REF2021

Institution: 10007140 Birmingham City University

Unit of Assessment: UoA11 Computer Science and Informatics

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

a. Overview

The Computer Science and Informatics research cluster is part of the School of Computing and Digital Technology (CDT) in the Faculty of Computing, Engineering and Built Environment (CEBE) at Birmingham City University (BCU). We conduct research in the theory and application of Computing and Digital Technology, with key areas of focus in Data Analytics, Artificial Intelligence, Digital Media Technology, and Cyber Physical Systems.

Since REF2014 we have achieved significant growth in research staff, outputs, doctoral completions and income; we have invested in our research infrastructure; and we have developed new partnerships with field-leading industry and institutions. In 2014 we returned 7.4 FTE staff and 30 outputs compared with the current submission of 30 FTE staff and 75 outputs. Doctoral awards have climbed from 1 to 19, while our doctoral community has grown from 27 in 2014 to 48. Research grant capture has increased modestly from a total of GBP3.5M in REF2014 to GBP4.6M, but with GBP3M of this awarded in the last two years showing good upward momentum.

With growth has come investment in quality. Our outputs now regularly feature in top-rated conferences including the ACM CHI Conference on Human Factors in Computing Systems, the Vehicular Technology Conference (VTC-Spring), the International Joint Conference on Artificial Intelligence, and in high-impact journals such as IEEE Transactions on Wireless Communications, Elsevier Computer Networks, and the Journal of Artificial Intelligence. Our project collaborators include Jaguar Land Rover, GlaxoSmithKline, Orange Telecom and many prestigious universities from around the world. Director of Research **Gaber** has been named one of the world's top scientists according to research by Stanford University and Elsevier (https://www.bcu.ac.uk/research/news-events/bcu-professor-named-one-of-the-worlds-top-scientists-according-to-study).

At the time of writing we stand on the verge of a transformational move to a new GBP70m facility adjoining the new HS2 terminus. From December 2021, BCU's STEAMhouse (covering Science, Technology, Engineering, Arts and Mathematics) will support interdisciplinary work across the arts, science and technology, building on the University's 178-year heritage of design and creative education. CDT will occupy 35% of the building, sharing it with incubation and corporate spaces. The Computer Science and Informatics cluster is taking a lead in developing strategies in STEAM.

Research Groups

The Computer Science and Informatics cluster consists of three research groups, each led by a senior academic and featuring researchers from all career stages alongside postgraduate students:

Data Analytics and Artificial Intelligence (DAAI). Led by **Gaber**, DAAI comprises 13 submitted staff who develop advanced machine learning and optimisation methods through 4 sub-groups. The Machine Learning sub-group focusses on deep learning, data stream mining, time series analysis, mobile and embedded machine learning, and text mining. The Evolutionary Computation sub-group on genetic programming, genetic algorithms and particle swarm optimisation. The Multi-agent sub-group on mobile software agents, multi-agent computer network routing protocols and agent-based machine learning systems. The Knowledge Engineering sub-group on automatic ontology engineering, ontology-based information retrieval and using ontology in healthcare systems.

Digital Media Technology (DMT Lab). Led by **Williams**, DMT Lab comprises 9 submitted staff who specialise in the development of methods for creating, processing, analysing, evaluating and distributing digital media. Its HCI sub-group specialises in user experience design, virtual/augmented reality, accessibility and assistive technology, and sensor-driven interaction. The Graphics and Vision sub-group focuses on synthetic image generation, digital twins, animation and computational geometry. The Sound and Music Analysis group uses audio signal processing and machine learning techniques to achieve music information retrieval, intelligent music production, digital audio effects, rhythm and metre analysis and automatic music transcription.

Cyber Physical Systems (CPS). With a total of 9 submitted staff led by **Aneiba,** CPS brings together the Cybersecurity and Software Engineering groups reported in REF2014, adding a further strand in future communication systems. This group specialises in software-defined networking (SDN), network function virtualization (NFV), high computing performance (HCP), future networks (5G and LPWAN), blockchain, and trustworthy protocols and systems. CPS develops innovative solutions, methods and techniques across multiple application domains such as Smart Cities, Smart Manufacturing and Smart Mobility, delivered through two intersecting research themes, Future Information Networks, and Secure and Trustworthy Systems.

Group leaders are responsible for developing (i) group research strategy and plans (ii) research staff capabilities and careers (iii) research seminar series (iv) research funding applications (v) research equipment bids (vi) plans for symposia and conferences, and (vii) opportunities and context for visiting scholars.

School, Faculty and University

To provide strategic leadership to these groups the School has established a Research Steering Committee comprising: Associate Dean of Research and Enterprise (Professor Cham Athwal) at the Faculty level; Head of School (Professor Andrew Aftelak); School Director of Research (**Gaber**), supported by research group leads (**Gaber**, **Williams** and **Aneiba**); and the School Director of Innovation (Professor Makhan Sharma). This team meets monthly to discuss the overall strategy of research in this UoA, set and review operational plans for its implementation, and allocate a devolved budget that permits swift responses to the needs of staff undertaking key projects, enabling better planning for junior staff careers, meeting urgent equipment needs, and servicing visits, seminar series, and other key features of a vibrant research environment.

As set out in BCU's REF5a, the University's Doctoral Research College (DRC) supports all aspects of the doctoral student journey from application to examination, while the Research, Innovation, Enterprise, Employability (RIEE) team oversees grant awards, engagement with industry, contracts, IP policy, technology transfer, governance and enterprise. Both areas have, as the 5a explains, received significant investment since REF2014, with the measurable impact on PhD completions and external funding summarized above.

The University's investment has also allowed the benefits of research to be seen in our undergraduate and postgraduate taught programmes. Building on the work of the DAAI group, data science has emerged as a strong thread across many of our courses, while HCI and future networks research feature strongly in curriculum development at taught PG level. The success of our research-informed teaching strategy is evident in our top third (30/109) ranking in the latest Guardian University Guide for courses in Computer Science and Informatics.

b. Research strategy

REF2014-2021

The future strategic vision in this UoA's return to REF2014 was to **deepen excellence in core disciplinary subjects, harmonise theory and practice, strengthen collaborations and partnerships with research users,** and **thus achieve stronger impact in selected interdisciplinary and application areas**. This was further refined in light of the University's

Strategic Plan 2016-2020 that promoted **growth in all research indicators** and emphasised the role of research in **stimulating regional transformation** with an ambition for BCU to be recognised as '*the University for Birmingham'*.

Deepen excellence in core disciplinary subjects, harmonise theory and practice, growth. This has been achieved by:

- Growth in staff with significant responsibility for research to 31 following three recruitment campaigns and investment in existing staff; appointments of new Professors in Machine Learning (**Gaber**) and Telecommunications (**Patwary**).
- Adoption of a research-centred workload that makes at least 25% of time available for all research active staff to conduct research and allows for reduction of other workload for staff to pursue funded projects, regardless of whether the external funding pays for investigator time.
- Allowing the establishment of two new research groups and growth of all three to reach critical mass in their core disciplines and fuel growth in PhD numbers (48 currently enrolled) and completions (19 including 1 by publications route); allowing the development through PhD projects of new foundational knowledge and applied research results as demonstrated by growth in numbers and quality of research outputs.
- Using this knowledge and expertise to work with industrial partners and end users in funded projects to gain new insights and develop pertinent research questions and directions for further PhD topics. Demonstrated by growth in research awards.

Strengthen collaborations and partnerships with research users. This has been achieved by a range of measures including:

- Events and outreach including RIEE supported brokering of partnerships across local authorities, Local Enterprise Partnerships (LEPs), stakeholder groups and private-sector partners.
- Partnership with regional public sector bodies in two large ERDF funded programmes that engaged SMEs and developed their research and innovation capabilities (Innovation Engine and Big Data Corridor).
- Faculty sponsored events to foster internal collaborations with engineering and built environment researchers.
- Enabling the formation of partnerships with companies and public sector organisations to bid for and deliver a range of digital transformation projects. These have included in Manufacturing with Jaguar Land Rover and their machine tool suppliers, and several regional SMEs; in Construction with Walsall Housing Group, Beattie Passive and Carillion Energy Services; in Smart City and Sustainability with United Utilities, Singular Logic, Birmingham City Council and Traffic for West Midlands; in Healthcare with GlaxoSmithKline and several NHS trusts; and in the Tech sector with Orange Telecom and Microsoft.

Achieve stronger impact in selected interdisciplinary and application areas, **stimulating regional transformation.** This has been achieved by a range of measures including:

- RIEE facilitated workshops and training around knowledge transfer and impact by both internal staff and with external input from impact experts Saskia Walcott (Walcott Communications) and Professor Mark Reed (University of Newcastle).
- Staff mentoring provided on an ongoing basis from research group impact leads who also organise industrial visits and specialist workshops.
- Enabling the award and continuing successful delivery of several large funded projects such as IoT4WIN, Red-Alert, DfMA, Perseus, 5G Connected Forest and 12 KTP partnerships (described in sections 3 and 4).

This interdisciplinary working with partners, including research users, has become intrinsic to the research/impact strategy of this unit, and **the selected impact case studies** provide examples of the success of this approach:

1. An interdisciplinary project (with architects and construction companies) on personalised retrofit packages. **Basurra and Gaber** have collaborated with regional partners Beattie Passive Retrofit (industry lead and construction delivery partner), Carillion Energy Services, InteSys and iZdesign, together with Birmingham City Council, which provided the housing stock for the project. The research contribution was a novel algorithm that optimises deep retrofit packages for reducing energy consumption and carbon emissions in previously energy-inefficient houses whilst making occupants' lives more comfortable. The Stroma Group (the UK's leading provider of training and certification for property energy assessors) is working with Basurra to develop an enhanced tool (iRET) based on this research, that supplements the current Stroma SAP government-approved calculator used in around 2,500 daily assessments for Energy Performance Certificates. Full details are given in **[ICS1].**

2. Partnerships exploiting Augmented and Virtual Reality systems for the benefit of the healthcare industry and providers. Findings from DMT Lab's world-leading research for improving the quality of experience and interaction capabilities of AR/VR systems are being used by the global pharmaceutical company GlaxoSmithKline (GSK) in a Knowledge Transfer Partnership (KTP) with **Williams** and **Frutos-Pascual** to develop new AR/VR based tools for product analysis and consumer environment design, and for raising the awareness of the potential benefits of AR/VR throughout the company. **Williams'** and **Wilson's** work with separate NHS Trusts has culminated in the design for an AR based platform for delivering radiotherapy training and treatment set up, and a VR app that is being used for ophthalmology training respectively. Full details are given in **[ICS2].**

3. Our third project provides intelligent software tools to support music production. Working with a community of music producers, **Stables** carried out research into intelligent music production tools that leveraged semantic descriptors to power technologies such as automatic track grouping or effect recommendation. Parallel to this his team developed web-powered production suites which also gather large volumes of production data, furthering the understanding of the music-mixing process and lowering the barriers to entry for professionals and hobbyists alike. These tools have been used in prestigious recording studios such as Abbey Road Studios and downloaded by 15,000 other users in 20 countries. The research has led to a **Stables** co-authored book, *Intelligent Music Production*, published by Taylor & Francis (Routledge) in 2019 (ISBN: 9781315166100). A spinout company Semantic Audio Labs is developing and commercialising the research outputs and employs 6 staff, including **Stables** on a partial (0.2FTE) secondment. Full details are given in **[ICS3].**

Future Strategy

Central to our future plans are the opportunities afforded by STEAMhouse for interdisciplinary research, innovation and public engagement projects. The fruits of our future work with designers and artists in BCU's internationally renowned arts faculty, and business experts, health specialists and a host of other research practitioners from across the university will be evident in the next REF cycle. This GBP70m project, part-funded by the Birmingham and Solihull Local Enterprise Partnership, will also transform the scope and scale of our relationships with industry in the UK and internationally. A partner institution, STEAMhouse India, is set to open in 2022. Increasingly, we will seek to develop expertise that addresses the big challenges to society working both regionally and seeking to amplify our impact through collaborations in India.

In that context, the next REF cycle will see further progress in building research capacity through:

- increasing the proportion of REF-returnable Category A staff from 34% to 60%, so furthering our capacity for grant capture, industry partnerships, and research-informed teaching
- doubling our doctoral community through STEAM bursaries and industrial partnerships aimed at finding solutions to process and technological problems
- doubling our external research income through further collaboration domestically and internationally, taking advantage of opportunities presented by STEAMhouse India.

- nurturing applicants and developing proposals for independent research fellowships from EPSRC, Royal Society, Leverhulme Trust, other UK research councils, and foreign governments and foundations
- exploiting our internationally leading research for the benefit of UK industry and attracting more research funding from overseas (non-EU) to BCU.

We expect to achieve those aims in the context of our three existing research groups, with a new remit to develop research capability among existing and junior staff.

Governance processes in our home Faculty (CEBE) have played no less significant a role. Our research endeavours are held to the highest standards of compliance with ethical obligations and standards, so that integrity with regard to legal and professional frameworks is paramount. CEBE has a well-established ethics committee that stipulates and ensures that "All those engaged with research have a duty to consider how the work they undertake, host or support, impacts on the research community and on wider society". All research projects are submitted for ethical approval prior to commencement; we observe strictly the Research Integrity Concordat and the process and governance structures at University level as set out in 5a.

That includes full compliance with the Concordat on Open Research Data, in which we are supported by the University's Open Access Officer. Open Access has been a key component of our UoA strategy, and has in part been realised by introducing Personal Research Accounts. Staff members with quality outputs have an account incremented by an amount of funding supporting their research. Accounts are incremented only if the output is deposited in the University's Open Access repository. Researchers are also encouraged to make their datasets publicly available; server facilities are made available to support the policy. Examples of open datasets attached to projects underway in our UoA include (i) Image datasets (**Williams**) (ii) Big Data Corridor and Birmingham in Real Time datasets (**Tawil**), (iii) Citygate (**Aneiba**), and (iv) Semantic Audio datasets (**Stables**). Open Source code and applications arising from our research are routinely made publicly available via GitHub.

Section 2. People

Staffing strategy and staff development

We aim to provide a research environment that is attractive to new researchers, and which supports and nurtures researchers at all stages of their careers. All new appointments must demonstrate individual excellence in their research outputs and/or potential (as evidenced by publications, funded projects, industry links, doctoral/postdoctoral performance), while consolidating or complementing existing research strengths. New early-career staff are allocated additional research time and reduced teaching and administrative duties during their first three years of appointment, and are mentored by senior staff and attend structured staff development programmes, including mandatory training for supervising research students.

We also recognise the need to invest in senior strategic appointments. Out of the 20 new appointments made during the current cycle, eight have been researchers with an established record of internationally excellent or world-leading research in the areas of Artificial Intelligence and Machine Learning, Future Communications Systems, Cybersecurity, and Digital Media Technologies. Of those eight senior appointments, **Gaber** and **Aneiba** have taken up leadership positions in our research clusters while **Azad, Patwary, Asyhari, Arshad, Creed,** and **Harvey** have played a key role in securing external funding, mentoring junior staff, and building industrial and HE collaboration.

For all appointments, we have drawn on international fields of applicants in order to secure the best talent. Five of our new appointments in the current cycle have been recruited from outside the UK: **Aneiba** (Libya), **Hockman** (Canada), **Abdallah** (Australia), **Azad** (Ireland), and **Adedoyin-Olowe** (Nigeria).

Recruitment, Workload, Support

We encourage, enable and expect excellent research from our staff. To this end we:

- Appoint only staff who have, or can be expected to develop, a profile of 4* and 3* research outputs and significant engagement with the research community.
- Enable and recognize research activity in our workload model: all staff are allocated dedicated research and grant-preparation time of at least 25% FTE and rising to 50% (at a salary cost in this UoA of GBP727,430 in 2019/20 alone); additional research time is protected for staff holding grants and for staff in the first years of their academic career.
- Offer close support and mentoring for all staff, particularly new staff and early career researchers (ECRs), via the research group leaders and Director of Research; for established staff, we offer support in meeting the expectations of the University, making promotion attainable: in this REF period sixteen of our staff have been promoted, four to Senior Lecturer (**Tait, Basurra, Fouad, Kovalchuk**), one to Reader (**Palomar**) and eleven to Associate Professor (**Williams ,Tawil, Aneiba, Creed, Bhogal, Mahbub, Azad, Hockman, Stables, Wilson and Harvey**).
- Using our system of annual appraisal and objective-setting, adjust workload expectations according to research performance, as reviewed by senior research staff.
- Mentor junior staff so that they are positioned to prepare for leadership opportunities and future promotion and conferment rounds.

As noted above, over the next REF cycle we expect to build capacity from 34% of staff with significant responsibility for research to 60%, which is expected to equate to returning 65 FTE.

Incentives and Requirements

Newly appointed academics are assigned an experienced or senior member of academic staff as mentor, to provide support in all aspects of work, especially the development and implementation of a personal research strategy. Doctoral supervision is a key element of the research environment for BCU and all relevant staff are expected to engage with the University's SEDA-accredited Research Supervision Training Programme.

Recognising the value of incentives, the power of local decision-making, and the desirability of giving staff early experience of budgeting, we award every research-active member of staff a Personal Research Account (PRA). The value of each account depends on individual performance against objectives for (e.g.) submitting funding bids, publishing papers of recognised quality, or seeing doctoral projects through to successful completion. The available fund can only be used to further support research activities such as:

- Buying research equipment,
- Attending conferences and networking events,
- Funds for short-term internships to support their research.

The PRA scheme is a valuable tool in helping all academic staff understand how research activity can assist them in plotting paths to promotion and conferment, so increasing the leadership and intellectual capital of our UoA and its host School.

Research staff are expected to engage with all aspects of academic life, including having membership of departmental and professional committees, assisting with supervision of research students and masters and undergraduate projects, showcasing research at university open days, playing a role in the development of research grant applications, and giving informal graduate-level courses. The University's Doctoral Research College (DRC) and School Research Committee make development opportunities and training courses available to all research-active staff.

To enhance the vibrancy of our research environment, we support a large number of active research seminars. In addition to the School seminar series, we have specialist seminar series in Artificial Intelligence and Machine Learning, Cyber Security, Future Communications Networks and Systems, HCI, and Image Processing and Computer Vision. Our seminar series have been enriched by the involvement of more than 20 international visitors, among whom have been Visiting Scholars from the Wuhan University of Science and Technology (WUST) (PR China), Anna University (India), Kazan Federal University (Russia), St Petersburg State University (Russia), and the University of Coimbre (Portugal). These visits have yielded greatly in terms of joint bids and publications. For example, Wei Hu's seven month visit from WUST, to work alongside **Wang** in the DMT Lab in 2016, has since led to joint publications of a book, 3 journal papers and 15 conference papers, the organisation of 3 conferences, and the success of a grant bid to support research student visits from WUST to BCU.

Mentoring

All new lecturers and research fellows are mentored by senior staff in their research groups. Mentors typically recommend them to international conference committees and journal editorial boards as paper reviewers or members, introduce them to collaborators in academia and industry, and offer support for promotion or future conferment applications. Research Fellows are important members of our research community; our 5G Connected Forest project alone has three Research Fellows and one Research Associate. We have a strong record of providing ample opportunities for their development and integration into permanent research or teaching and research posts. All these are essential in developing the next generation of UK researchers to lead the world in their fields.

Industry Links

Industry links are core to our strategy for both research and its impact. They are facilitated by dedicated officers in RIEE. As a UoA, we support staff to undertake industry secondments: **Wang** was seconded to a blockchain development company based in New York for 0.8 of his time for one year in 2018/19; since 2019, **Stables** has been seconded for 0.2 of his time to a spin-out company that he himself founded; **Patwary** was seconded to West Midlands 5G for 0.5 of his time for one year in 2019/20.

Research students

Scaling up our PGR community has been a key part of our strategy. By training the next generation of academics and innovators, we nurture our discipline and its impact on the communities around us. In the current cycle we have recruited students of ever-higher quality via different scholarship schemes: international funding, university scholarships (including STEAM scholarships), funded research projects, and through industrial collaborations. Recruitment takes place through a variety of channels: academic mailing lists, publicity to current UG and Masters students (helped by strong growth of our taught Master's programmes during this period); advertisements in official websites (findaphd.com and jobs.ac.uk) and via industrial partners. All applications are reviewed by two members of staff, and interviews are conducted by a panel of three.

All new PGR students undergo formal research training as part of our career development support arrangements. Within the School, they are required to complete a PGCert in Research Methods which covers generic Computer Science research skills. Additional area-specific training is given as necessary. More generic training is provided via the University's Doctoral Research College (DRC), which has a wide range of courses related to research and personal development. All PGR students are allocated a supervisory team comprising a first supervisor, one or more second supervisors and in some cases additional external advisors. Beyond their supervisory team students attend workshops with and have regular contact with the Director of PGR Studies who is available to them for additional or alternative academic and pastoral support. Support is also available from the DRC and from the University's Education Development Service (EDS).

All PGR students are offered opportunities to develop their teaching skills and supplement their income through Visiting Lecturer and Demonstrator schemes. Training is provided through dedicated 'Teaching for PGRs' modules and through training within the School (providing subject specific guidance, for example in running lab sessions). We view our PGR students as full members of our research community, moving towards formal roles in HE and/or industry. The weekly plenary seminar is entitled the "PGR Seminar" to encourage participation.

We provide all PGR students with a desktop or laptop computer and a desk within the same open office area as the research fellows, academic staff and respective leaders of their research group. This ensures that they are fully immersed in the workings and culture of their group, facilitates opportunities for research discussions with fellow students and academic staff, and thereby supplements their career enrichment beyond scheduled sessions with their supervisory teams.

Progress monitoring: For full time PGR students, regular progress reports are produced by Supervisor and student, and examined by the PGR Director of Studies and the University's Doctoral Research College (DRC). Progress reports are produced at 12 months, 24 months and 30 months, with six-monthly reporting thereafter until completion. At the end of each academic year, the full time PGR students must undergo a formal assessment for progression, involving the latest written report, oral presentation and a viva voce examination by two independent assessors. Students who have difficulty at this stage are proactively supported in developing and delivering a research and study plan, overseen by the Director of Studies and the DRC. Arrangements for part-time students are similar, with longer timeframes to reflect their part-time status. The PGR research unit is managed by a senior research staff member and administratively supported by three research administrators from the DRC. All completed PhD students have obtained appointments in industry or as researchers or junior lecturers in universities.

The success of these arrangements is evident not simply in the growth in completions and overall volume noted above, but in outstanding individual achievements by some of the PhD students. Outstanding Paper awards have been given by journals and conferences including the Audio Engineering Society's 2020 John Eargle Scholar (Matthew Cheshire); the International Conference on Emerging Technology in Computing, Communication and Electronics 2020 Outstanding Research Paper Award (Dalia Elbanna); and Best Student Paper Award in the 2018 International Conference on Computational Collective Intelligence (Fatima Abdallah).

Equality, Diversity and Inclusion (EDI)

Our School EDI committee is purposed with embedding inclusive practice across CDT. Chaired by the Associate Dean for Student Learning Experience & Academic Quality, it includes representatives from all staff and student levels. The group meets monthly and is leading the School's efforts to address diversity issues locally and in the sector. The School supports and implements policies for Equality and Diversity in Employment Policy, Trans Policy, the Equal Opportunities Policy, Maternity, Paternity, and Adoption Leaves not only for teaching staff but also for all research staff. Alongside the EDI committee, School staff are encouraged and supported to engage with groups within the university such as the Black, Asian and Minority Ethnic (BAME) Steering group, the Disabled Steering group, the Mental Health and Well-being Network, and the LGBT+ Staff Network.

Among Cat-A staff in CEBE, 40% have identified as BAME, higher than the BCU average of around 25%; while 5.6% have declared a disability, which is close to the BCU average of 5.2%. Meanwhile 76% of Cat-A CEBE staff are male compared to the BCU average of 48%. Gender equality is well recognised as a particular issue in the male-dominated discipline of computer science. We claim some success in redressing the balance. A BCU Women in Computing group (BCU WIC, @bcuwic) was setup by **Bhogal** in order to create a sense of community among women studying computing and related subjects. Events have included female computing alumni panels, social evenings, industry guest speaker sessions, and a Women-Only Careers Networking

event, with plans for debates and female team hackathon events such as *Stem 4 All* and *Women in CEBE*.

In May 2016, BCU was awarded an Athena SWAN Bronze Institutional award in recognition of its commitment to advancing gender equality through a four-year Action Plan (2016-2020) based on mentoring, interrogation of key processes, and community action. The School has encouraged and supported our female academics to participate in women leadership development programmes such as the Aurora Leadership Programme funded by Higher Education Academy. We also seek to ensure that our internal processes and culture are conducive to creating an environment in which women computer scientists can prosper and reach senior positions. Gender diversity issues are explicitly considered at all appointment and promotion panels.

Now, twelve of our academic staff (three Readers, four Senior Lecturers, and five Lecturers) are women, a majority of whom are submitted to REF2021 **(Kovalchuk, Abdallah, Fouad, Adedoyin-Olowe, Frutos-Pascual, Bhogal,** and **Palomar**). Female staff hold senior research leadership roles within the school. **Kovalchuk** leads the data science research team within the DAAI research group; **Bhogal** is Head of the Computing and Data Science Department, and Professor Sharon Cox leads the Digital Transformation Department. Professor Hanifa Shah is Pro-Vice-Chancellor & Executive Dean for the Faculty of Computing, Engineering and the Built Environment.

Section 3. Income, infrastructure and facilities

Income

As outlined in the 5a and Section 1 above, one of the missions of the university is to foster economic growth and social innovation for the benefit of citizens, businesses and public sector organisations, and in our 2014-2020 strategy we have chosen to do this is by developing sustainable industry-academic partnerships to generate income and achieve impact. Supported in this endeavour by RIEE we fund visits to networking events, such as those organised by funders like UKRI, make industry visits and host industry seminars. External and internal experts have been invited to deliver bid writing workshops and seminars. In addition, as part of the quality control procedures within the unit, we have put in place a system of peer review panels for large bids, especially to prestigious schemes. Regular cross-faculty research events and meetings have supported successful collaborations between Computing researchers and their counterparts in Engineering and the Built Environment as well as many industrial partners. Examples of interdisciplinary research involving research groups in UoAs 11, 12, and 13, are in the IoT4Win, DfMA Houses, Perseus and 5G Connected Forest projects below.

Strategically we are focussed on supporting productivity improvement in the **industrial sector** especially manufacturing, construction and digital tech, and supporting the **public sector** to provide a better environment through Smart City, Sustainability and Smart Health. We have obtained income for these ambitions in the following ways (further details on the projects and their contributions to the economy and society are presented in Section 4):

Industrial Sector
Leveraging our existing knowledge and expertise, we have carried out research in collaboration with industrial companies that also aims to improve their processes, services or products and crucially their productivity and profitability. When working with **individual companies** a major source of funding for this activity has been through Innovate UK/industry funded KTP schemes. From a base of being awarded one KTP in each of the years 2015, 2016 and 2017, with support from the Knowledge Partnership team within RIEE who initiated KTP specialist workshops with individual research groups in early 2018, staff from this UoA are currently engaged in **9 live KTP** projects, with 5 KTP awards in 2018/2019 and 4 in 2019/2020. During the REF period we have been awarded a total of GBP2.1M of KTP funding. In other cases individual companies have used their own funds alone to engage our expertise for their research issues such as GBP70K of funding from Orange Telecom (France) on security of inter-vehicle communication (2019): GBP20K from

Huopai Media (USA) on blockchain technology (2018), GBP59K from Anster Ltd towards a PhD studentship on big data in social care (2019).

We have also gained funding for **large collaborative projects** involving several industrial and academic partners and achieving strategic sector-wide impacts:

- EU H2020 funded IoT4Win - Internet of Things for Water Innovation Networks on applications of secure smart tools for water monitoring. Project value GBP638K, grant to BCU of GBP458K (2017)
- Innovate UK funded Design for Manufacture and Assembly Houses on use of knowledge-based engineering tools to support the off-site manufacture of energy-efficient houses. Project value GBP973K, grant to BCU of GBP186K (2018)
- Joint UK Government/Industry Advanced Propulsion Centre (APC) funded Perseus project for Jaguar Land Rover Electric Drive Unit manufacture on use of digital technologies to support flexible manufacturing. Project value GBP10M, grant to BCU of GBP200K.

Public Sector
We have partnered with the public sector in two major innovation and enterprise focussed European Regional Development Fund (ERDF) projects that acted as vehicles to create **regional** impacts from the results of our research and expertise. Working with regional government, NHS trusts and public transport authorities these projects supported SMEs to develop their technical capabilities to engage with the challenges and priorities of these public sector organisations:

- Innovation Engine: Project value GBP3.2M, grant to BCU of GBP318K (2015)
- Big Data Corridor: Project value GBP2.6M, grant to BCU of GBP237K (2016).

These projects led to two research and development projects directly funded by Birmingham City Council in order to enhance its technical capabilities:
- Data Science Collaboration, grant to BCU of GBP130K (2018)
- Birmingham in Real Time traffic visualisation and vision based traffic counting, grant to BCU of (GBP26K) (2017).

More widely **nationally and internationally** in the public sector:

- EU H2020 funded Red Alert – developing real-time terrorism alerts based on online activity, with police forces and other technology partners from several EU countries. Project value GBP1.7M, grant to BCU of GBP209K (2017)
- EU Erasmus+ funded PhD Hub – development of an EU-wide platform for academic/industry research collaboration. Project value GBP992K, grant to BCU of GBP117K (2017)
- DCMS funded 5G Connected Forest project - supporting Nottinghamshire Councils and industry to develop 5G connected technologies for forest monitoring and forest based business and leisure activities. Project value GBP10M, grant to BCU of GBP806K (2020).

We have also received several other smaller awards, including two audio processing mini-projects with GBP31K from EPSRC and GBP50K from AHRC funded major consortiums respectively.

From 1/8/2013 to 31/7/2020, we secured a total of **GBP4.6M** external funding working with partners in projects that had a total value of **GBP28.1M**. These figures exclude the two ERDF projects mentioned above, but do include the IoT4Win and DfMA Houses projects which are also reported in UoA12 and 13 respectively.

It should be noted that 20 of the 31 staff submitted in this return joined BCU during this REF period, and then spent time adjusting to their new roles before contributing fully towards research bids. From a relatively low base at the start of the cycle, the new staff have helped the UoA to develop a strong upward momentum in funding, as seen in Table 1, with a sustained grant capture of

around GBP1.5M in each of the last 2 years (research income of around GBP50K per person per year) and a large proportion of which has not been yet obtained as income captured in REF 4b.

13/14 (GBP)	14/15	15/16	16/17	17/18	18/19	19/20
27,974	243,590	169,735	516,004	606,889	1,484,190	1,570,000

Table 1: Research funding totals per year secured in UoA 11

This upward trend, supported by a strong pipeline of submitted bids awaiting decisions as of July 2020, gives us confidence in achieving a target of averaging GBP2M in grant awards per year during the next REF period. We intend to further enhance our role in the regional economic ecosystem by reaching and maintaining a portfolio of around 12 live KTPs, and targeting regionally devolved funding that supports digital approaches to sustainable low carbon regeneration. We will also seek to diversify our income via two routes. Firstly, by substantially strengthening our efforts in nurturing applicants and developing proposals to EPSRC, Royal Society, Leverhulme Trust, and other UK research councils and charities. Secondly, by targeting international collaborations and associated funding especially through our strong and growing presence in India.

Infrastructure and facilities

RIEE provides four dedicated research and innovation officers who are located within the CEE faculty and two central partnership managers to facilitate the research groups' activities. They provide professional administrative support, identify funding opportunities, provide assistance with grant applications, help to increase impact, and encourage multidisciplinary research. The wide-ranging practical help afforded allows the School to focus its resources on specific areas of strength.

The School has made strategic use of the University Strategic Investment Fund (SRIF) to support areas of research excellence: since 2014, circa **GBP700,000** has been invested in the research environment, infrastructure and ICT facilities, including:

- GBP125,000 on a High-Performance Computing rack that is a dedicated resource within the DAAI research group for Machine Learning computations. This complements the use of cloud platforms provided at favourable rates through our strategic relationships with MS Azure, AWS, and IBM.
- A total of GBP450K arising from SRIF, equipment donations from our work with WM5G and from the equipment budget in the 5G Connected Forest project, has allowed the CPS research group to establish a new 5G research lab that contains state-of-the-art communication technologies and equipment. This includes 5G Private Network Infrastructure, 5G end devices, Nokia NDAC (Nokia Digital Automation Cloud) software platform, IoT sensors, robotics and drones. As well as being used to support our research objectives for the 5G Forest project, this equipment has already led to further collaborations with critical infrastructure (water) and healthcare (NHS Trusts) and offers BCU the potential to create a multi-site 5G private network for non-commercial purposes.
- GBP100,000 on DMT Lab infrastructure: these include motion capture and AR/VR equipment as well as a HCI lab that provides a dedicated, controlled environment for conducting usability studies and capturing high-quality recordings of user behaviour for the study of novel interaction methods. This infrastructure accelerates the development DMT Lab's research ideas to practical prototypes and promotes our outputs to impact partners.

In December 2021 the School will move to the new GBP70M STEAMhouse building, with dedicated state-of-the-art laboratories for each of the research groups, which will also enhance interdisciplinary working. The School will occupy 35% of this building, which it will share with incubation spaces and other corporate tenants. The building is designed to engender collaboration of School researchers with the SMEs and larger tech companies located in the building as well as the many academic and business visitors from across the university and the region attending its events and using its facilities.

Staff and PGR access to relevant scholarly material has also improved with increased investment in the University library's holdings of Computer Science and Informatics resources (GBP93K spent in 2014 compared with GBP129K in 2019). Over 12,136 titles have been made available in the REF assessment period. Currently there are 67 direct subscriptions from the School's library journals' budget. Additionally, we have more than 665 relevant publications available for the subject area from the library databases such as ACM Digital Library, IEEE Xplore Digital Library, ScienceDirect Freedom Collection, SMPTE Digital Library and SpringerLINK Lecture Notes in Computer Science (LNCS) and Wiley Online Library.

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

Collaboration and interdisciplinary research

Our approach to research and impact is inherently interdisciplinary. Collaboration with other disciplines at BCU is encouraged and commonplace, but is set to receive an additional boost with our central role in the new STEAMhouse facility. Every research group in the UoA is represented in our current collaborative portfolio of funded research, and there are collaborations with researchers from every Faculty across the University as well as a diverse range of industrial and academic partners. We have numerous research collaborations with other institutions regionally, nationally and internationally, as follows.

Regionally:

Tawil has built a sustainable industrial consortium around an Open Big Data platform for public services. The EU funded Big Data Corridor project (BDC) linked West Midlands based businesses with emerging technologies and helped them combine and utilise their own and regional data. BDC worked with 43 SMEs, servicing industries in the health, transport, education, and tourism sectors. This work has led to a Birmingham City Council (BCC) funded Data Science Collaboration to research approaches for the integration of Data Analytics and AI into the operations of a number of BCC departments. Further activities with BCC, West Midlands Combined Authority and Travel for WM have been engendered by the BCU led Birmingham in Real Time project that has mapped traffic flows in the region. In the Design for Manufacture and Assembly (DFMA) Houses project funded by Innovate UK, **Tawil** has also worked with Built Environment researchers at BCU to collaborate with Hadley Industries and Walsall Housing Group to carry out research on Knowledge Based Engineering tools that help to optimise the off-site manufacture of energy efficient houses within Hadley's factories.

As described in our impact case studies, **Bassurra and Gaber** have worked with local government and Beattie Passive to apply computational methods for the design of zero carbon housing retrofit solutions. **Gaber and Faoud** have a collaboration with JLR through the APC funded Perseus project to support their plans for reconfiguring their Wolverhampton Engine Plant to manufacture Electric Drive Units. **Williams and Frutos-Pascual** have developed a collaboration between the DMT Lab and the Children's Brain Tumour Research Team at Birmingham Children's Hospital to investigate novel image processing methods for segmenting brain tumours. **Wilson** has worked with the West Birmingham and Sandwell NHS Trust to develop a virtual reality app which enhances the teaching of the correct process doctors need for eye examinations, allowing medical students to learn complex ophthalmology diagnosis.

KTPs have served as an important mechanism for achieving impact with medium-sized companies in the region. During this REF period, our UoA has been awarded 12 KTPs, of which 9 have been gained in the last 18 months – further evidence of our accelerating progress. As described in the 5a, the University now provides a well-resourced facility for engaging in KTPs. Future plans are for the UoA to be active in around 12 KTPs at any one time, eight of which should be with regional companies.

Nationally:

The staff investment described in Section 2 has led to enhanced collaborations by CPS researchers (**Aneiba, Asyhari and Abozariba**), with leading research and industry partners such as University of Surrey 5G Innovation Centre, University of Cambridge, Cranfield University, IBM, Nokia, and BT. **Asyhari** is also an academic visitor to Cranfield University, has a research collaboration and academic visitor status at Coventry University, as well as external PhD supervision at Birkbeck College and a research collaboration with the University of London's BIDA Cyber Security Lab. This CPS group also collaborated with BCU's Sensors and Control research group from UoA12 Engineering on 5G, IoT Sensing, AI/ML, UAV and Robotics technologies, helping to secure UK DCMS funding for the 5G Connected Forest Project. Internal interdisciplinarity apart, this project brings academic, industrial and local government collaboration with partners such as Nottinghamshire Country Council, Netmore IoT Solutions Ltd, Nottingham Trent University, ISPB 2006 Ltd, Gooii Ltd, Harworth Group, Parkwood Outdoors and Stagecoach. The BCU team is using the aforementioned technologies to develop a 5G-assisted forest monitoring system, which is envisioned to provide value-added services to forest stakeholders and help overcome sustainability challenges that face woodland in Nottinghamshire.

Tait has a long-standing research collaboration with the University of Cambridge/Cambridge University Hospitals around autism and early brain development, as part of the Cambridge Human Imaging and Longitudinal Development (CHILD) Study in the Autism Research Centre. He performs cross-sectional and longitudinal analysis of structural and functional MRI data using the University of Cambridge High Performance Hub for Clinical Informatics. He attends progress meetings and provides technical support to PhD students working on the CHILD dataset. As reported in section1, **Williams** has a strong collaboration with GSK nationally and internationally, as well as with Newcastle NHS Trust. **Stables** has collaborated with Dr Matthew Baker, University of Strathclyde, and Dr Dominico Viciananza, Anglia Ruskin University, on data sonification for the analysis of cancerous tissue samples by providing real-time audible feedback for clinicians and surgeons whilst using a spectroscopy device to scan in-vitro tissue samples. As well as publications in the Journal of Neuro-oncology, Analyst, and the International Conference on Auditory Display, the project led to articles in the New Scientist, Scientific American and a number national newspapers in the UK and Ireland in addition to ongoing commercialisation efforts.

Internationally:

Gaber teamed up with Engineering researchers at BCU and international technology companies and water supply consultancies to apply for a Horizon 2020 grant. The IOT4WIN project is founded on partnership with UK-based United Utilities, a Greek/Romanian technology firm, Singular Logic, and a Spanish ICT and water consultancy company. Together, they have brought academic expertise and industrial practice to bear on the use of smart sensors, IoT, Big data and AI/ML technologies to solve water use challenges, such as (i) how to provide real-time updates on the quality and quantity of water in urban areas (i) how to predict demand and future maintenance procedures for water, and (iii) identifying cyber-physical security issues such systems may face. Funding was awarded under the Marie Sklodowska-Curie Grant Agreement no.765921.

Williams is applying his image and audio processing expertise in a Horizon 2020 funded project involving numerous European academic and law enforcement partners. The Red-Alert project (https://redalertproject.eu) seeks to identify real-time indicators of extremists' threats. It is led by SIVECO, a Romanian company specialising in the execution of complex cybersecurity projects, with the involvement of (i) law enforcement agencies from the UK, Romania, Israel, Spain, and Moldova (ii) a law association based in Malta (iii) universities and research institutes from Israel, Hungary, and the UK (City University); and technology-providing companies from the UK, Spain, Israel, and Hungary.

How to connect European academic and industrial partners has been the focus of an EU-funded project led at BCU by **Aneiba** and **Palomar** (http://phdhub.eu). The aim was to establish a collaborative research platform in order to accelerate industrial research activity through and by

PhD projects. Consortium partners were the Universities of Alcalá, Thessaloniki, and Lodz, and Euroconsultants S.A., LSI Software, and Auger Torque.

Working with Orange Labs (France), **Mahbub** secured GBP70K to work on the project 'Isolation and Resilience of Autonomous Vehicles'. The project investigated mechanisms and techniques that can be applied to address the safety and security challenges in connected autonomous vehicles. Bringing cybersecurity expertise to industry, the purpose was to (i) detect and limit the impact of intrusions at the level of in-vehicle networks that can compromise the safety of autonomous vehicles, and (ii) ensure secure and isolated communication channels for the ECUs in-vehicle network.

In 2018, **Hockman** established a productive collaboration and shared expertise between DMT Lab and Georgia Institute of Technology (US), AudioLabs FAU (DE),and Johannes Kepler University Linz (AT) on a Music Transcription and Community Evaluation research project.

In 2019 **Creed** developed a partnership with Microsoft to develop new technology that will help people with disabilities become more independent in the workplace. As a grantee of Microsoft's AI for Accessibility programme, BCU has received GBP15,500 to help develop a prototype technology system that enables people with limited mobility to control computers using voice commands and eye movement. The new technology aims to unlock a range of careers for people with disabilities by removing the need for a mouse and keyboard, paving the way for their increased participation in professions such as coding, web development and computer programming, which in turn contributes to filling nationwide skills gaps.

With a view to progressing and widening the scope of our research in applications of digital technology in the manufacturing sector, BCU has been developing the Munjal-BCU Centre of Innovation and Entrepreneurship (STEAMhouse India) in collaboration with the Hero group of companies – the largest (by volume) manufacturers of motorcycles and bicycles in the world. To support future research at the Centre, we have developed collaborations with several universities in that region of India including Indian Institute of Technology Ropar, Panjab University, Lovely Professional University and Chandigarh University.

Contributions to the discipline and community leadership

Members of our UoA are active in launching and leading activities for the benefit of the scientific community and broader public, enhancing the development of our subject and its application to real-world problems. Through chairing conferences and panels, serving on editorial boards or scientific committees, acting as peer reviewers or examiners, we have helped our discipline come up with new solutions to tough problems; through working with SMEs and other non-academic organisations, we have worked to improve the living environments and potential of our citizens. The latter aim is supported by our strong and active Industrial Advisory Board, with members from SAS, Microsoft, Cisco, Oracle, ABP Food Group, Arqiva, Nccgroup, Mottmac, Qlik, Coalfire, Verizon UK, and Music Tribe.

Individual contributions include:

Gaber has chaired conferences and programme committees include (1) 34th International ECMS Conference on Modelling and Simulation (ECMS 2020), Track co-chair for Machine Learning for Big Data; (2) 3rd IEEE International Conference on Data Science and Computational Intelligence (DSCI 2019), General co-chair; (3) 39th European Conference on Information Retrieval (ECIR 2017), Doctoral Colloquium co-chair; (4) IEEE Mobile Data Management (MDM 2016), Programme committee co-chair; (5) 5th International Conference on Emerging Internetworking, Data & Web Technologies (EIDWT 2016), Track chair for Machine Learning on Large Data Sets & Massive Processing; (6) 13th International Conference on Mobile and Ubiquitous Multimedia (MUM 2014),Demonstrations and Posters chair; (7) 16th IEEE International Conference on High Performance Computing and Communications (HPCC 2014), Track chair for Database Applications and Data Mining; (8) IEEE Mobile Data Management (MDM2014), Advanced

Seminars co-chair; (9) 2014 FTRA International Symposium on Frontier and Innovation in Future Computing and Communications (FCC 2014), Programme committee co-chair. Alongside **Basurra**, he won the 2018 IEEE Access Best Multimedia Award Part 2.

Williams has chaired conference tracks and programme committees for IEEE International Symposium on Mixed and Augmented Reality (ISMAR) - Scientific and Technical Committee Member (2016 to present) and VS Games Committee (2017 to present) as well as performing a grant application review role for EPSRC Digital Economies - panel member (February 2019). He has also reviewed for the journals: i) IEEE TVCG; ii) IEEE GCA; iii) IEEE SPL; iv) Elsevier CVIU. **Stables** was the Head of the Local Organising Committee for the 22nd International Conference on Digital Audio Effects (DAFX-19) held at BCU in September 2019. He founded the Workshop on Intelligent Music Production and its 5th Workshop was co-hosted with DAFX-19. He also organised the 16th Rhythm Production and Perception Workshop hosted at BCU in 2016. He has reviewed research proposals to ERC. Alongside **Hockman,** he won second place in the 2015 DAFX Best Paper Award, who was also an organiser of the 9th International Workshop on Folk Music Analysis hosted at BCU in 2019.

Aneiba is a member of the research bids reviewers at the EU H2020 evaluation panel for their Digital Innovation Hubs (DIH) federation for large-scale adoption of digital technologies by European SMEs, "DigiFed"; and Academic Editor for MDPI Future Internet Journal. Aneiba has reviewed articles for Elsevier Computer Networks journal. He has initiated an IoT community by building the first citywide open public LoRaWAN network in the city of Birmingham (@TTN_Birmingham**)** as a contribution to the regional innovation community. **Asyhari** is Academic Editor, PeerJ Computer Science and Associate Editor for IEEE Access. He is member of the technical committees for International Conference on Artificial Intelligence, Automation and Algorithm (AI2A), IEEE International Conference on Communications (ICC), International Conference on Information Technology and Computer Communications (ITCC), International Conference on Cyber-Technologies and Cyber-Systems. **Arshad** is Associate Editor for the IEEE Access journal, Associate Editor for the Cluster Computing journal, and has been Guest Editor for a Special Issue on Exploring the Socializing Aspect of Wearable Internet of Things (WIoT) in the Elsevier Internet of Things journal.

Kovalchuk has been a member of the editorial board of MPDI journal "Computers" since 2007, the Co-Chair of the IEEE Workshop on e-Health Pervasive Wireless Applications and Services since 2013, and has reviewed EPSRC grant applications. **Azad** has performed an editorial role for Genetic Programming and Evolvable Machines - Springer, as well as reviewing grant applications for the European Research Council (ERC), and NERC/EPSRC. Dr Azad has also reviewed articles for the journals: i) IEEE Transactions on Evolutionary Computation; ii) Genetic Programming and Evolvable Machines - Springer; iii) Applied Soft Computing - Elsevier Publishers. Winner of Silver award GECCO HUMIES 2015. **Abdelsamea** is a reviewer for a number of journals including (i) IET Image Processing (ii) IEEE Transactions on Neural Networks and Learning Systems (iii) IEEE Transactions on Medical Imaging (iv) Neurocomputing (v) IEEE Signal Processing Letters, and (vi) Journal of Computers.

Harvey chaired tracks at the following conferences: (i) International Conference on Graphics and Interaction 2017, 2018 and 2019 (ii) The Visual Computer 2015 and 2016 (iii) Spring Conference of Computer Graphics 2015 and 2016 (iv) IEEE International Conference on Multimedia and Expo 2019 and 2020; and (v) VS Games (2018 and 2019). He has also served as a reviewer for EPSRC. **Wang** is AES Standards Committee Member of SC-02-02 & SC-02-12-H and ETSI Industry Specification Group (ISG) on Non IP Networking (ISG NIN). He was the head of the organising Committee for SmartCom 2019: The 4th International Conference on Smart Computing and Communication, and SmartBlock 2019: The International Conference on Smart Blockchain.