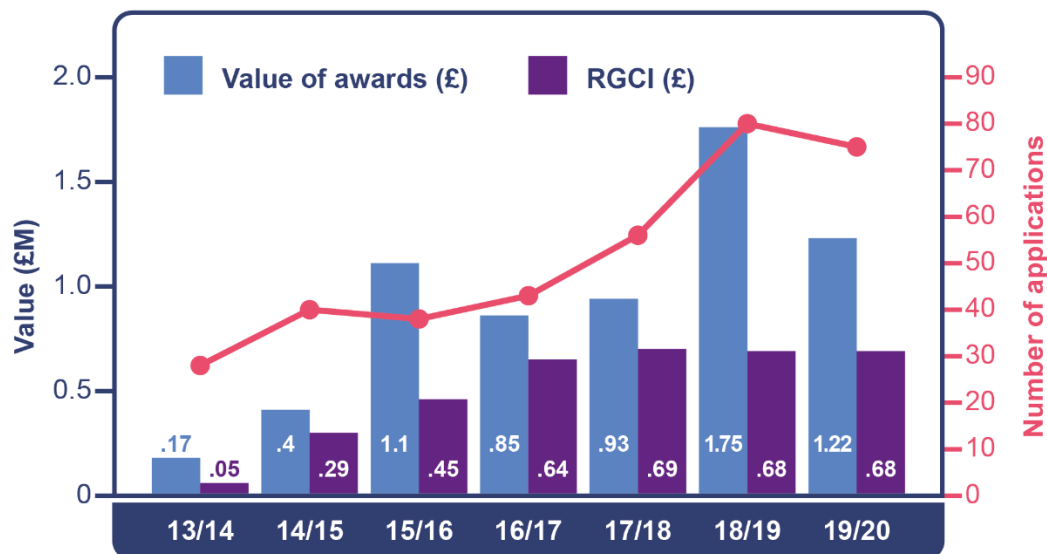


Figure 6. The transformation of research grants culture in our unit. Number of applications (red line), successful awards (light blue), RGCI (dark blue).

The UoA research director works closely with the Research and Innovation Services (RIS) to disseminate relevant funding calls, while UKRI and UKRO funding-related news are disseminated via monthly RIS research bulletins that highlight relevant research policy news, training and briefing events, and funding opportunities. Further support is provided by a research mentor (section 2.1).

Research development managers in RIS work closely with our researchers and provide PIs with bespoke support through pre-award and post-award officers. RIS facilitates networks for increasing the impact and quality of proposals by linking staff based on shared research interests (within the university and beyond). RIS runs an extensive array of training programmes and drop-in sessions to support research grant applications, including an elite training programme ('Next Generation of Large Award Holders') for researchers who have already won small to medium-sized grants and need to transition to larger applications. There is a focus within RIS on supporting ECRs through: (i) 'Writing retreats' to allow dedicated space and time for continued, formative feedback on prospective proposals; (ii) 'Impact in funding applications' sessions help PIs in

developing frameworks for pervasive impact throughout the proposal; and (iii) 'Fellowship Ready' sessions support ECRs who have already applied for grant funding as a PI and intend to develop personal fellowship applications.

Evidence:

Examples of funding to enable multi- and interdisciplinary research:

- EPSRC First Grants, secured by three members of staff: *Shum*, EP/M002632/1; *Khelifi*, EP/L006812/1, *Jiang*, EP/P009727/1;
- Leverhulme Trust, £357k, 'A Radical New Interdisciplinary Space for Sonification': *Vickers* (as PI), with UK- and EU-based partners;
- EU H2020_PERCEPTIONS (Grant ID-833870), €4.99M, Northumbria share €522k: led by *Lawson*, with 24 partners; ESRC-ES/M003574/2, 'CuRAtOR: Challenging online fear And Othering': on new digital services that facilitate widescale empathy with specifically chosen, often othered groups led by *Lawson*;
- EPSRC-EP/M023001/1, £164k, Digital Economy Research Centre (*Kirk, Lawson*), NU Psychology (*Briggs*);
- eight KTP projects totalling more than £1.2M from Innovate UK, industry, and the Technology Strategy Board;
- HEFCE, the Institute of Coding (IoC), £512k.

3.2. Infrastructure and facilities

The university recognised our unit's ambitious and innovative vision by making a significant investment (£7m) in our new building, which was completed in 2018 and supports the realisation of our research and impact strategy. It is an award-winning (<http://www.northumbria.ac.uk/about-us/news-events/news/cis-building-win>), purpose-built, state-of-the-art facility that creates an outstanding research and learning community environment for all staff and students, right at the heart of the city centre campus. It features a low-carbon design and is equipped with smart IoT sensors interfaced with a specialised building management system, which improves general efficiency and provides IoT-based resources and environmental data for our researchers. The building design is inclusive, featuring accessible ramps, push-button automated doors, accessible lifts and toilets, visual contrast to aid navigation, and laboratories equipped with several automatic, height-adjustable desks.

Our building was designed to create a community hub for more than 1,200 students and members of staff, enabling them to innovate, learn and research together. To encourage collaborative working, the building houses a mixture of research spaces, including four-seater soundproof booths, configurable IT labs, UXD labs, an animation lab, two computer network labs, academic offices, collaborative spaces, generic labs and breakout areas that allow informal collaborations and networking. In tandem with the expertise provided by business development managers (section 2.1.1), these spaces and their smart infrastructure support the unit's staff in the

development of impact. The building is also used as a 'living lab' research resource where data from smart sensors are used to inform new generations of offices and homes. Examples include:

- *Rogage's* and *Clear's* multiple projects as part of BIM Academy Enterprises Ltd (our spin-out company) and Smart Connected Homes communities;
- a new UKRI-funded team (healthcare practitioners, architects, designers, and building users), to design tech-enabled prototype houses, as flexible supportive environments for people across their life course ('Flexible living to age in place'; Catalyst award; *Rogage*).

With growing demand for e-infrastructures and industrial demand to investigate big data and complex systems, our new High-Performance Computing Centre (HPCC) enables our staff to tackle the digital, health and mobility challenges of the NE LEP and UK Industrial Strategy Grand Challenges respectively. The HPCC (over £350k) consists of equipment that includes 35 server nodes, a total of 940 CPU cores, 2,432 GB RAM, 2 NVIDIA Tesla, 88 TB Lustre parallel storage, 132TB HDD storage, 4320GB SSD storage, all facilitated through an Intel Omnipath 100Gb fabric interconnect node. The HPCC enables the unit to facilitate digital impact. For example, our staff has worked with **Startech Inc.** to improve a property management portal with a big data approach (*Li*, UKRI Innovation Voucher).

Examples of HPCC-enabled cross-cutting projects with national and international partners:

- Ageing society – ubiquitous sensing: *Ho* (PI, £11k, Royal Society) worked with the Newcastle upon Tyne Hospitals NHS Foundation Trust and Jadavpur University (India) to develop smart environments with sensor fusion designed to monitor older adults.
- Sustainable communities: *Clear* (Co-I, £31k, Innovate UK) is part of a UK team (including Cardiff University and Scotland's Rural College) to design and develop an interactive visual tool for regional food system stakeholders to interact with landscape models of food production and negotiate an alternative regional food system (<https://tgrains.com>).
- Health and Life Science – social eHealth and self-assessment: *Khelifi* (PI, £106k, with Share Global Health) developed a system for the automated screening of diabetic retinopathy on diabetic patients.
- AI and data – drone-formation control: *Shum* (PI, £124k, UK Government, Defence and Security Accelerator) examined how unmanned aerial systems can be countered in the future by implementing state-of-the-art deep-learning algorithms to analyse video content, the flow of people and vehicle movement within various environments.

With our increased research activities, requirements for rapid tooling to explore computing concepts as well as to meet the demands of collaborative projects have rapidly expanded. A £500k capital investment by the university led to the Rapid Prototyping Centre (RPC), which comprises (i) computer-controlled 3D printers (e.g. 24 Makerbot PLA 3D, 2 Stratasys OBJET24 3D, 3 Formlabs SLA/SLS 3D); (ii) flatbed precision laser cutters (e.g. 3 CAD/CAM Technologies FB, 1

Epilogue, 1 5-axis Mazak CNC machine); (iii) 3D scanners (e.g. 1 Markerbot, 1 David 3D, 2 Sense 3D, 1 Next engine); and (iv) prototyping equipment (e.g. 3 BUFA Fume Extraction systems).

Examples of RPC-enabled research:

- Digital (tools), 'Playing Out with IoT': staff members generated rapid prototypes from designs inspired by children, in order to create digital outdoor play in their own neighbourhoods (Co-I: *Lawson*, £685k. EPSRC. 2017-19).
- Health and Life Sciences – wound healing: *Shum* and *Ho* (£10k, ERDF Newcastle-Gateshead Initiative), in partnership with Newcastle upon Tyne NHS Hospital Foundation Trust and **Indigio Multimedia** (<https://indigomultimedia.com>), examined novel portable hardware technology with custom 3D sensing technologies (made through the RPC) to develop a vision-based system for measuring and visualising wounds and healing processes.
- Industrial innovation – ultrasonic prototype: *Aslam* (PI, £26k, **BELIMO**, <http://www.belimo.co.uk>): the RPC produced novel components to aid research into prototypes for heating, ventilation, and air flow measurement for industrial collaboration.

3.2.1. External facility access and collaborations

Access to high-quality instrumentation and data sources not available internally is facilitated through a range of external collaborations and partnerships. Our unit works with the Smart Connected Buildings network, the Newcastle Urban Observatory and wider networks provided through the BIM Academy Ltd to access frameworks and to exchange collaborative information, as well as giving access to the largest set of publicly available real-time urban data in the UK. These collaborations inform our ongoing research, enabling the interoperability of building models and tools to overcome technical barriers around data exchange in the built environment (*Rogage*).

CyberClinic (www.nucyberclinic.com), an initiative launched by our **CyberNets** group, influences information security practices of businesses through a research-led consultancy on security risks, testing and mitigation advice. Members of our **CyberNets** group and technical staff use our unit's computing infrastructure to create and finalise virtual private networks for tests with external collaborators (academic and industry). Configurations include access to virtual machine networks over our computing infrastructure, to conduct scans and infiltration testing. We are now listed as 'go-to' (cyber) security advisors by the North East Business Resilience Centre (NEBREC-www.nebrcentre.co.uk), a non-profit partnership with the north-east police force.

3.3. Future intentions for laboratory estates

Key priority areas for the unit's five-year strategic plan to 2025 are:

- (i) to reconfigure our general-purpose computing lab (completion summer 2021) to provide a state-of-the-art (137m²) dynamic research environment for all our research groups. This lab

will be based on a bespoke planned management system capable of orchestrating suitable sharing patterns. The new lab will provide an enhanced testing environment, for instance for the DH&W research group that regularly recruits (older adult) volunteers to participate in wearables-based physical testing studies such as gait or walking analysis;

- (ii) to restructure our current IT technical support. As our unit's research output and significance continue to grow, we are in the process of creating positions for experimental officers (technicians with doctoral degrees) to work alongside our academic staff and to further innovate and sustain our unit's growing research profile. These technical scientists will be trained in specialised areas of computing science, aligning with our research groups.

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

Collaborative research across discipline and subdiscipline boundaries remains at the heart of our research and impact strategy. The support developed after REF2014 enabled our unit to expand the impact of its research by creating strong interdisciplinary and multidisciplinary collaborations with local, national and international entities to tackle the UK's Grand Challenges (e.g. ageing society) and the UN's Sustainable Development Goals (e.g. industry innovation and infrastructure). Within the unit, QR funding was invested in targeted research support, which aimed to cultivate existing collaborations and initiate new research networks. Administrative support to PIs from RIS, for funded collaborative projects, enables academic staff to focus on research aims and project milestones. During the current REF period we have achieved local and international impact through externally funded collaborations with industry (section 4.1) while supporting our staff to develop significant networks (section 4.2), which has resulted in a diverse range of academic impact (section 4.3).

Evidence:

During the current REF period we have achieved:

- **INDUSTRIAL IMPACT:** 27 externally funded collaborations with industry; leading roles in 10 professional body networks; 8 invited high-profile industrial speaker events; new products resulted from our 2 patent awards;
- **INFLUENCE ON POLICY AND PROCESS:** playing key roles in over 11 international networks and influencing national-level decision-making in over 8 countries;
- **ACADEMIC SIGNIFICANCE:** 19 academic honours and awards; 37 memberships of industrial, governmental or international advisory boards; over 38 keynotes and invited presentations; organising of 76 conferences external to Northumbria; 11 senior editorial positions.

4.1. Major industrial collaborations

Contributing to and working with industry is core to the unit's research strategy. Our strategic aim was (and is) to provide research expertise and scientific excellence for the digital and health sectors to generate economic and societal benefits, both locally and beyond.

Our research in AI, computing vision, and the IoT helps well-established companies to diversify their services and innovate within their field, leading to increased wealth creation. For example, in 2015 **ADLINK** (www.adlinktech.com/en, £300M turnover) approached our **CyberNets** group to create a novel solution for data transfer and the sharing of large volumes of data in IoT systems. *Jin* and *Fehringer* used their expertise in data sharing, analysis, and management of IoT systems with diverse sensors and networking protocols to develop a successful KTP that contributes to the development of the flagship product ADLINK EDGE (ICS *Jin* and *Fehringer*).

Our research expertise in cloud-based deep learning approaches using the Google Cloud Platform facilitated a joint project with **Smyths Toys** (www.smythstoys.com). *Zhang* worked with **Smyths Toys** through a KTP project (£140k) for the design and implementation of multimodal ensemble approaches to forecast the sales trend of a given item without historical sales data. Our unit also nurtures innovation at the early stages of industrial development. For example, *Godfrey* worked with **Mymo Group Ltd** (www.mymo.co.uk), leveraging seed funding (ERDF Newcastle-Gateshead Collaborative GX project, £10k) and input from other groups (e.g. CPI www.uk-cpi.com) to develop an AI algorithm to create a product capable of analysing a runner's gait pattern. The Mymo product, launched in October 2020, is a low-cost IoT device for reducing injury in runners of all abilities. Its launch has led to an ERDF Intensive Industrial Innovation Programme PhD project. Additionally, it has also enabled the company to work with *Godfrey* and with the Northumbria Healthcare NHS Foundation Trust towards exploring the diversification of the Mymo product in older adult medicine via the Purposeful Health Growth Accelerator (www.purposefulhealth.co.uk) and the Research England Development (RED) Fund.

Examples of industrial collaboration projects:

- AI and data – commerce: *Jin* (with **Notify Technology Ltd.**), *Sice* (with **Mobile Health Networks Ltd.**), *Strachan* (with **British Telecom**), *Yang* (with **Cathie Group Ltd.**).
- Industry innovation: *Seker* and *Belatreche* secured £230k (KTP with **WhoCanFixMyCar.com**) to develop (AI) software that generates quotes for customers on the basis of past work carried out at garages.
- Industry innovation – data analytics: *Yang* secured £88k (KTP with **Cathie Group**) to develop a smart system for geodata-processing procedures and the analysis of large datasets for offshore projects

4.2. Transforming practices and perspectives, influencing policies and networks

Our unit promotes both fundamental and applied research that attempts to challenge the state of the art and to have a lasting impact on practices, policies and networks by influencing and transforming them. After REF2014, our unit developed a strategy for our social computing and digital health research to influence society. This is a strategy with a trickle-down effect on community-based groups (section 4.2.1). Collaborations across our two research clusters impact

digital policy (e.g. identity and culture), so that our researchers introduce best practice by providing toolkits and frameworks for the use of civil society organisations such as Citizens UK and the Office for Civil Society. With international partners, our unit tackles issues with major societal and political implications, such as the origins of misinformation and fake news. For example, through a Qatar Science Foundation project (NPRP12S-0312-190332, *Khelifi, Bouridane*), we are developing authentication procedures for digital videos, detecting forgeries, and identifying the smartphones that were used to produce them.

New ways in which our unit is tackling digital challenges:

Funded by Horizon 2020, the *PERCEPTIONS* project (€4.99m; Co-I *Lawson*, £443,000) began its first phase of empirical research within social commuting; the aim was to understand the context and impact of migration. Given our unit's expertise in social computing, this project, with its data in 11 languages from 14 countries, will help inform and influence narratives, imagination and perceptions of the EU.

Our multidisciplinary research in social computing and digital health to influence society is evidenced by a diverse range of projects. Our unit is one of two organisations that comprise the new £3.7M CDC (EPSRC – EP/T022582/1; Co-Is *Montague, Lawson*). The CDC will allow citizens to grasp the possibilities of the digital revolution, while addressing key challenges to their online safety and privacy. Work led by *Amos* established the UKRI funded **Network for Enhanced Evacuation Drills (NEED)**, a consortium of experts in evacuation dynamics, fire safety, immersive tech, data science, AI, and computational simulation. Beyond current academic limitations due to the pandemic, our unit is equipping the UK to better understand data-driven approaches to COVID-19. *Warner* (Co-I on the new AHRC project OMDDAC, £394k) will investigate whether an increased use of digital information as part of UK's response to COVID-19 could lead to a breakdown in public trust. Research from our **DH&W** group has led to the creation of a new UK multidisciplinary consortium for research into traumatic brain injury. The **Traumatic Brain Injury (TBI) Research Network** (www.tbi-research.uk) is a consortium of 13 institutions, charities, National Institute for Health Research (NIHR) organisations and industrial partners. Although only recently established, the **TBI** network has been a platform for the world's largest global women's rugby survey (13 languages), influencing policies designed to make the game safer and more inclusive.

4.2.1. Contributions to society, community and public engagement

Our unit is committed to ensuring that computing science addresses educational challenges within society, such as the digital divide. Using topics from our applied research (e.g. health, cybersecurity), we endow future generations with the skills they need to compete in the global digital economy. Many of our researchers have community links at local, national and international

levels, embedding their research into a range of educational outreach and public engagement activities for wider societal impact. For example, our unit collaborates nationally in the £40M IoC (*Vickers*), which brings together industry, government, higher education and outreach partners, engaging a diverse group of people into digital careers. Our engagement strategy also extended to conducting over 50 IoC events, where more than 1,100 learners completed various courses, from 'Teach the Nation to Code: Python' to 'Network Forensics' and 'Packet Capture'. *Amos* is an active participant in the events organised by the Speakers for Schools charity and regularly gives talks on careers and general computer science to secondary school children.

As part of our NUSTEM initiative, pedagogic research from our **DLL** research group has reimagined STEM outreach. Funded initially by a £1.2 million HEFCE grant in 2013–14 (*Strachan*), the research developed a theory of change (ToC) methodology for planning, participation, and evaluation tools for organisations that are aiming at social change. The sustained ToC approach led to improved knowledge of STEM subjects and broadened children's educational aspirations from groups under-represented in STEM education and careers, and also generated improvements to primary curricula (REF ICS *Strachan, Pickard*). The success of NUSTEM's public engagement led to our ToC approach being adopted by a number of partner organisations, including Gateshead and Derby Colleges. This has led to improved gender diversity in vocational STEM courses and enabled the North Tyneside Combined Authority to develop new adult education initiatives. To extend the geographical reach of collaborations, we also provided research assistance and project funding to colleagues working in Nigeria. Researchers in the **DLL** contributed to rapid response efforts in Ekiti State during the COVID-19 pandemic, helping to ensure that around 35,000 students remained engaged in learning activities during lockdown (ICS *Dele-Ajayi*).

Our research tackles challenges linked to health and ageing through a diverse range of community networks. For example, *Clear* (Co-I, £203k funded by BBSRC, ESRC, NERC and the Scottish government) as part of the T-GRAINS project (<https://tgrains.com/>) is working with large supermarket chains, local markets, independent shops and the public, to investigate a regional-based UK food system to provide healthy and sustainable diets and to explore if resilience in the system can be achieved through strengthening social capital among food system stakeholders. Focusing on healthy living and healthy lifestyles (*Rooksby, Cecchinato*) engaged football fans in a project involving the co-design of a mobile application to promote physical activity. This project was conducted in collaboration with the University of Glasgow and the European Healthy Stadia Network CIC (<https://healthystadia.eu> project partner) and was funded by the EPSRC GetAMoveOn Network+. *Cecchinato* (**NorSC**) used her research in digital distraction and human computer interaction to work with UK collaborators towards creating a web platform to help remote workers (e.g. during the COVID-19 pandemic) with their digital self-control, productivity, and work–life balance (<http://www.eworklife.co.uk>).

Our unit's ongoing interdisciplinary biosensor and AI research focuses on the development and deployment of a well-being informatics framework, where human well-being is measured by juxtaposing three domains: physical, mental, and social–relational. During the current REF cycle, we provided a sabbatical, funding for a research assistant, and equipment funding to develop this research. One strand of that work has become a UK national flagship project developed with the **Tyne, Esk and Wear Valley NHS Mental Health Trust**, one of the largest organisations of its kind in the UK (6.5k employees servicing 1.8M people). Northumbria's academics developed several digital tools that offer patients an active role in their recovery journey. One of these tools, a well-being diary, was used to assess the 'music for well-being' intervention, which was opened to the public during the Covid-19 pandemic and was used by over 50k people (ICS *Sice*).

Cybercrime costs the UK economy billions of pounds per year, and the human factor in cybersecurity is a key vulnerability. Cybersecurity awareness has been raised among over 1,000 older people (a group considered among the ones most vulnerable to cybercrime) in the north-east of England through the efforts of our **CyberNets** researchers, who work with the University of the Third Age, developing and training CyberGuardians. The project empowers older adults to become reliable sources of information for cybersecurity queries from their peers, through interactive workshops with presentations, live demonstrations (e.g. password cracking) and hands-on activities (e.g. phishing test) (REF ICS *Nicholson*).

4.3. Academic significance and international collaborations

Collaborations with tangible outputs – that is, funded collaborative projects, publications and/or patents – include the following geographic regions:

- Africa: Jijel University (*Khelifi*), University of Cape Town (*Sice*), The National Centre for Research and Development, Algeria (*Khelifi*), Stellenbosch University (*Godfrey*);
- Australia: Deakin University (*Anderson, Li*), University of New South Wales (*Godfrey, Wei*), Griffith University (*Vickers*), University of Queensland (*Godfrey*);
- North America: Harvard University (*Godfrey*), Dalhousie University (*Aslam*), University of Alberta (*Chen*), University of Waterloo (*Godfrey*), Simon Fraser University (*Ho*), University of Idaho (*Khan*), Oklahoma State University (*Mao*), University of Washington (*Woo*);
- Asia: Al-Zaytoonah University of Jordan (*Anwar*), Jadavpur University (*Shum*), National University of Singapore (*Belatreche*), Qatar University (*Bouridane*), Swinburne University of Technology (*Issac*), Sichuan University (*Mao*), University of Electronic Science and Technology of China (*Woo*), Yuan Ze University (*Zhang*), Shen Zhen University (*Li, Wei*), North-Eastern Hill University (*Issac*), Shenzhen Institutes of Advanced Technology (*Wei*), National University of Computer and Emerging Sciences, Karachi (*Khelifi, Bouridane*);
- Europe: Trinity College Dublin (*Chen*), Tel Aviv University (*Ho*), Lund University (*Amos*), University of Groningen (*Jin*), Aalborg University (*Mao*), VU University Amsterdam (*Rooksby*),

Nottingham University (*Li*), University of Copenhagen (*Jin*), University of Ulster (*Amos*), University of Luxembourg (*Wei*).

Evidence:

Our partnerships have determined a marked increase in the proportion of journal articles with international co-authors – from 55% in 2014 to 70% in 2020, across 90 countries (data from SciVal March. 2021, outputs with Northumbria address).

Our unit is proactive in its international, multi-institutional collaborative efforts to promote multidisciplinary research, education and professional training on sustainable green solutions.

Example:

The EU Erasmus Mundus gLINK partnership (€3M, PI *Aslam*; <http://www.glink-edu.eu>) comprises 9 European HEIs and 9 Asian HEIs and has enabled the following exchange between developing and developed countries, for collaborative research and development:

- 31 faculty staff members,
- 20 postdoctoral researchers, PhDs,
- 37 Master and 47 undergraduate students.

More than 120 joint research papers were published in journals and conference proceedings. Among the partner institutes, the project also enabled 4 successful funding awards that resulted from collaborations developed through gLINK.

Recently the unit has been awarded capacity-building funding in digital health; the 'Digital Health Monitoring and Care System' funded by the Erasmus+, a Higher Education–International Capacity Building project (€950k, *Aslam* €120k, 2020-2023). Together with colleagues from the UK, EU, Pakistan, Thailand and Mongolia, we are developing innovative education modules for digital health monitoring.

4.3.1. Discipline contributions

Our post-REF2014 strategy, driven by our research clusters and groups, was to increase the number of high-quality papers (Figure 7). The number of journal articles with international co-authors increased by eight folds during this REF period by comparison with REF2014 (source: Scopus). Our **NorSC** research group, which has been one of the leading contributors to the ACM CHI Conference since 2017, evidences how our research is leading global excellence. Furthermore, our increased research output during the current REF cycle is creating academic impact and inspiring commercial innovation; this is true especially of the recent publications cited in patents filed by major companies such as **Samsung**, **Tata**, **Adobe**, and **Aeroflot** (SciVal 2020).

Our research has prompted the delivery of over 30 invited presentations and keynotes. Examples include *Ali* (DICE-IET, 2017, Pakistan), *Woo* (ISGT, 2018, Singapore), *Aslam* (ICDAMT, 2018, Thailand), *Belatreche* (PAIS, 2018, Algeria), *Godfrey* (EMAS, 2019, Germany), *Issac* (EGTET, 2019, India), *Shang* (ISCAM, 2019, China) and *Zhang* (PRML, 2020, China).

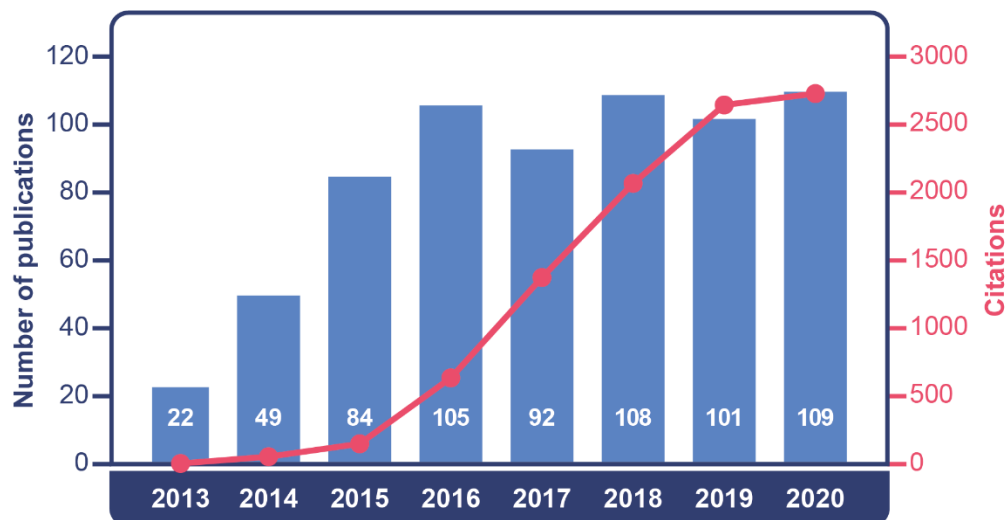


Figure 7. Number of publications and citations in the current REF cycle.

The unit, often with the help of the university's events team for larger meetings, supports staff members in organising events such as conferences and workshops. Representative of our broad multidisciplinary research and of our strategies in tackling global issues, these events have ranged from Threats to Openness in the Digital World (2015, *McLeod*) and Leading into Wellbeing: The Power of Mindsight (2015, *Sice*) to the British Machine Vision Conference (2018, *Mistry, Ho, Godfrey, Yang, Belatreche, Li, Anwar*), Motion, Interaction and Games (2019, *Ho, Mistry, Godfrey, Belatreche. Aslam* (Program Chair), co-organised with Le-Minh (UoA12), and the University of Glasgow IEEE ComSoc 2020 Summer School (a flagship training event of the IEEE), which was attended by over 170 participants from 43 countries.

Staff members contribute substantial expertise across the breadth of our research activities, having peer-reviewed articles for more than 150 journals. These include a diverse range of IEEE journals (e.g. *Transaction on Industrial Informatics*, *Transactions on Wireless Communications*, *IEEE Access*), *Elsevier Neurocomputing*, *Scientific Reports: Nature*, as well as the *Journal of Gerontology* and the *Journal of Internet Medical Research*. Annually, staff in our unit (e.g. *Cecchinato, Rooksby, Warner, Pointon, Vasiliou*) undertake significant reviewing and administrative responsibilities for the major global CHI conference. Our researchers also support the work of funding bodies in reviewing projects for funding. For example, *Amos, Bouridane, Godfrey*, and *Lawson* are full members of the EPSRC peer review college, while *Ho, Issac* and *Anwar* are associate members. *Jin* aids Innovate UK in project reviewing and selection.

Internationally, reviewer examples include *Khelifi* for the Research Foundation – Flanders (FWO) funding organisation.

4.4. Summary

This submission demonstrates a sustained upward trajectory in the research performance of UoA11 since RE2014. This claim is based on a step change in RGCI income (£3.4M) and PGR population (79 awards); the quality and relevance of our research outputs (as indicated by citation metrics); the success of our research strategies, which have enhanced, and will sustain, our environment; and the significant contributions made to the discipline and to relevant user groups and policymakers. Substantial investment in state-of-the-art infrastructure (£7M building) and research facilities, combined with a significant transformation in the breadth and calibre of our staff base, creates a sustainable environment, allowing the unit to tackle current and future societal and scientific challenges.