Institution: University of Salford

Unit of Assessment: 11

1. Unit context and structure, research and impact strategy

Unit context and overview

With a focus on the needs of our industry partners, the goal of the Informatics Research Group (IRG) is to produce internationally excellent research that drives real-world economic and societal impact. We align with global agendas around building resilient technological infrastructure, promoting inclusive and sustainable industrialisation and fostering innovation through the use of data, artificial intelligence and machine learning. An example of our international reach includes our partnership on the EU-funded SUCCEED programme, contributing to the adoption of mass digitisation and development of common standards for storage and dissemination of cultural heritage documents across five European countries. In this REF period we have increased the number of active researchers, internationalised our funding and built associated networks, and grown the size of our PhD community. We have intensified our impact through 11 Knowledge Transfer Partnerships (KTPs), being a partner in the AI and Cyber Foundries and working with a range of companies and public sector organisations including the Office for National Statistics, LG-Energy, Humn.AI and Add Energy Ltd.

The IRG is based within the Salford Innovation Research Centre (SIRC) in the School of Science, Engineering and Environment (SEE), which was established in 2015 to form an interdisciplinary research environment bringing together: Acoustics; Autonomous Systems and Robotics; Engineering; Informatics; and Materials and Physics.

Members are listed against their primary affiliation, although many work in cross-disciplinary collaborations:

- **Data Science and Artificial Intelligence (DSAI) (6.0 FTE: Antonacopoulos**, **Meziane**, **Pletschacher**, **Preiss**, **Saraee**, **Vadera)** includes cost-sensitive data mining, medical image processing, natural language processing, digitisation, document image analysis and recognition, and data mining and machine learning.

- **Telecommunications and Information Security (TIS) (6.0 FTE: Alani**, **Belguith**, **Dargahi**, **Hegarty**, **Linge**, **Takruri-Rizk)** addresses key questions around: network traffic prediction, spatial and temporal optimisation in cloud computing, millimetre wave 5G networks, latency reduction in C-RAN networks.

- **Software Engineering and Visualisation (SEV) (4.0 FTE: Bass**, **Gaber**, **Hughes**, **Roberts)** has strengths in developing large-scale agile software development methodologies, IT infrastructure in developing countries, intelligent systems and trust-based security models.

Research strategy 2015 – 2020

The SIRC research strategy spanned 2015-20 to drive economic prosperity through enhanced utilisation of productivity-enhancing digital technologies and big data and artificial intelligence approaches in Industry 4.0. Computer Science and Informatics research has linked into the SIRC strategy through a strong collaborative ethos, forging links with industrial partners to deliver research impact.

Our 2015-20 strategic priorities were:

- ***Grow our research base***

We have invested in and developed our researchers, especially early career researchers (ECRs). We have increased our submission by 23% to 16 FTE from 13 FTE in REF2014. We have expanded through a process of recruiting research-active staff, ensuring alignment with strategic priorities and a balance of recruitment across career stages.

- *Diversify our funding portfolio and grow our involvement in international networks*
  We have invested in key facilities that support our strategic research programmes. We have received awards from 11 different funders; 49% has come from UK government/industry sources; 42% from European programmes and 10% from Research Councils, UK charities and overseas organisations.

- *Grow our community of postgraduate researchers (PGRs)*
  We have provided PGRs with an excellent research training experience and increased the number of PhD degree awards to 46 from 41 in REF2014; an increase of 12%.

Since 2014, Computer Science and Informatics has increased the number of research outputs in SCOPUS-indexed journals by over 35%, from 76 to 103. Over the same period, the field-weighted citation index (FWCI) for our outputs reached 2.24 compared to the global average of 1.0 (SciVal) demonstrating that our work attracts academic attention and contributes to driving research forwards across multiple informatics disciplines.

Key research and impact achievements since 2014

Data Science and Artificial Intelligence (DSAI)
A focus of this group has been pattern recognition and digitisation (**Antonacopoulos**, **Pletschacher**). Research included a multi-year collaboration (until 2024) with the Office of National Statistics to digitise census data, making it available to the public and industry via digital applications. Collaborations with other major libraries and international organisations has generated substantial impact, outlined in one of our REF3 submissions, fundamentally improving the accessibility and utility of critical but previously inaccessible organisational data, directly influencing digitisation strategy and enabling the creation of new large-scale automated document recognition systems by large organisations, using machine learning approaches.

DSAI has delivered AI and big data solutions for emerging technologies such as autonomous vehicle-to-vehicle and vehicle-to-infrastructure communication (**Saraee** with TIS). DSAI members also contribute to the AI Foundry project, which aims to support up to 170 SMEs to adopt the latest practices developed by our AI researchers, for innovation and growth, including 'building back better' from the COVID-19 pandemic (**Antonacopoulos,** Aspin (leaver), **Hegarty, Hughes, Meziane, Preiss, Saraee, Vadera** (lead)).

Telecommunications and Information Security (TIS)
TIS research has improved the energy efficiency in large-scale telecommunication, wireless body sensor networks and households (**Takruri-Rizk**) leading to societal and economic benefits. Further projects have addressed reducing computational complexity in Cloud-RAN mobile networks (**Alani**) and low-complexity non-intrusive load monitoring using unsupervised learning and generalised appliance models, which won the Chester Sall award (2019) at the IEEE Consumer Technology Society (**Linge**).

Belguith, **Dargahi** and **Hegarty**, with input from another five IRG members, lead the Salford contribution to the £6m Greater Manchester Cyber Foundry project (ERDF funded), working with the Greater Manchester Chamber of Commerce and 150 Greater Manchester SMEs to translate the latest cybersecurity research into practice. Example research includes designing (ML-based) tools to automate security monitoring, or rapidly disseminate information to non-specialists for fraud detection, and blockchain solutions for secure transfer of data. Salford partners have included: LG-Energy; TeamKinetic; Fister Educational; CPD-Online Productions; Salford Foundation and Humn.AI.

TIS has produced outputs on network security, privacy enhancing technologies, authentication, access control, blockchain, applied cryptography and forensics. Impact is evident in cybersecurity and privacy practices in sectors with major security and privacy concerns, such as cloud computing, 5G networks, autonomous connected vehicles and healthcare (Dehghantanha, leaver). Research has led to improvements in security and privacy challenges in emerging networks, increased usage of attribute-based encryption for security and privacy, cryptography and threat detection (**Belguith**); and the creation of novel clone detection methods based on multidimensional scaling that is being developed towards enhanced security for Internet of Things (IoT) devices (**Dargahi**).

Software Engineering and Visualisation (SEV)
SEV research impacts software development and deployment, quality compliance and risk mitigation in areas including large-scale offshore software development programmes and cloud-based computing. This has benefitted our industry partner, Add Energy group, as evidenced in our second REF3 submission (**Bass**), through development of innovative software for the optimisation and enhancement of asset registers and leading to significant operational efficiency. The company has attracted £4m in revenue to date through exploitation of its software products, including the innovative AssetC software.

Visualisation research includes the investigation of immersive virtual/augmented reality for accessibility services (**Hughes**) and as a platform for data- (Aspin, leaver) and medical- (**Gaber**) visualisation. Presenting and exploring data and hypothesising within large-scale dynamic environments sits tightly connected to Data Science and AI. The core research question relates to how to create dimensionally scaleable dynamic visual models that present complex data systems in a way that is intuitively comprehensible and therefore enables the ability to make well-informed data-driven decisions.

Future research and impact plans

Vision: *With data and information at the heart of Industry 4.0, we seek to develop novel methods, algorithms and systems in the areas of cyber-security and digital infrastructure, learning behaviours and predictive models. Using this knowledge, we will work with our partners in industry to develop innovative applications that make a national and international impact.*

Group aims:

1. **Digital Innovation**: We will develop emerging digital applications and technologies, such cybersecurity, blockchain, AI and machine learning, to deliver improved performance and prosperity, whilst addressing barriers to their adoption.

   IRG will bring together aspects of digital society, public engagement with STEM, to create a '*top-five digital economy',* including 5G adoption (MediaCityUK in Salford being the commercial 5G network in the UK) through close partnerships with TalkTalk and Siemens, and cybersecurity, leveraging our developing collaborations with GCHQ in Greater Manchester.

2. **Robotics and Automation**: With the opening of the £13m **North of England Robotics Innovation Centre (NERIC),** due for completion in 2023, we will work with engineers to develop new artificial intelligence and robotics innovation for the healthcare industry, automotive sectors (including autonomous vehicles) and Industry 4.0 development (automation and Internet of Things).

3. **Smart and Sustainable Living:** IRG will leverage the University's built environment expertise (UoA13), to improve digital infrastructure (Internet of Things, 5G and network infrastructure, sensors etc.) including improvements in digital literacy, sensor technology and cybersecurity considerations. IRG will collaborate closely with the new Energy House

2.0 facility, a £16.5m investment (£8.2m secured from ERDF) due to open in 2022, particularly around data analytics through adoption of smart meters and sensors.

Objectives:

- *Increase the diversity and number of staff* with relevant expertise, by developing ECRs through our three-year research plan process and making appropriate strategic appointments. Particular attention will be paid to equality and diversity and the disruptive effects of COVID-19 on career progression, for example on caregivers.

- *Increase the number of PGR enrolments and completions* in IRG through growth in domestic and international recruitment. This will allow us to boost our knowledge base, enrich our scholarly community, build our global partnerships and collaborations and grow the next generation of scholars.

- *Increase the value and duration of external research funding* to allow for greater stability and depth in our activity. This will be achieved through increasing our number of collaborative research grant applications.

- *Expand the impact of IRG research* for non-academic users by considering impact activities at an early stage in each project and providing tailored support through strategic internal funding and staff support.

- *Fully exploit our increasing investment in digital infrastructure* via the North of England Robotics Innovation Centre (NERIC) and Energy House 2.0.

  IRG will collaborate closely with engineering colleagues, with the overall aim of facilitating digital innovation and AI and data science solutions for SMEs to enhance productivity and prosperity across multiple industrial sectors, including manufacturing, industry 4.0 and healthcare. This builds on and expands our successful Cyber- and AI-foundry projects, with similar goals, and further embeds our research and impact in the applied aspects of computer science and networks, cybersecurity and software engineering.

Our researchers are supported in developing their impact through formalised annual impact action plans, which are implemented through a School Impact Coordinator (**Antonacopoulos**) to monitor progress against objectives and to discuss future impact activity.

To complement our REF3 submissions (**Antonacopoulos** and **Bass**), we are building on existing impact activity in the following areas:

- Addressing cybersecurity and privacy-preserving issues in cloud computing (**Belguith** and **Dargahi**) and collaboration with GCHQ through the GM Security and Trust Partnership (**Vadera**)
- Developing future mobility solutions in Greater Manchester, utilising big data and visualisation approaches towards improved Mobility as a Service (MaaS) and Connected Autonomous Vehicle infrastructure (**Saraee**)
- Developing leading platforms in Media Accessibility through AI and interactive technology integration (EU COST action; **Hughes**)
- Using virtual reality as an exposure therapy intervention for those suffering trauma, e.g. victims of the Manchester Arena bombing in 2017 (**Roberts**).

Active participation in digital innovation will also be at the heart of the Greater Manchester *Digital, Creative and Media* strategy, through our work on digital innovation at the MediaCityUK campus and close collaboration with the creative industries including the BBC, ITV and museums in our locality.

Research integrity and open research practices

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

To ensure data are sustainably accessible and discoverable, and to enhance the integrity and efficiency of data sharing, validation and re-use, our researchers are committed to the University open access strategy, managed through the University Library. 100% of submitted staff have ORCID identifiers to share details of publications and datasets; all in-scope research outputs are deposited and made available as open-access as pre-prints or accepted versions in the University of Salford Institutional Repository (USIR) or on external pre-print servers such as arXiv. Authors whose work was funded through UKRI sources have access to funding for Open Access Article Processing Charges (7% of our total outputs have benefitted from this funding). Institutional Open Access Funds were also available based on internal peer review of the paper by the Research Centre Director and ADRI. Agreements with several academic journal publishers also reduce or remove the cost of publishing open access in their journals: 21 outputs benefitted from institutional funding or publisher deals.

2. People

Staffing strategy

To accomplish our goal to grow our research base, two strategies were adopted: firstly, to retain and develop existing academic staff (**Alani**, **Antonacopoulos**, **Linge**, **Meziane**, **Pletschacher**, **Roberts**, **Saraee, Takruri-Rizk**, **Vadera**) and secondly to recruit research-active staff to bring new expertise and knowledge to each of the three IRG research groups (**Bass**, **Belguith**, **Dargahi**, **Gaber**, **Hegarty**, **Hughes**, **Preiss**). **Bass** was recruited to strengthen research in software engineering with emphasis on agile methods and software deployment methodologies with specific applications to the cloud; **Belguith**, **Dargahi** and **Hegarty** were recruited to provide expertise in cybersecurity, forensics and cyber physical systems as part of establishing the Telecommunications and Information Security group; **Hughes** was recruited with expertise in visual computing to develop the link between the software engineering and data science and AI teams towards developing tools and methods for visualising complex data. **Gaber**'s recruitment was to span expertise between software engineering, machine learning and cybersecurity; **Preiss** was recruited to link natural language processing and Artificial Intelligence with established excellence in pattern recognition.

IRG has 7 Professors (**Antonacopoulos**, **Linge**, **Meziane**, **Roberts**, **Saraee**, **Takruri-Rizk**, **Vadera**), 2 Senior Lecturers (**Bass**, **Hegarty**) and 7 Lecturers (**Alani**, **Belguith**, **Dargahi**, **Gaber**, **Hughes**, **Pletschacher**, **Preiss**). All 3 groups have representation from Lecturers and Professors ensuring that there is strong leadership and developmental opportunities for ECRs, so that each area remains sustainable. Staff have had opportunities to advance in their careers through promotion in recognition of their contributions to excellent research since REF2014. **Bass** and **Hegarty** were promoted to Senior Lecturer and **Antonacopoulos** and **Saraee** were promoted to Chair. Specifically, **Saraee** was promoted in recognition of the development of industry-focused data science. **Antonacopoulos** was promoted due to continued excellence in pattern recognition, image and document analysis, and digitisation.

Career development and support

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

Newly appointed staff are allocated a formal mentor from amongst the senior staff in their disciplines to support them during their first year of employment at the University and are given an enhanced research allocation (and a reduced teaching workload) as an investment component. Such an approach was very successful for IRG, as evidenced by the promotion of **Bass** to Senior Lecturer in Software Engineering. SEE has recently established an ECR Network to ensure that this community has a voice within School activities. Local coordination with the University-wide mentoring scheme (REF5a) is managed by **Bass**.

Supporting high-quality bidding, outputs and impact activities
Staff have access to regular SEE and University internal funding calls to support research output production and dissemination (including open-access APC charges), pump priming, impact generation and conference travel. Funding is prioritised towards staff members within their first 2 years of appointment and staff requesting support must demonstrate how their project aligns with School and SIRC strategic priorities. £17.5k in support has been provided to 10 staff to pump-prime research, attend conferences, or disseminate research findings. The University operates a policy whereby 25% of overhead income from research awards is provided into a staff discretionary account, which is used for staff and PGR students to attend conferences, organise workshops (e.g. the Empirical Software Engineering workshop, held at Salford, with MMU and UCLAN, **Bass**) or activities that enhance research quality or impact.

Complementing the Salford Early to Experienced Career Researcher Enterprise Training (SECRET) programme, through SEE and SIRC, staff receive more tailored guidance for bidding, publication quality and impact activities. The School ADRI discusses available external grant opportunities and facilitates cross-disciplinary bid development at weekly School research meetings. To support staff to produce high quality research outputs, SIRC organises an internal peer review process that provides feedback to all authors on their publications using the criteria of 'originality, significance and rigour'.

Development of research impact is a priority and supported in multiple ways. Internal funding from the University's Research Impact Fund has supported expansion of impact-generating activities for **Antonacopoulos** and **Bass**. Annual impact action plans were introduced in 2018 to support researchers to develop their impact in a strategic manner to maximise the benefits of the research for wider society. School Impact Coordinators (**Antonacopoulos** for SIRC) meet regularly with plan holders to discuss future activity: **Hughes** has an action plan to generate impact from his Immersive Accessibility project and also a joint plan with researchers in SEE's Biomedical Research Centre (BRC) to develop impact around virtual reality/immersive technology within biomedical education. An additional 10% research workload has been provided to support the development of impact case studies included in REF3.

To provide a supportive research community and facilitate interdisciplinary collaboration we organise away days and a regular research seminar series. The seminar series is open to both staff and PGR students and includes both external academic and industrial speakers, for example the Chief Scientist for SINTEF Digital, Norway, who gave a talk on Large-Scale Agile Development and Coordination (2018); and collaborators such as Carnegie Mellon, USA with a talk on

Institutions and Capabilities in Incremental Design (2017); and Health Innovation Manchester, with a seminar on the application of data science to health (2019). SEE's Professorial Network also provides a forum for discussion of leadership and management of research activities across the School.

Ensuring an excellent postgraduate research experience

Creating an effective and supportive environment for research students is a core element of the School's and IRG's priorities, therefore, we have invested (with support from HEFCE) in our PGR office infrastructure including a full refurbishment of a modern, state-of-the-art PGR facility (£589k) and PC suite (£530k), including dedicated PGR meeting room facilities (£31k).

We have supported PhD progression through regular monitoring and supervisor training to ensure support for students is of a high quality. Mandatory training for all new supervisors ensures that the supervision teams are trained and educated in supervisory skills. PGR student supervisor training is regularly refreshed and is monitored alongside PGR progression through SREC. Any issues with progression are identified and resolved at an early stage through the supervisory team, the ADRI and the Doctoral School (for example 66% of our PGR students have been granted COVID-19-related extensions to aid progression). At School level, all staff actively engage with learning agreement development, annual progression and final viva assessments, ensuring a common understanding of expectations across supervisory teams and an independent audit of PhD progression. Students have monthly formal meetings with their supervisory team, ensuring an excellent supervisor-supervisee relationship develops. Supervisory teams are usually comprised of a main supervisor, a co-supervisor and an independent personal tutor. To develop their supervisory skills ECRs are paired with more senior researchers as part of supervisory teams.

To complement the Salford Postgraduate Research Training (SPoRT) programme (see REF5a), SEE runs a first-year PhD student symposium with training around delivering scientific presentations at seminars and conferences, and all PGRs contribute to the University-run Salford Postgraduate Annual Research Conference (SPARC), where students and ECRs present their research and gain feedback. These cover aspects of doctoral studies such as expectations in the progression points, preparing for the viva, academic writing, research and software development methodologies and data analysis using NVivo and SPSS. In addition to centrally provided training, in computer science PGRs are encouraged to attend PGT modules related to their research domain. We have informatics-specific training sessions on methods for selecting research sites and data collection and data analysis when using qualitative methods in areas such as computer-supported cooperative work or computer human interaction. Workshops covering academic writing for journal and conference papers have explored consideration of time management styles.

The training and development experience encourages PGRs to apply for grants, publish and present their work at conferences during their PhDs to build a track record. Support is given around selecting target conferences and appropriate journals within the field. £300 a year is provided for each student to assist with conference attendance. Exemplars of PhD student successes include: Abdullahi (**Dargahi** with an Engineering colleague) who published an interdisciplinary paper on autonomous vehicle to infrastructure communication; and Odero (**Dargahi**, **Takruri-Rizk**, with an Engineering colleague), who published a cross-disciplinary paper detailing improvements to computer network and IPv6 security. Many of our students take up academic positions at the conclusion of their postgraduate studies: **Takruri-Risk** has supervised 4 students (with 5 publications) that have gone on to permanent academic positions in Saudi Arabia, Dubai and Iraq; **Vadera** has supervised PhD students that are now, or have been, academic tutors at Salford (2), MMU and the Ghadems Higher Institute of Science and Technology, Libya.

Equality and diversity

The University is a member of the Athena SWAN charter. The former School of Computer Science and Engineering (CSE) (which merged with other Science and Engineering schools to form SEE in 2019) gained an Athena SWAN bronze award. Our Self-Assessment Team is chaired by

Takruri-Rizk, who has an international profile for work on gender and STEM and was awarded an MBE in 2009 for services to Women, Black and Minority Ethnic people in Science, Engineering and Technology education. She works with national and local organisations (e.g. Equal Opportunities Commission, Opportunity Now, Royal Academy of Engineering, Skillset, Women's Engineering Society) and with industry (e.g. Airbus, BBC, Gargill, Gamma, Morson, United Utilities) around ensuring STEM inclusivity. Through outreach and engagement events we seek to promote the role of women in science and inspire female students from across UK schools/colleges to study STEM subjects for a future career in the industry, helping the industry to be inclusive and diverse. For example, Salford has hosted the annual British Computer Society Lovelace Colloquium, a free conference for female students to promote informatics careers (**Bass, Belguith**) which attracted 110 presentations from women in STEM in 2019, featuring prominent Senior Software Engineers from Bloomberg and the BBC.

Takruri-Rizk and the Athena SWAN self-assessment team are working to match our achievements with BAME improvement in gender equality. We are supporting female ECRs to take on leadership of major projects (e.g. **Belguith** will take over as Salford lead for the Cyber Foundry). Regular School and University-level promotions workshops feature successful applicants sharing their experience of the promotion process to support those considering Readership/Professorial promotion and specifically seek to support under-represented colleagues. We are committed to improving representation of female academics within IRG. Four staff in our submission are female (25%), which is an increase from one in REF2014. Whilst an improvement, we recognise there is much we need to do to achieve full equality and we are committed to appointing more women computer scientists and working with schools to develop the pipeline of future women leaders and graduates in computer science.

The selection of staff for REF submission and outputs followed our Code of Practice closely. We have excellent representation of BAME staff, with eight members being from a BAME background (62%); six (46%) have been appointed since REF2014. Attribution of REF2 outputs to female staff is 7% below our proportion of female submitted staff (18% compared with 25% submitted female staff). However, 45% of outputs are attributed to BAME staff in a submission where 31% are from a BAME background.

3. Income, infrastructure and facilities

Income

We have undertaken 30 projects across the REF period with total income of £2.24m from 11 funders. 49% of income has come from UK government/industry sources and 42% from EC programmes. The final 10% is from Research Councils (EPSRC and ESRC), UK charities and overseas organisations.

Supporting our industry collaboration strategy, IRG has been involved with 11 KTPs (Innovate UK, value £1.1m), each evidencing translation of our research into real-world impact. Partner SMEs include: Financial Services (Car Finance 24; Humn.AI; Ripe Insurance Services; **Dargahi**, **Saraee**), Data Mining and Marketing (Social Sense, Idox Software Ltd.; **Vadera**), and Internet of Things (Invisible Systems; **Bass**, **Correa**, **Meziane** and Add Energy group; **Bass**). We regularly publish outputs with industry partners, for example co-publication of an article detailing the reduction of smoking in school-age children, through a KTP with Social Sense Ltd. (**Vadera**).

Artificial Intelligence and Data Science
Significant funding has been awarded to the area of document recognition and digital conversion. A strategic focus of this group is a collaboration with the Office of National Statistics (**ONS; £272k**), which been extended to digitise data from three census years, making it available to the public via digital applications (**ONS: £500k**, 2020-24; **Antonacopoulos**). The **Aggregating content in Europeana project** (EU CIP programme: €4.1m total, €391k to Salford, 2012-2015) developed digitisation methodology and infrastructure to migrate the Europeana newspapers collection to a new digital platform (**Antonacopoulos**, **Pletschacher**). This work founded the Salford Pattern

Recognition & Image Analysis (PRImA) research lab that has supported a number of further projects:

- **SUCCEED** (FP7 €1.9m total, €192k to Salford) was funded to promote the adoption and validation of research in mass digitisation with 7 other partners that included the British Library and the Bibliothèque National de France. This work further enabled the development of the PRImA research lab (**Antonacopoulos**, **Pletschacher**).

- **eMOP** (Andrew W. Mellon Foundation: $734K total, $86K to Salford) developed capability for a cloud-based system for annotation and for document recognition system training (**Antonacopoulos**).

- **ZoneMaster** (EU Eurostars programme: €1.1m total, €50k Salford subcontract) developed several digitisation evaluation methodologies which were subsequently tested in a commercial protype development environment (**Antonacopoulos**).

Artificial Intelligence research notably includes the Salford contribution to the £6m ERDF Greater Manchester AI Foundry project, which aims to support up to 170 SMEs to adopt the latest practices, developed by our researchers in Artificial Intelligence, for innovation and growth, including 'building back better' from the COVID-19 pandemic. (**Correa**, **Meziane**, **Vadera** (lead)). Further income in AI and Data Science has supported:

- Developing and applying data mining and immersive visualisation techniques (through OCTAVE) to categorise the victims of crimes (The Centre for Crime and Justice Studies crime profiling project (**ESRC: 'A Profiler for Crime, Criminal Justice and Social Harm' £150k**; Aspin, **Meziane**, **Saraee**)).

- Developing comprehensive insurance solutions for Autonomous Vehicles (**Saraee**, £130k **KTP** with Humn.AI).

- Combining Artificial Intelligence and IoT technologies to optimise energy usage (£130k **KTP** with Invisible Systems Ltd. (**Correa**)).

- 4 KTPs (each £130k; **Innovate UK** led by **Vadera**) in AI applications that have: 1) developed novel churn models for a software house that enabled an objective approach to targeted retention of customers and new business (IDOX; 2013-2015); 2) provided insights into one of the largest Social Norms programmes in the UK that reduced smoking among children (Social Sense Ltd.; 2015-2016); 3) utilised machine learning to reduce the time to consider insurance applications and improve conversion rates whilst obtaining the best interest rates for its customers (CarFinance247, 2016-2018); and 4) applied Bayesian models for dynamic pricing and understanding and planning around customer churn rates (RIPE Insurance; 2018-20, with **Saraee**).

- **Privacy4Forensics (EU FP7: €231k**) project that developed tools for, and identified best practice for carrying out, privacy-respecting forensics investigations including Windows, Android, OSX and Internet of Things (IoT; **Vadera**).

Telecommunication and Information Security
TIS leads, and 50% of IRG members contribute to, the ERDF Greater Manchester Cyber Foundry project that works with 150 Greater Manchester SMEs, including the Greater Manchester Chamber of Commerce, to adopt latest best cybersecurity practices to protect them from cybercrime (**Belguith**, **Dargahi**, **Hegarty)**. Partners have included: CPD-Online Productions, Fister Educational, Humn.AI, LG-Energy, Salford Foundation and TeamKinetic (See Section 4).

Software Engineering and Visualisation
A strategic focus for SEV is digital innovation with Add Energy group, who are establishing an on-campus facility at Salford (from 2021) to facilitate research collaborations. This follows 2

successful KTPs (Innovate UK: each £130k) that have led to the creation of an exhaustive taxonomy of software development artefacts and established in-house commercial software development capabilities, which is further detailed in (REF3; **Bass**). Other SEV research income has included:

- **Immersive Accessibility** (Part-H2020 funded, total of €2.9m: €205k to Salford; 2017-2020) was established to develop an integrated, web-based 360° Immersive Accessibility (ImAc) service (including Subtitles, Audio Description, Audio Subtitling and Sign Language) that overcomes the limitations of existing web-based 360° video players. Collaborators included 8 academic, industrial and charity partners across Europe including the German Aerospace Center (**Hughes)**.

- **CROSS-DRIVE** (Part EU funding, total of €3.59m: £315k to Salford; 2014-2016) led to the development of a new, collaborative, interactive and immersive approach for exploring 3D time-dependent Mars atmospheric data in distributed teams and virtual reality (**Roberts**).

Infrastructure and facilities

Informatics research occupies a number of dedicated laboratories located in the Newton, Cockcroft and Maxwell Buildings. In 2017, the University embarked on developing a Campus Masterplan and our future interdisciplinary collaboration strategy is planned around capitalising on the unification of the 3 science schools into SEE, to develop multidisciplinary research in areas such as environment, biomedicine, energy and the built environment. Within the Masterplan, the new £65m SEE building, due for completion 2022/23, will provide 15,366m^2 of state-of-the-art collaborative workspace including workshops and studios at the heart of the Peel campus, consolidating SEE from 5 buildings into 1. For IRG the building will house computer suites, software laboratories, a CISCO imaging and computer lab, a cybersecurity suite, a data science suite and training suites for postgraduates and undergraduates.

To strengthen the research in the areas of data science, visualisation and information security the University made a £84k investment in cloud infrastructure, aimed at developing a big data analytics and visualisation platform to support research. We have invested in a Hypervisor (multi-node) private cloud, consisting of 6 Dell PowerEdge rack servers located in our data centre (4 OS and 2 management servers), offering up to 120 vCPUs, 755GB RAM and ~3TB of storage space. Each node has either one or two 20-core Intel Xeon E5-26XX Processor(s), with CPU speeds ranging from 2.3GHz to 3GHz, and memory ranging from 64GB to 256GB. The data centre and wider IT infrastructure is serviced by a dedicated technician.

PRImA
The Pattern Recognition and Image Analysis (PRImA) research lab has been supported by the School in terms of space provision, matched funding for projects as well as through Staff Innovation grants. The PRImA lab has enabled interdisciplinary collaborations, with social sciences and humanities researchers internationally, national and other prominent cultural institutions, non-profit and government organisations. It has enabled the development of 6 Research Assistants and Research Fellows (among which, **Pletschacher** progressed to a lectureship) and 5 PhD students. The PRImA lab has participated a number of research grants and contracts (see **Antonacopoulos**) and has produced software that is being commercially licensed to other organisations. The PRImA Lab has hosted visiting researchers from India, South Korea and Switzerland. While the majority of the activities have been in digitisation and document recognition (e.g. the Aletheia document analysis system and the PRImA digitisation performance evaluation methodology), a prominent example of other work is the successful collaboration with civil engineering researchers to create the Dewaterability Estimation Test (DET) device, for which a patent has been granted and a spin-out company created to exploit it: ATW (UK) Ltd.

OCTAVE
The School provided over £700k in investment in the previous REF period on OCTAVE and has invested in its maintenance and support through this cycle, including dedicated technical support

for research utilising this resource. OCTAVE is an 8-sided virtual immersive environment that provides both virtual and augmented reality capabilities impossible to deliver with standard head mounted VR equipment. In this period, this investment has led to visualisation research involving students and external stakeholders, and impact through outreach. For example, the facility has enabled a multi-user immersive data visualisation for the ESRC-funded crime profiling project (Aspin, **Meziane**, **Saraee**) that studied the relationship between victims of crimes, their characteristics and features, and the types of crimes committed through immersive visualisation.

OCTAVE has been used to support: research bids including tele-collaboration (**Roberts**), Big Data (Aspin, **Saraee**) and medical and psychology research (**Roberts**); 22 outputs (University-wide); and 11 PhD students. OCTAVE is complemented by **ThinkLAB**, a VR/XR collaboration facility designed to bring University teams and external partners together in an atmosphere of collaboration and co-creation. ThinkLAB includes dedicated technical support with deep experience in Smart Cities and Collaborative Engineering to deliver virtual training environments.

Wider SEE infrastructure
SEE offers wider unique and state-of-the-art facilities such as **Energy House (and the future Energy House 2.0)**, a testbed for new energy systems and testing of energy efficiency; IRG staff contribute to this area through data analysis and machine learning applications to optimise energy usage (e.g. **Bass**, **Saraee**). Our purpose-built **Automotive and Autonomous Vehicle Technology (AAVT)** laboratory includes a £220k Navya autonomous shuttle that facilitates our contribution to cybersecurity of vehicles, vehicle to infrastructure networking and development of predictive models for insurance. This has led to an external collaboration with Project Darwin, a consortium that includes Telefonica, the UK Space Agency, European Space Agency and Oxford University.

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

Effective collaborations leading to economic and social impact

Research in Telecommunications and Information Security is co-developed with partners across Europe and the Middle East including: Ruse University (Bulgaria); Technical University of Cluj (Romania); ESTIA (France); University of Malaga (Spain); University of Rome La Sapienza (Italy); Birzeit University, Palestinian Polytechnic University, Palestine Technical University, Islamic University of Gaza, Palestine IT, Telecom Association (PITA), Jerusalem Electricity Distribution Company (JEDCo), Ministry of Telecommunication and Information Technology and Ramallah Municipality (Palestinian territories).

Staff have engaged with 44 SMEs to develop cybersecurity and data science solutions through the ERDF Cyber Foundry. Completed research and development technical assists have been in partnership with: Greater Manchester Chamber of Commerce; LG Energy; Reason Digital; TeamKinetic; Fisher Educational (10 ticks); CPD Online Productions; the Salford Foundation; Innovate Healthcare Management Group and Toasted Productions. Further collaborations are being developed with: DeepCognito; Accredited Acoustics; Café Renaissance and Autosermo. We are collaborating with the Manchester-based GCHQ research department to develop information security and natural language processing applications.

Research in software engineering includes partners that are seeking software solutions to improve their processes and operations. For example: Add Energy Ltd.; Idox Software Ltd.; Invisible systems Ltd. Research in visualisation and broadcasting is developed in collaboration with European partners including: I2CAT Foundation in Spain; the public broadcaster Rundfunk Berlin-Brandenburg; The Corporació Catalana de Mitjans Audiovisuals, the leading audio-visual media group in Catalonia; Motion Spell, an SME specialised in audio-visual media technologies in Paris; the Universitat Autònoma de Barcelona; Anglatècnic, an SME specialising in the engineering and development of software systems for the broadcast and IT sectors, Barcelona; IRT, an SME specialised in audio-visual media technologies jointly owned by the Public Service Broadcasters

of Germany, Austria and Switzerland and The Royal National Institute of Blind People (RNIB), a UK charity. The main achievements of this group include:

- New software products e.g. *AimHi*, *AssetVoice*, *Optibom* and *LookC*. The *AssetVoice* software has optimised the asset verification process used by BP in North America by helping it to collect asset inventory data that included refineries and offshore platforms. Our software development process has been adopted by Add Energy Ltd.'s R&D department, creating 5 jobs (see also REF3).

- Open-source software for personalised accessibility services for users with sensory or learning disabilities. The Immersive Accessibility Project (ImAc) integrates accessibility data with 360° immersive video and will be adopted by MPEG as part of their reference player. Further contributions have been made to the EBU, W3C, ISO, VRIF Standardisation Groups.

Research in Artificial Intelligence and Data Science is developed in collaboration with companies and the public sector. For the latter, partners include the NHS, for health-related applications such as the length of stay of patients in Intensive Care Units, Medical Image Analysis and classification of the plantar fascia and the Achilles tendon. Research has also been undertaken with The Centre for Crime and Justice Studies and Salford City Council for understanding the behaviour of disadvantaged groups.

The PRiMA group (led by **Antonacopoulos**) develops and deploys software tools for document analysis, digitisation and evaluation frameworks towards increasing the availability and accessibility of previously inaccessible, now digitised documentation. Software development has led to reduced costs of digitisation and adoption by libraries, public bodies and commercial service providers including over 25 partners across Europe, USA and Australia. Partners include: the European Centre of Competence in Digitisation; JISC/UK Data Service; Office for National Statistics; Texas A&M University, FamilySearch, USA; Australian Department of Defence, French National Library; National Library of the Netherlands and the State Library of Berlin. Furthermore, the group has influenced international digitisation policy, such as the European Commission's Digital Agenda for Europe (see also REF3). **Preiss** has used linguistic analysis-based relations to improve the accuracy of literature-based discovery techniques. The research showed that relations extracted through automatic linguistic analysis identify several orders of magnitude fewer instances of hidden knowledge than approaches that use term co-occurrence relations.

Contributions to the sustainability of the discipline

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

Keynote addresses and invited talks
In recognition of the international research profiles within IRG, members have received numerous invitations to give plenary talks as invited speakers at international conferences, national and international research groups:

- **Alani:** *IEEE 10th Computer Science & Electronic Engineering Conference (CEEC 18)* in the UK and the *3rd Scientific Conference of Electrical Engineering (SCEE2018)* in Iraq in 2018.
- **Antonacopoulos:** digital humanities at the University of Verona (2014), on document recognition at The National Archives (2014), on the future of document analysis and recognition at ICDAR2017 (Kyoto), and on historical document analysis at the National Library and Archives of Belgium (2018).
- **Belguith:** Smart Infrastructure theme at the ICT Brokerage event ICTurkey 2019 in Turkey and at the Subjectification of UK and Russian Smart Cities Workshop.

- **Gaber:** was Keynote Speaker at the *3rd International Conference on Robot, Vision and Signal Processing in 2015*, Taiwan and at the 2nd workshop on 'The Role of Information Technology in Sustainable Development', organised by UNESCO, in Cairo, Egypt in 2014.
- **Hughes:** at the Symposium on Subtitling Technology (IRT, Munich) in 2018.
- **Meziane:** gave 8 invited talks at international conferences including in UK, Egypt, France and Malaysia, e.g. *International Conference on Information Science and Systems* (Cambridge, UK) and 3 at the *International Conference on Frontiers of Information Technology* (Nice, France). Additionally, he has been invited to present seminars to research groups in CNAM Paris and ISEP Paris.
- **Saraee:** was the Keynote Speaker at the *4th International Conference on Web Research*, Tehran, Iran (2018).
- **Vadera:** gave 6 invited talks at international conferences and events, including in Dubai, Egypt and India, including the *Amity International Conference on Artificial Intelligence* (2019), an IEEE conference on *Signal Processing and Integrated Networks (2020)* and *Software and Information Engineering (2020)*.

International conferences hosted at Salford

Meziane organised 2 international conferences on application of Natural Language to Information Systems (NLDB) at the University of Salford in 2016 and 2019. He was the general co-chair of the conference and **Saraee** and **Vadera** were the co-chairs of the Programme Committee. The proceedings were published by Springer in their Lecture Notes in Computer Science series, LNCS 9612 and LNCS 11608. **Meziane**, **Saraee** and **Vadera** were among the editors of these 2 volumes.

Bass organised and chaired the IFIP WG 9.4 14th International Conference on Social Implications of Computers in Developing Countries (2017, Indonesia) that led to him organising the 17th ICT4D in June 2020. Proceedings of the conference were published by Springer Nature. As a result of being invited to give a talk at the Public Sector Cyber Security Conference at Salford (2018), **Dargahi** was invited to give a lecture at Copenhagen School of Design and Technology, 2019. She was also the invited speaker at the Healthcare Cyber Security Conference held at Salford (January 2020).

International conferences organised outside Salford

- **Antonacopoulos** co-founded and co-organised the conference series Digital Access to Textual Cultural Heritage (DATeCH) in association with the European Centre of Competence in Digitisation, in 2014 (Madrid), 2017 (Göttingen) and 2019 (Brussels), the proceedings of which were published by the ACM. **Antonacopoulos** was also Co-Chair of the 12th International Workshop on Document Analysis Systems (DAS2016), held in Santorini with proceedings published by IEEE-CS and General Chair of the 5th International Workshop on Historical Document Imaging and Processing (HIP2019) in Sydney, with proceedings published by the ACM.
- **Bass** organised and chaired the 7th and 8th International Workshop on Large-Scale Agile Development as part of the International Conference on Agile Software Development in 2019 in Canada and 2020 in Denmark respectively. The workshop proceedings were published by Springer Nature.
- **Gaber** was Co-Chair of the 1st International Workshop on Advances in Image Processing and Colorization (AIPC'16), Gdansk, Poland, 2016; the 2nd International Conference on Advanced Intelligent Systems and Informatics (AISI2016), Cairo, Egypt, 2016; the 3rd International Conference on Advanced Intelligent Systems and Informatics (AISI2017), Cairo, Egypt, 2017; the 4th The International Conference on Advanced Machine Learning Technologies and Applications (AMLTA2019), Cairo, Egypt; and the International Conference on Artificial Intelligence and Computer Vision (AICV'2020), Cairo, Egypt.
- **Hughes** organised the workshop on languages and media at the 12th International Conference on Language Transfer in Audio-visual Media, organised in Berlin and the Media4all workshop in Stockholm in 2019.
- **Vadera** was programme chair/co-chair for a number of conferences, including the International Conference on Information Management and Engineering (annually: 2015-

2020), the IFIP International Conference on Intelligent Information Processing (2016, 2020).

Prizes and awards
The quality of the research developed by the members of the informatics research group is recognised at the international level. **Bass** won the best paper award at the International Conference on Product-Focused Software Process Improvement (PROFES 2018) on his work on Influential Factors of Aligning Spotify Squads in Mission-Critical and Offshore Projects – A Longitudinal Embedded Case Study. **Dargahi** won the best paper award at the IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2017) for her work on the Feasibility of Attribute-Based Encryption for WLAN Access Control. **Vadera** won the Amity Research Award for the field of Artificial Intelligence and Neural Networks, 2018.

Leadership within professional organisations
Members are engaged in supporting and leading research agendas in their field of expertise. **Antonacopoulos** was elected in 2018 as the President of the International Association for Pattern Recognition (IAPR), following 4 years' service as treasurer. IAPR is an organisation of 50 national associations comprising ~10,000 members. **Antonacopoulos** and **Pletschacher** organised a series of international competitions that established the state-of-the-art in key digitisation challenges, notably the recognition of documents with complex layouts and the recognition of early Indian and historical Arabic scientific manuscripts with the British Library. **Antonacopoulos** serves on the Advisory Board of the EU-funded EURHISFIRM project, aiming to create infrastructure and digitise historical company and stock market data across Europe for economists to base their models on. Since 2016, **Pletschacher** has been a member of the Editorial Board of ALTO – the technical metadata standard for Optical Character Recognition maintained by The Library of Congress: the organisation responsible for standardising the way information acquired through digitisation processes is encoded, exchanged and interpreted to improve the availability of content. **Hughes** is leading the XRAccess Working Group on Accessibility Applications.

Peer reviewing for funding bodies
Antonacopoulos is an expert evaluator for the Belgian Federal Research Science Policy Office, the Swiss National Science Foundation. **Meziane** is the Vice-President of the French National Research Agency (ANR) for the Mathematics, Numerical and Digital Sciences sub-jury, a panel that awards research grants. **Antonacopoulos** and **Vadera** are members of the EPSRC college.

Journal Editorial roles
Alani is an editorial board member of the *International Journal of Mobile communication* and **Antonacopoulos** has served on the editorial board of the *Cultural Heritage Digitisation* journal. **Dargahi** is an editorial board member for 3 journals: the *ICT Express* open access journal, in the Special Issue on 'Blockchain Technologies and Applications for 5G Enabled IoT'; the *IEEE Transactions on Sustainable Computing*, in the Special Issue on 'Sustainable Cyber Forensics and Threat Intelligence' and the *International Journal of Multimedia Intelligence and Security*. **Gaber** is on the editorial boards of the *International Journal of Smart Sensor Technology and Applications* and the *International Journal of intelligent Engineering Informatics*. **Meziane** was the guest editor of 3 special issues of the *Data and Knowledge Engineering* journal on the Application of Natural Language to Information Systems. He is the editor of the special issues for the *International Journal of Information Technology and Web Engineering*. **Saraee** is the associate editor-in chief of the *International Journal of Web Research*. **Vadera** is a co-editor for the CRC Series of books on Emerging Trends in Biomedical Technologies and Health Informatics.

Specific editorial activities have included: **Antonacopoulos** as co-editor of the book 'Advances in Document Analysis and Text Recognition: Benchmarking State-of-the-Art Systems' published by World Scientific in 2018 in its Series in Machine Perception and Artificial Intelligence; **Dargahi** as co-editor of the 'Cyber Threat Intelligence' book by published by Springer in Advances in Information Security Series in 2017; and **Meziane** as co-editor of 2 volumes of the proceedings of the International Conference on Application of Natural Language to Information Systems, published by Springer.

Media engagement

Linge is called upon by national, regional and local TV and radio as a subject expert to comment on topical events such as the O2 network outage in 2018 (BBC Breakfast, Radio 5 Live and 12 regional BBC radio stations and Sputnik Radio) and trends in landline telephone usage as reported by Ofcom in 2019 (Sky News, BBC Breakfast). In 2015, he was invited by Vodafone as an independent technology expert to assist with the press and media campaign associated with the 30th anniversary of their launch of the first UK mobile network and similarly, in 2017, to assist New World Payphones with the media launch of their Amscreen public phonebox. In addition, his involvement with telecommunications heritage has resulted in various contributions including the BBC Timeshift documentary, 'Dial B for Britain'.