REF2021

Institution: University of Wolverhampton

Unit of Assessment: 11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

1.1 Introduction

The School of Mathematics and Computer Science is an interdisciplinary School, within the Faculty of Science & Engineering (FSE). It includes researchers with a range of backgrounds including computer science, mathematics, optics, communication systems and electronic engineering. The University of Wolverhampton (UoW) has a long history in delivering Computer Science degree programmes. From the late 50s to early 70s, the Wolverhampton Instrument for Teaching Computation (WITCH) from Harwell was used for teaching computing. However, this was not the case for research in computing and the majority of the academics in computing were not submitted within the UoW REF2014 submission. In recent years, there has been a targeted significant shift towards Computer Science research and clear objectives set to facilitate and encourage high quality research and capacity building in this area, which is reflected in our submission to UoA11 for the first time since 2001.

With the recruitment of a new Head of School of Mathematics and Computer Science towards the end of 2016, a strategy was set up based on employability of graduates and interdisciplinary research. As a consequence, a significant push was made on research-informed teaching (RIT). To achieve its overall strategic vision, it was important for the School to increase its research capacity and capability. This informed the creation of the Digital Innovations and Solutions Centre (DISC) in 2017, as home for all research conducted in computer science and responsible for the development of UoA11. Of the three academic staff from the computer science subject submitted to REF2014, only one is still at UoW. Our UoA11 submission comprises 12 academic staff with significant responsibility for research (12 FTEs), of whom 11 are new to the Unit since 2016 (with 10 of these joining UoW from 2018 onwards). Strategic new appointments have been made to replace those who have left, and include researchers submitting for the first time. Furthermore, since the creation of DISC in 2017 the external income generated by computer science as a Unit has grown from approximately GBP 75,000 per annum to approximately GBP 1m per annum (in terms of income secured).

1.2 Research Objectives and Performance

Figure 1 shows the overall strategic aim and objectives of DISC. DISC will serve to expand the range and reach of engagement of UoW within the field of Digital Technologies as it evolves to become a key underpinning discipline. It will allow UoW to position its assets and capability to respond to both the size of local and national digital opportunities as well as the scale of the challenge facing the digital economy. Consequently, conducting interdisciplinary and collaborative research, which forms a significant element of the grand challenges within the UK Government's Industrial Strategy, aligns with our key objectives. This alignment has informed the research structure of DISC and the formation of the four research themes as illustrated in Figure 2. To that effect, DISC research will impact on many sectors across the economy to create emerging fields. These include Architecture, Mobility, Creative Industries, Health Care and Wellbeing, Business and Finance, Human Dimension of Digital Technologies and Education.

The boundaries between the four research themes are porous, and positively encourage inter-disciplinary research, as well as the collaborative supervision of our postgraduate research (PGR) students. Subsequently, staff may be members of more than one theme. Key academics and researchers at different career stages have been recruited to build capacity within these themes, supported by funding from the University's Research Investment Fund 3 (RIF3). Several support mechanisms were put in place to enhance research outputs, income generation and to generate societal and economic impact. To that effect, over the REF period and more precisely since 2017, a concerted effort has been placed on increasing research capacity and shifting the centre of

gravity towards a grade point average (GPA) of 3*. Since REF2014, an improved research infrastructure and PGR working environment promoting interdisciplinary collaboration has been engendered with the formation of DISC. Strategically, this supports the growth in digital technologies through targeted high quality impactful research and knowledge exchange, enhancing links with industry and businesses. In addition to underpinning the curriculum, the DISC research strategy has focused activities towards the nationally recognised grand challenges and our research is strategically aligned with the UKRI/UK Industrial Strategy, whilst meeting the needs of our local place.
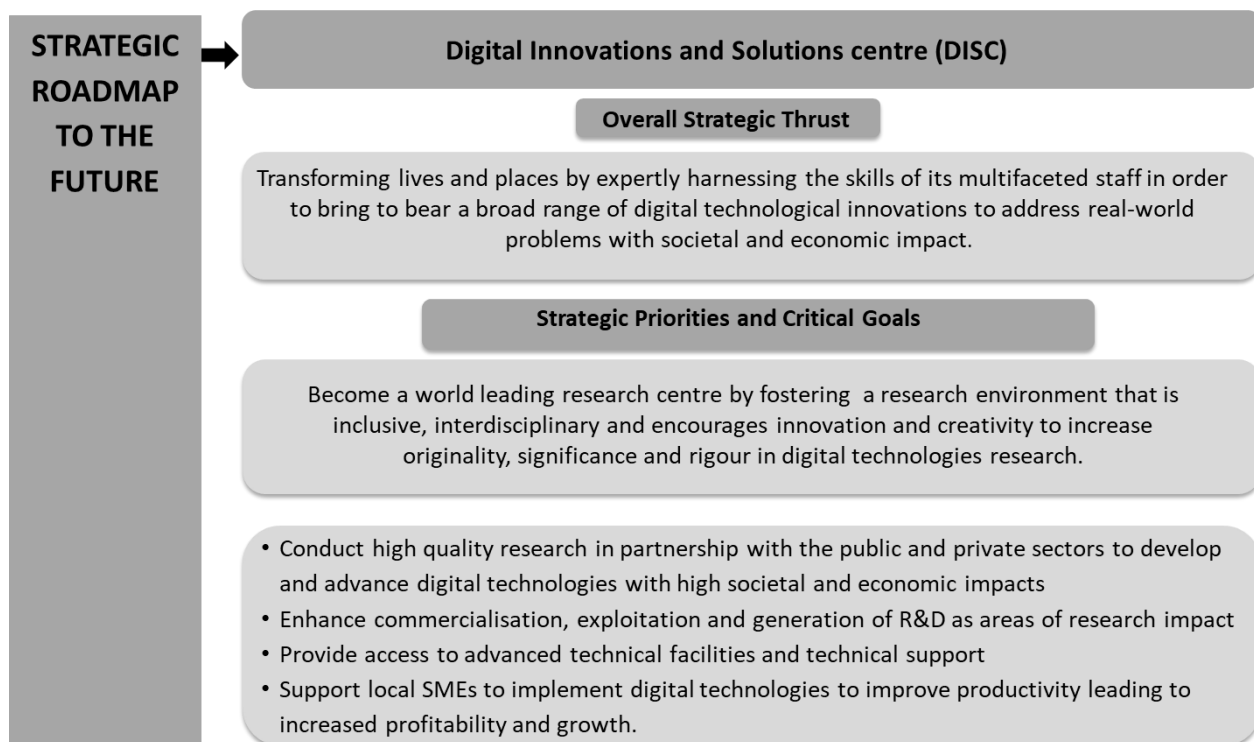
STRATEGIC ROADMAP TO THE FUTURE

Digital Innovations and Solutions centre (DISC)

Overall Strategic Thrust

Transforming lives and places by expertly harnessing the skills of its multifaceted staff in order to bring to bear a broad range of digital technological innovations to address real-world problems with societal and economic impact.

Strategic Priorities and Critical Goals

Become a world leading research centre by fostering a research environment that is inclusive, interdisciplinary and encourages innovation and creativity to increase originality, significance and rigour in digital technologies research.

- Conduct high quality research in partnership with the public and private sectors to develop and advance digital technologies with high societal and economic impacts
- Enhance commercialisation, exploitation and generation of R&D as areas of research impact
- Provide access to advanced technical facilities and technical support
- Support local SMEs to implement digital technologies to improve productivity leading to increased profitability and growth.

Figure 1: DISC research strategic aims

Research Themes	Cybersecurity	Future Networks & Autonomous Systems	Immersive Technologies	Artificial Intelligence and Data Science
Research Priorities	• Systems & network security • Digital forensics & incident response • Data & privacy • Risk management & modelling	• IoT/Sensor Technologies • Network and wireless communication systems	• Enhancement of the Immersive Economy – VR/AR • Creative Industries • Digital Health - Medical Visualisation	• Developing the Data based economy • AI and data analytics for health and social care, sustainable infrastructure, construction and manufacturing.

ENHANCING RESEARCH CAPACITY

Quality and Compliance	Commercialisation	Scientific development	Pedagogy

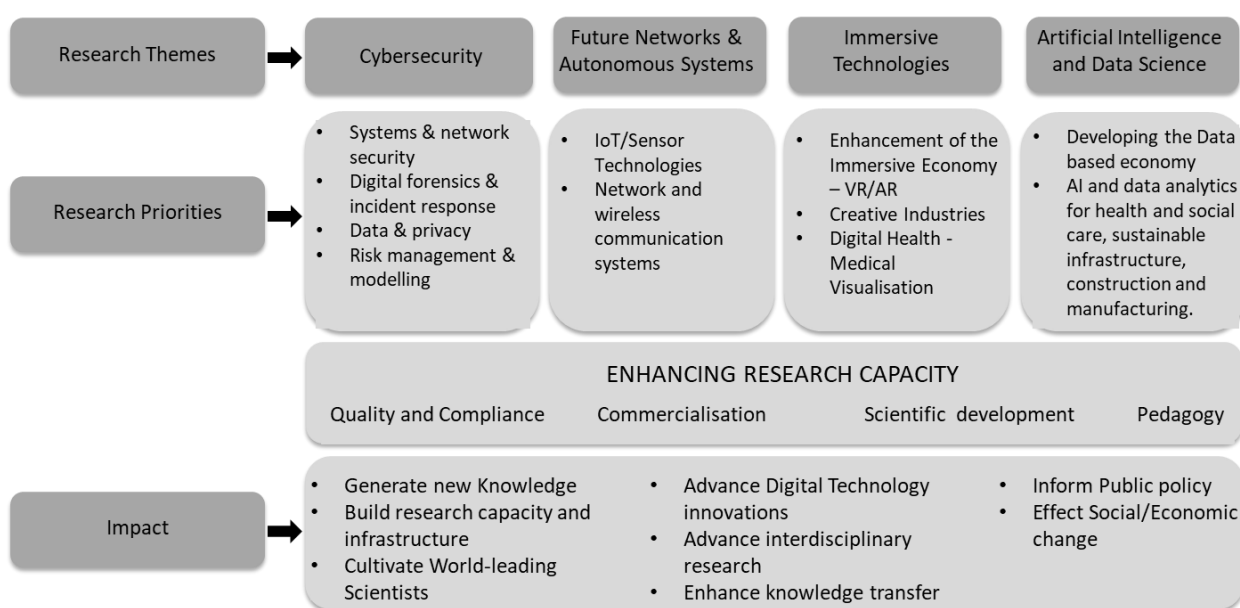| Impact | • Generate new Knowledge
• Build research capacity and infrastructure
• Cultivate World-leading Scientists | • Advance Digital Technology innovations
• Advance interdisciplinary research
• Enhance knowledge transfer | • Inform Public policy
• Effect Social/Economic change |

Figure 2: Research themes within DISC

To support the overall DISC vision and strategy to transform lives and places, a concerted effort began by investigating the local regional needs for digital skills, support and innovation. As a consequence, DISC benefited from initial funding in 2017 from the Marches Local Enterprise Partnership (LEP) of GBP 20k to conduct a feasibility study to identify the needs and volume of digital businesses in the Marches region. This was followed by funding from the European Research Development Fund (ERDF) in the Marches of GBP 1.29M for a Digital Enterprise project (under the name SOLVD) that is being delivered in partnership between UoW and the local authority. The funding from the ERDF with contributions from UoW of GBP 708k and the Telford & Wrekin Council of GBP 73k is targeted to increase the research capacity of UoW in the digital technology field by recruiting specialist staff in digital technology as well as business co-ordinators and advisors to ensure effective business support and knowledge exchange between companies and the UoW (https://www.wlv.ac.uk/business-services/funding-and-support/solvd/). As such, SOLVD has supported DISC, and shall continue into the next REF cycle, in achieving 2 of its key objectives: i) collaborative research and; ii) enhancing our regional engagements.

DISC as a centre will serve to expand the range and reach of engagement of UoW within the field of Digital Technologies as it evolves to become a key underpinning subject for multiple projects. Through the establishment of DISC, UoW will position itself to respond to the opportunities and challenges of the digital economy. Consequently, this strategic plan will continue to underpin the next REF cycle.

The 4 research themes are now described:

1.2.1 Cybersecurity

The cybersecurity research theme looks to respond to the continued growth and importance of the digital economy, which have large potential benefits to society but at the same time create new risks and challenges. The fast-changing nature of the risks and opportunities means that future policy and practice must be informed by excellent research. Through collaboration with businesses and the public sector, DISC will ensure that new ideas are rapidly translated into new products and services that benefit society as part of its main strategic aim (see Figure 1). Furthermore, and in response to national policy and opportunities emerging as part of the Midlands Engine, UoW has made since 2016, in this REF cycle and continuing into the next cycle, a major investment in Research, Development and Innovation engagement in academic areas related to cybersecurity. For example, in partnership with the Herefordshire County Council, UoW has set up the Cyber Quarter - the Midlands Centre for Cyber Security based on the Skylon Park, Enterprise Zone in Hereford. This is a GBP 9M project which forms an industry facing arm to support business and the public sector against the continued threat of cyber-attacks to enhance their resilience and also to encourage collaboration through our research and development activities.

An important part of the DISC strategic objective is the commercialisation and exploitation of R&D. To that effect, members of DISC have been active in exploiting opportunities which led to funding from Innovate UK, as part of the Department of Digital, Culture, Media and Sport's (DCMS) Cyber Security Academic Start-ups Accelerator Programme, to develop University spin-offs in the area of cybersecurity. One such spin-off is engaged in the development of an intelligent decentralised data management platform based on a patented algorithm that utilises smart ledgers for electronically regulating data sharing within a supply-chain. The technology reduces incident response times and time to access data, avoids single points of attacks by securely distributing data across different nodes, and provides immutable logs and audit trail with "always-on" chain of custody.

All of the above activities have set the base for the cybersecurity theme to grow its research and business engagement as well as supporting RIT to reduce the skills shortages in cybersecurity. Our aim is to enhance the standing and ability of DISC to support cyber research and subsequently to develop and sustain a leading world class cybersecurity research theme that produces research activities and outputs to influence cybersecurity policy and decision making to ensure the protection and resilience of businesses and individuals in cyberspace.

1.2.2. Future Networks & Autonomous Systems

Our vision within the Future Networks & Autonomous Systems theme is to be one of the major contributors towards the evolution of next generation communication networks in terms of both fundamental and applied research. Network autonomy as well as reliability and ultra-low-latency are the major foci of the developing research and the members within this theme aim to provide world-leading research contributions to the future generations of telecommunication networks.

Considering DISC's objectives to conduct collaborative research and enhance its regional engagement, members have worked with O2/Telefonica to secure funding to launch the UK's first 5G accelerators in Birmingham, Coventry and Wolverhampton. The project is delivering the UK's first region-wide 5G testbed, backed by the DCMS and the West Midlands Combined Authority (WMCA). As part of the bid, the 3 5G accelerator facilities will comprise a centrally-located office and demonstration spaces with access to cutting-edge 5G technology, both indoors and outdoors, extending several kilometres.

The true potential for 5G has not been fully exploited and this project will allow us to conduct research in this field to enhance the 5G technology and its applications. The technology will enable the realisation of the smart and sustainable cities concept by developing transport products and services to combat road congestion, reduce emissions, highlight parking space availability, maintain infrastructure, and improve traveller experience.

1.2.3 Immersive Technologies

Immersive technologies such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and Haptics have been growing at a fast pace in recent years and are transforming lives by bringing virtual environments with users' sight, sound and touch. DISC members have been active in developing applications of immersive technologies in various sectors such as creative industries, healthcare and training. One of these applications involves the use of VR and AR technologies to improving the sight capabilities of persons with severe visual disabilities. Our research, which is partly funded by the Beacon Centre for the Blind, looks to identify the features and characteristics of VR devices that enable improved visual acuity, the vision conditions where improvement is most profound, and how a VR device can be modified to enhance the benefits. Some of the future work is looking at using OLED displays to develop a curved screen to increase the field of view.

The other application is to address training where our research team has developed a real-time immersive and natural hand-based interaction system using optical sensors and motion controllers. In this research, we explored how hand-based input mechanisms might offer more natural approaches to VR interaction that are more intuitive and immersive than traditional motion controller approaches. One of the applications of the system that has been tested is a Virtual Laboratory which enables students to conduct chemical experimentations in a safe environment.

However, the main drawback of current VR systems is that they are based on stereoscopic imaging technology which is known to cause eye fatigue/strain and motion sickness. This has been known for many years and there are reports now calling for more research on the long-term effects of VR use. To remedy these shortcomings, our research is focused on the next generation of more sophisticated depth-illusion technologies. The ReCreate3D (Redefining Creativity through Enhanced Immersive 3D Experiences and Tools) project is working towards the development of a fully immersive augmented reality system based on the light field imaging principles that offer multi-user realistic and fatigue-free immersive experience without the need of wearing specific eyewear. ReCreate3D has the potential to provide a significant impact into healthcare such as surgical simulation training, minimally invasive surgeries and diagnostic imaging, and into creative industries such as cultural heritage and audiences of the future.

1.2.4 Artificial Intelligence and Data Science

Members of DISC are pioneering conscious multisensory integration (CMI) research. The CMI research sheds light on a completely new perspective on how the brain integrates the multisensory information at the cellular level, and the basic processes driving different conscious states. It creates a paradigm shift in our understanding of the fundamental intracellular mechanisms responsible for producing coherent thoughts, perceptions, and actions, which are well-adapted to different situations and long-term goals. The CMI lab in DISC is exploring and exploiting the potential of CMI theory to bring evidenced positive change to a number of areas of economic and social importance, including multisensory human-computer interface, neurological disorders, emotion-sensitive robots, and context-aware 5G-IoT. The CMI research has the potential to deliver a step-change in how 'healthcare' and 'automation' could be delivered in future. The CMI theory/ research has led to the following 2 projects:

- For the first time, attempts to explore the development of a truly cognitively-inspired and personalised, privacy-preserving 5G IoT-enabled multimodal (MM) hearing aids (HAs) has led to AV-COGMHEAR. The aim of this project is to address the low uptake of existing audio-only (A-only) HAs, which remain largely ineffective in restoring intelligibility in environments where overwhelming noise is present. The proposed MM HA research is providing the UK with a timely opportunity to improve HA uptake, reduce NHS hearing-loss cost (~GBP 450M/ year), and gain a leading position in the future MM HA industry. The work is conducted in collaboration with University of Edinburgh, University of Glasgow, Edinburgh Napier University, University of Manchester and University of Nottingham.

- Mindful, Energy-Efficient Computing and Electronic Systems (MEECES), for the first time, attempts to seamlessly mimic the fundamental structure and function of the pyramidal cell (using low-power fault-tolerant microelectronics digital/analogue circuits) to acquire energy-efficient cooperative computing. MEECES promises to provide the research community with a new mindful processing architecture (MPA) for high-performance massively parallel computing, addressing the key research challenges in brain inspired HPC. The proposed project provides a timely and unique opportunity for the UK to gain a leading position in exploiting the cellular level contextual MM signal processing for highly energy-efficient computing platforms. This work is conducted in collaboration with University of Edinburgh, NASA, and University of Plymouth.

In collaboration with the Royal Wolverhampton NHS Trust, members of DISC are investigating the use of machine learning in the diagnosis of anaemia in pregnancy. This takes into account interacting biological variables, such as haematological measurements and the characteristics of the woman's physiological changes associated with pregnancy and gestation, and is based upon function outcomes. Risk assessment and assignment made with the diagnosis, is required to be updated throughout pregnancy and adjusted in line with the dynamic changes taking place during the pregnancy.

DISC is also a member of the Exercise in Disease manaGement and rEhabilitation (EDGE) project funded by the UoW's Research Investment Fund (RIF4). The project aims to develop a multidisciplinary prehabilitation/rehabilitation service within UoW, informed by end-users and governed by a robust World Health Organisation (WHO) implementation framework. DISC's input to the EDGE project is around developing AI based clinical-decision making algorithms.

Furthermore, members of DISC are working on multimodal access and retrieval of heterogeneous data to aid users in discovering relevant information. The aim is to create future search engine technologies by means of artificial intelligence and machine learning to be applied in a variety of domains such as scholarly search, enterprise search, digital humanities, healthcare and cyberstalking.

1.3 Impact

The aim of DISC is to enhance the capacity for impactful research through its strategic objectives (see Figure 1) by engaging with industry and the public sector to:

(i)   drive commercialisation, exploitation and generation of R&D
(ii)   support local SMEs to implement digital technologies to improve productivity leading to increased profitability and growth.

Although DISC has been in existence since 2017, in a very short period our Unit has successfully developed 2 impact case studies which align to our strategic vision, themed under 'Cybersecurity' and 'Digital Innovations'.

Fundamental to our research strategy are real world applications of our research with societal and economic impact. This has enabled us to deliver the outputs associated with the funding received from the Marches LEP and ERDF. These projects allowed us to support numerous businesses to implement Digital Technologies through business assists. In addition, the drive towards RIT has played a significant role in developing both impact case studies. These include development of research informed training programmes in Cybersecurity through the initiation in 2017 of the Cyber Industry Curriculum (CIC) project supported by funding from both the Office for Students (OfS) and industry. This allowed us to provide support to businesses and the public sector, both nationally and internationally, through bespoke training delivered to practitioners. Furthermore, one other key objective in our research strategy is to enhance commercialisation, exploitation and generation of R&D as areas of research impact. This has led to creation of three spin-out companies, which form part of the impact case studies.

DISC will continue to provide industry and businesses access to cutting edge digital technologies to generate economic growth by facilitating interaction between stakeholders supporting enterprise, new businesses and job creation. As a result, the economic and social impact of DISC will continue beyond this REF reporting period.

1.4 Open Research

We aim to make research available on UoW's open access repository (WIRE), above and beyond compliance requirements for REF. This includes support for Gold Open Access (OA), for example we have supported GOLD OA for publications in IEEE Access, Frontiers in Computational Neuroscience, International Journal of Computer Vision, Scientific Reports by Nature Research, IEEE Transactions on Industrial Electronics. We use Quality-Related (QR) funding to that end, and focus support for OA on early career researchers (ECRs) who have limited external income from research grants.

Furthermore, to drive an open research environment we have made software tools derived from our research available as open source applications to researchers, developers, beginners and the wider community to experiment and to enable further advances and applications of the technology. An example of these is the PlenoptiSign software app which has been developed as an open-source software tool for geometry estimation of a light field captured by a Standard Plenoptic Camera. PlenoptiSign is implemented as a Python software package to assist a growing community of users in an experimental or prototyping stage of a plenoptic imaging system. The underpinning research was published in an open source journal and the software is hosted on an open access repository on GitHub.

1.5 Research Integrity

The research conducted within DISC has impact on the lives of people whether through the use of artificial intelligence and data analytics in health, the online protection of vulnerable adults and children or the use of immersive technologies to help visually impaired people. Consequently, it is important that DISC operates within a framework of research integrity, and ensures that research

is conducted according to appropriate ethical, legal, and professional frameworks, obligations and standards, including the Concordat to Support Research Integrity. The four themes in our research structure are led by experienced academics, providing leadership in both research integrity and research management and promote the principles of the research integrity Concordat.

Within DISC, research proposals are submitted for ethical approval and scrutinised by the School of Mathematics and Computer Science Ethics Panel. A report is then submitted to the Faculty of Science and Engineering (FSE) Ethics Committee for monitoring and final approval. All student research projects are subject to scrutiny in the same way as staff projects, thus exposing students to the principles of ethics at an early stage of their career through constructive feedback.

2. People

2.1 Staff
The Unit is made of 12 academics, and all but one (Buckley) were recruited in this REF period. The recruitment strategy focused on building the subject's research and teaching capacity and to that end we prioritised recruitment of senior research staff. This was followed by recruitments of early and mid-career staff who had the potential for moving into leadership positions. To be competitive in the labour market and support career development, we recruited to permanent posts only. Aggoun was appointed at the end of 2016 as Head of School, followed by appointments of a further 10 academics with significant responsibility for research: Pillai as professor in Cybersecurity, Patwary as professor in Telecommunications, Al-Khateeb as senior lecturer (SL promoted to reader in Cybersecurity in 2020), Ahsan as lecturer in Artificial Intelligence (AI) (promoted to reader in AI in 2020), Kbaier and Al-Shakarchi appointed as SLs. Early stage researchers that we recruited include Gascoyne, Cabukoglu, Bottarelli and Ersotelos. The academic staff are supported by several project managers and technical support staff.

2.1.1 Staff Development Strategy

Fully aligned with UoW policy, DISC implements the Concordat for Supporting the Career Development of Researchers at all stages. Being a new Unit, we had to recruit a range of staff at different levels of their academic careers but also to encourage existing staff who do not have significant responsibility for research to engage in research as part of strategic staff development and progression framework.

A priority is given to support the development of early career researchers (ECR), by providing protected research time in their workload allowance and assigning a mentor to support their publications strategy, funding bids, and developing an impact profile. Since 2006, the UoW has operated an Early Career Award Scheme (ERAS) which annually awards 10 grants of up to GBP 5,000 alongside a tailored mentoring and action learning programme to facilitate the research career development of ECRs. Over this REF reporting period, our Unit benefited from two ERAS awards. In line with our commitment to career progression and development of academics with significant responsibility for research, 3 members of academic staff are now registered to pursue a PhD in Immersive Technologies, Artificial Intelligence and Cybersecurity respectively. Following support with leadership development, in 2020 two academics were promoted to readership positions.

While ECRs receive special focus, DISC administers a Research Mentoring Scheme for researchers at all stages of their careers. Mentoring is designed to be a supportive approach to furthering individual career ambitions, helping staff set annual and longer-term objectives for enhancing the quality of publications, public engagement and impact projects, and developing individual and group bidding strategies for external funding. Mentoring meetings follow a bi-annual self-audit of individual research activity, and mentors continue to provide support at other times. Agreed individual research plans feed back into strategic planning for research support, including protected research time.

All staff benefit from a Faculty-wide mentoring scheme and from rigorous Faculty-level annual appraisal. The research activities of all staff in DISC are captured by Symplectic Elements, a research information management system. Records include new external funding awards, outputs, postgraduate supervision and internal service, which in turn inform the annual appraisal.

2.1.1 Recruitment Strategy

In the last 4 years, emphasis has been placed on bringing our research and educational provision more closely together, so that all our all students benefit from RIT for greater societal benefit. To deliver this objective it was important that we increase our research capacity/capability both in terms of human resource and research activities at the 3*/4* levels. Our recruitment strategy has been to balance senior with early stage research appointments, while carefully considering fit with our research themes and subject disciplinary coverage. Senior appointments develop depth and provide continuity in research and subject leadership. The increase of academic staff with significant responsibility for research is being achieved through staff development and recruitment of high calibre academic staff through replacement posts and the University's research investment fund (RIF). RIF is an initiative which competitively allocates GBP 6M over a 3-year period to support research infrastructure and staff. Over this REF period, DISC used the RIF funding to recruit of a professor and a reader in Cybersecurity, and funded academic staff's research time to accelerate and enhance their research activities. As mentioned in the introduction 11 of 12 academic staff in the Unit joined UoW from 2016 (and 10 of the staff in the Unit joined from 2018). More recently, 2 new readers in Data Science have been recruited but joined after the 31 July 2020.

2.2 Research Students

2.2.1 Recruitment and Studentships

Data show that 30% of our 2019/20 postgraduate taught students have previously studied at undergraduate level at the UoW, illustrating that our students return to us for further study. Data also show that 42.9% of our 2017/18 and 2018/19 full-time undergraduate students came from a Black, Asian and Minority Ethnic (BAME) background compared to 17.7% for the sector, with 63.4% female compared to a sector average of 53.9%. Hence, an important part of our strategy for increasing PhD recruitment is to encourage our undergraduate and postgraduate taught students to progress to research degree programmes. All our students are offered a 20% student discount towards their PhD fees, and are encouraged to take an active part in DISC research seminars, workshops, public lectures, and conferences alongside their PGR student compeers.

It is important to widen our recruitment reach for PhD students and to support this, the Faculty offers annually 20 fee-waived studentships for home students wishing to pursue a PhD programme. The Faculty also provides PhD studentships match-funding for externally funded projects. We also operate 50/50 funding of PhD studentships with industry partners.

Since 2014, 6 PhD students have graduated from DISC in computer science and as of December 2020, DISC has 22 PGR students registered to study towards a PhD degree. All recruited PhD students will pursue research in one of the 4 research themes identified in Figure 2. To increase the PGR students' employability, this year we introduced the Student Transition Teachers (STT) scheme enabling students to work as assistant teachers on 0.6FTE while reading for PhD for the remaining 0.4FTE. DISC is the beneficiary of 2 STTs, who are pursuing a PhD in AI and Data Science.

2.2.2 Research Skills Training

All PGR students in DISC have membership of the UoW's Doctoral College (DC). The DC provides a comprehensive and holistic generic Postgraduate Researchers' Development Programme and works in collaboration with other UoW services, including Careers and Employability, Learning Information Services (both of which have dedicated PGR Advisors) and the Students Union to

enhance the postgraduate experience and encourage a vibrant research student community at UoW.

The Postgraduate Researchers' Development Programme, which is delivered throughout the academic year, provides face-to-face and online workshops (fully online since March 2020). It is mapped to the Vitae Researcher Development Framework. The PGRs Development Programme is supported and enhanced by additional initiatives that include Start Right (focusing on early stages of doctoral study), Writing-up and Accessing Professions (focusing on doctoral completion and transition to the world of work), and Prepare to Teach sessions.

The DC research skills training is supplemented by subject-related training within DISC, as outlined below.

2.2.3 Monitoring and Support

All PGRs in DISC are supervised by a team of researchers who are specifically chosen for their differing complementary supervisory expertise and sets of research skills in order to optimise support for PGRs. The 12 submitted academics to the UoA are all involved in PGR supervision. The Director of Studies (DoS) is the primary supervisor and is supported by additional members of staff with appropriate subject knowledge and supervisory experience. New members of staff undergo a programme of research supervisor training and all supervisors are required to undergo periodic refresher sessions. The supervisory team provides an opportunity for less experienced members of staff to develop and hone their supervisory skills. The supervisory team meets with PGR students at least once a month (FT) or bi-monthly (PT). Each student participates in the Annual Progress Review process in which two independent academics assess their progress in data gathering and primary research; personal skills development; and research dissemination and impact over the preceding 12 months.

We support our students by engaging them in industry partnerships directly, by building their confidence via professional networks, and showcasing their talent at conferences, seminars and workshops, and inspiring the next generation of researchers by PGRs' involvement in teaching. In July 2018, a group of PGR students attended a daylong conference at Barclays Bank Radbroke Hall Technology Centre. In both 2018 and 2019 our students took part in the three-day Guide SHARE Europe (GSE) conference, sponsored by the hosts. DISC was also an academic partner for the CodeMesh 2018 conference in London, and students attended the conference via sponsored places. The number of students from all levels of study attending the CodeMesh 2019 has increased significantly and DISC contributed GBP6,000 towards the conference fees. In October 2018, the UoW hosted an IBM workshop on Blockchain Technology where our students and industry professionals developed practical demonstrations of this new technology. In December, 2018 we joined the Linux Foundation and the Open Mainframe Project enabling collaboration with industry partners and access to leading edge technologies for our students. Furthermore, in order to improve the experience and raise the profile of our female students, we actively supported participation in the British Computer Society Lovelace Colloquium.

More recently a group of our students took part in the IBM Developer 2020 Call for Code University Edition Finalists (https://developer.ibm.com/blogs/call-for-code-university-finalists/). The team of UoW students finished runners up in this international developer initiative focused on applying technology to solve the world's biggest challenges including climate change and COVID-19 (https://www.wlv.ac.uk/news-and-events/latest-news/2020/october-2020/student-foodbank-idea-bags-second-place-in-global-technology-competition.php). Their project LUPE (Lockdown Use Purchasing Environment) used the IBM Blockchain and Kybernetes Cluster technologies to provide a straightforward way for small businesses to continue to find customers digitally in the local community — and where there is unsold food, offer a way for that food to be distributed to local charities and food banks.

PGR students are accommodated in the Faculty's postgraduate space, with desks, networked PCs, and informal meeting spaces. All PGRs have access to specialist workshop areas for

experimental work. Further, the Mathematics Support Centre administered by staff from the School is highly valued by the Computer Science students at all levels where individual or small group support is available. As well as physical library resources, the UoW Learning Centre also provides PGRs with academic skills support via the Skills for Learning programme. PGR students on campus can attend workshops or ask for 1-to-1 help on a range of skills such as academic writing and referencing. PGR students can also access a range of online skills material at: www.wlv.ac.uk/lib/skills. The UoW Student Support website offers advice on a variety of matters (careers, counselling, student union advice). PGR students themselves have set up a Doctoral Student Society, which organises research-related events such as writing retreats as well as social engagements.

2.3 Equality and Diversity

DISC is a firm supporter of the University of Wolverhampton strategy which aims to cement our position as the University of Opportunity and demonstrates our purpose of developing people and place. As such, we offer students, including PGRs, from a wide range of backgrounds the chance to benefit from Higher Education, and the success of all of those who choose to work, study and research with us is our priority.

Equality, diversity and inclusion (EDI) are taken into account at all stages of staffing processes. Recruitment panels for staff and PGR students aim for gender and ethnic diversity, but all consisted of at least one female and one member from the Black, Asian and Minority Ethnic (BAME) community. DISC has 12 staff with significant responsibility for research (12FTEs), and 75% (9FTEs) of staff are from the BAME community, of whom two are female. All senior research staff (professors and readers) identify as BAME.

However, only 17% of submitted staff are female, and there are no women at professoriate level in DISC. In order to address this, the School of Mathematics and Computer Science appointed an Athena SWAN Lead with the target of achieving gender parity in readers and a ratio of 30:70 in the DISC professoriate by 2025. As part of the Faculty's Gender Equality Action plan, workload allocation, supervisory team compositions and participation in research funding bid teams are monitored for gender diversity, to support 'growing our own talent'. In the last three years, DISC recruited three female academics with significant responsibility for research, two of whom at SL and L levels are participating in the REF 2021 submission. The third is a reader who joined DISC after the REF staff census date of 31st July 2020 and is not included in this REF cycle.

3. Income, infrastructure and facilities

3.1 Research Income

The DISC core strategy of disseminating research expertise through collaboration with local communities and with public, private and third sector bodies has also informed its strategy for grant capture – a focus on mutually-beneficial, collaborative projects which has proven to be successful in the current cycle. Prior to 2017, most of the research funding was from Knowledge Transfer Partnership (KTP) programmes. Since 2017, the emphasis is to widen the sources of research funding to improve sustainability.

DISC has benefitted from the ERDF funding of GBP 1.29M plus GBP 73k from the Telford & Wrekin council to setup SOLVD, which is a new initiative between UoW and Telford & Wrekin Council to improve knowledge and skills for the digital economy in the region, to improve productivity and profitability of local companies. SOLVD also provides opportunities for project collaboration from which to launch funding bids.

DISC is co-leading a GBP 3.2M EPSRC research project that aims to develop multimodal hearing aids designed to autonomously adapt to their surroundings. DISC received GBP 394k for its share of project from EPSRC as part of the Transformative Healthcare Technologies for 2050 programme. The project will provide the UK with a timely opportunity to improve hearing aid

uptake, reduce NHS costs, and gain a leading position in the future multimodal hearing aid industry.

DISC were also beneficiaries of Innovate UK funding as part of the DCMS (Department of Digital, Culture, Media and Sport) Cyber Security Academic Start-ups Accelerator Programme to develop university spin-offs in the area of cyber security. Under this scheme, DISC was awarded a total of GBP 309k for 3 separate projects to setup spin-off companies. DISC has been successful in securing funding in 3 consecutive rounds of the programme and setup 3 spin outs: *Cydon Ltd* (https://www.cydon.co.uk/), an intelligent data management system; *OnlynShield Ltd* (https://www.onlynshield.co.uk/), which provides a safer internet surfing for children through the development of an intelligent safeguarding software platform and a child-centred shield against harmful content and communications; and *CyberMIND Technology Ltd* (https://cybermindtech.com/), which provides an Artificial Intelligence-based platform helping Cyber Security professionals detect, predict and manage stress.

DISC is a member of the consortium led by O2/Telfonica which is setting up the UK's first 5G accelerators in Birmingham, Coventry and Wolverhampton. The project is funded by WM5G, which is the organisation responsible for delivering the UK's first region-wide 5G testbed, backed by DCMS and the West Midlands Combined Authority (WMCA). In addition to receiving state-of-the-art 5G infrastructure, DISC will receive GBP 60k per annum to be reinvested to fund PhD studentships in the area of 5G technology.

As part of its research informed learning strategy, DISC has been the beneficiary of 2 separate sets of funding by OfS to provide MSc programmes and hence increase the potential of recruiting PhD students to DISC. These projects are,
  (i)   Cybersecurity Industry Curriculum (CIC) which received GBP 192k funding from OfS and GBP 480k in-kind funding from partners to train the next generation of cybersecurity professionals.
  (ii)   Intelligent Data (iData) which received GBP 720k funding from OfS and over GBP 1M in-kind support from partners to respond to this surge in demand for skilled individuals in AI and Data Science, but also to address the lack of diversity in these subject areas.

3.2 Organisational Infrastructure and Research Facilities Supporting Research and Impact

The UoW has a strong research infrastructure including a Project Support Office (PSO) that provides pre- and post-award management support. All projects emanating from DISC are first discussed with PSO to seek advice and guidance, including support with the development of the project application and support through the submission process. The team in DISC has been engaged extensively with the UoW Impact Officers who provided guidance and advice around the development of the impact case studies, but also the wider impact strategy for DISC and associated researcher development, including IP protection.

UoW has invested significant resources on research infrastructure to support research growth in Computer Science. In addition to the RIF3 funding which enabled support for the cybersecurity theme, UoW is investing close to GBP 200k to refurbish the space in the University of Wolverhampton's Science Park as the home of DISC (see Figure 3). This involves the creation of 4 state of the art laboratories, one for each theme on the ground floor, as well as a space for PhD students and postdoctoral research assistants on the second floor. This will provide a vibrant space for exchange of ideas, development of research bids and showcase research projects.

Figure 3: Space earmarked for DISC

Furthermore, the Science Park will be the base for the 5G accelerator led by O2/Telefonica and as a result DISC will have access to the state of the art 5G technology, enabling DISC members to conduct high quality research in the field of wireless communication technologies and applications.

The Cyber Quarter - Midlands Centre for Cyber Security (see Figure 4) will provide a step change in the research capability of UoW in the field of cybersecurity. It provides an opportunity to significantly reshape the computing education, including PGR and research-informed professional training, and provides employment opportunities for UoW graduates and a fertile ground for knowledge exchange. It will differentiate UoW from other universities operating in the field of cyber and will bring about growth in research, impact, income generation. It addresses the decline in demand witnessed in recent years in computer science by providing a specialist focus.
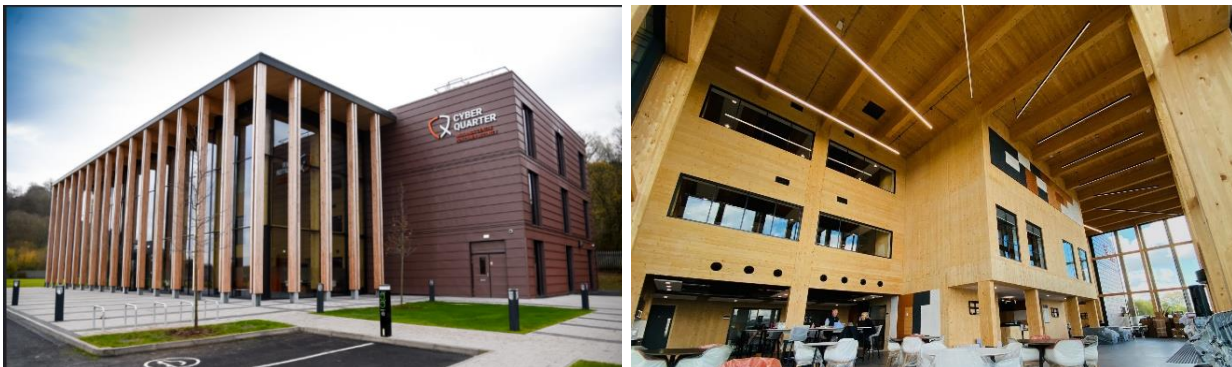

Figure 4: Snapshots of the new Cyber Quarter - the Midlands Centre for Cyber Security

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

The material in this section is evidence of the work of DISC regionally, nationally and internationally. The activity discussed shows clearly how vital and lively the work of the DISC is and how it evidences our collaborative ethos. We value our commitment to societal and economic impact and contribution to the successes and sustainability of the digital economy, both in the UK and worldwide. The themes' leaders work with all staff in DISC and across UoW to maximise synergies and interdisciplinary reach of our research activities to increase impact.

4.1 Research Collaborations, Networks and Partnerships

Conducting high quality research in partnership with the public and private sectors to develop and advance digital technologies with high societal and economic impacts is a key objective of our overall strategy. Cyber Quarter and SOLVD projects are providing opportunities to build partnerships with regional businesses and local authorities.

The SOLVD project is working with regional businesses and helping them to develop novel digital solutions. Our intent beyond this REF period is to deliver a number of grand challenges (defined

with the help of large organisations) and bring SMEs together alongside the UoW research base to develop new and innovative digital solutions. The Cyber Quarter project offers business engagement facilities and is catering to industry needs of cyber R&D, testing and training. Both projects have engaged with over 150 businesses in Shropshire, highlighting the skills needs of the employers and hence tailoring the programmes to increase the skill set and meet the employers' demand. We see these collaborations and partnerships as a platform from which to launch future research funding bids to further our contributions to the success of the digital economy.

As part of our co-pioneering world's first audio-visual hearing-aid technology, we have strong relationship with the hearing aid (HA) industry and end-users, including clinical and wider industrial application. For example:

(i)   Global HA manufacturer Sonova is acting as lead liaison for planned engagements with the wider HA industry and future stakeholders, including standardisation bodies. Sonova is also providing access to end users and focus groups, through their subsidiary, Bruckoff Smart Hearing Glass (Germany).

(ii)   Digital Health & Care Institute (DHI) (a Scottish innovation centre) provides access to a world-class network of health and social care providers, and clinical prototype demonstration environments.

(iii)   Deaf Scotland (DS) and Action on Hearing Loss (AoHL [the leading, charity-run organisations for deaf issues in Scotland] help to define end-user engagement, needs, and expectations, and also facilitate future engagement with new stakeholders (iv) Nokia/Bell Labs, Alpha Data, and the Data Lab (Scottish innovation centre) facilitate new industrial engagements to exploit step advances in real-time AV processing, privacy-preserving AI, self-organising 5G (and beyond), chip design, flexible electronics and smart care home applications.

Similarly, as part of our pioneering pyramidal cell driven high performance computing (HPC) mindful processing architecture (MPA) technology - Mindful, Energy-Efficient Computing and Electronic Systems (MEECES), we are working closely with:

(i)   NASA-JPL to apply MEECES technology for the development of the next-generation of autonomous Mars Rovers.

(ii)   Brain Research and Imagining Centre (BRIC) to develop an artificial brain for alternative cost-effective behavioural and cognitive testing procedures.

(iii)   Alpha Data for the (proof-of-concept) exploratory configurable-circuit implementation of the proposed MPA.

(iv)   Scottish Microelectronics Centre (SMC) for integration and microfabrication of MPA.

We are collaborating with the Royal Wolverhampton NHS Trust to develop innovative technology solutions for healthcare needs. For example, in collaboration with the diabetic centre at the trust, the DISC team has developed a non-invasive device for continuous monitoring of glucose level in the blood. Further collaborative work with the trust involves the development of new AI algorithms to assist in the diagnosis of anaemia in pregnancy by taking into account various interacting biological variables.

In order to develop future immersive technologies enabling fatigue free viewing by many independently of the viewer's position and without the need for head gear, we are collaborating with national and international institutions and businesses. We have been working towards advance light field imaging as the enabling technology allowing capture and replay of full 3D scenes in live outdoor events and settings. Some of this work is conducted in collaboration with ARRI Cine Technik GmbH & Co KG, Munich, Germany, a leading motion picture manufacturer to develop the first single aperture 3D camera based on light field imaging. Another advantage of light field imaging is the possibility it offers to refocus in post-production, hence removing the need for retakes of the scenes and subsequently reducing the cost of visual content production. Collaboration with Washington University allowed the design and implementation of real-time refocusing technology. Collaboration with Royal Holloway University and Southampton University focusses on the development of metamaterial-based optical elements to provide a wide viewing angle of the light field vision system.

4.2 Indicators of Wider Influence

Staff within DISC play important roles in national and international networks reflecting our research interests.

4.2.1 Editorial Roles

A number of academic staff in DISC have editorship roles. For example, Pillai has acted as guest editor of the *IEEE Transaction on Aerospace and Electronic Systems* (2015-2018) and Aggoun acted as guest editor of *IEEE/OSA Journal of Display Technology*. Other editorships/guest editorships include Springer *Cognitive Computation*, *Frontiers in Blockchain*, *Fourth Industrial Revolution*, *Blockchain in Industry*, *Sensors Journal* as well as area editor of *KSII Transactions on Internet and Information Systems*.

4.2.2 Prizes

Aggoun has received the 2017 Premium Award for Best Paper in the Institute of Engineering and Technology (IET) Biometrics and the best paper at the IEEE Broadcast Symposium (2013). Al-Khateeb is working with RMIT University Australia, in joint research supervision which led to a Best Paper Award at the 2018 Cyber Forensic and Security International Conference.

4.2.3 Fellowships and Memberships

Ahsan holds fellowships with Howard Brain Sciences Foundation, MIT Synthetic Intelligence Lab and Oxford Computational Neuroscience Lab. Al-Khateeb is a jury member for the Cybersecurity category, within the Startup Europe Awards (SEUA). This European Commission initiative is supported by the President of the European Parliament and the President of the Committee of the Regions in 2019. Patwary is the academic research lead for a DCMS funded 5G Testbed to accelerate the visitor economy in the East Midlands and the principal data architect for DCMS funded 5G project that facilitate capacity to test and validate attainable productivity enhancement with 5G wireless connectivity within the West Midlands. Aggoun acted as member of the European Commission Future Media Internet task force and the 3D Immersive, Interactive Media cluster with the remit to develop future strategies and hence provide a vision of future challenges that face the Networked Media technologies. Pillai is acting as a peer reviewer for EPSRC (standard calls) and British council (Newton Fund calls).

4.2.4 Invited Keynotes, Lectures and/or Performances, or Conference Chair Roles

Pillai is the Co-Chair of the IEEE 5G Roadmap Satellite working group (2018 - present) and a Founding member of the IEEE Special Interest Group (SIG) on Big Data for Cyber Security and Privacy (2017). Ahsan is the local organising committee chair, IEEE World Congress on Computational Intelligence (IEEE WCCI) 2020, 19 - 24th July, 2020, Glasgow (UK). Al-Khateeb's work with RMIT includes a study in collaboration with Oman and approved by the Omani NDFL (National Digital Forensic Laboratory) to collect primary data. Furthermore, Al-Khateeb is registered as a Proficient PhD Supervisor for Higher Degree Research (HDR) students at RMIT. Al-Shakarchi acted as publication Co-Chair of the 2nd IEEE International Conference on Fog and Mobile Edge Computing (FMEC 2017), he was a member the technical program committee in IEEE International Conference on Communications 2017, Paris, France as well as program committee member of Multimedia Wireless ad-hoc Networks 2014 Conference in Benidorm (Spain). Patwary acted as Co-Chair for IEEE International Network Generation Roadmap (Future Network Initiative).

Members of DISC have been invited as keynote/invited speakers at many events including, IEEE 5G Summit 2019, Tangier, Morocco; IEEE WINCOM 2019 Morocco; IEEE FNI Workshop 2019, Milpitas USA; International Multidisciplinary Conference: Sustainable Development & Smart Planning 2020, 1st 6G Summit 2019, Levi Finland; IEEE Globecom 2019, Hawaii, USA; IET 5G Workshop, 2020; "The impact of COVID-19 on the global cyber security landscape", 30th October

2020; Westminster eForum policy conference on Cyber Security and Resilience across the UK economy - policy priorities for supporting businesses of all scales, securing consumer devices, and responding to COVID-19, the "AI and cybersecurity – challenges and opportunities for your business", IoD West Midlands Spring Dinner, 28th March 2019; the "The changing landscape of cybersecurity: All businesses need to be aware"; Keynote address, Cyber Security: Business insight conference, Birmingham, 17th October 2018. These showcase the high esteem of our research in academic and practitioner fora.