Institution: University of Salford

Unit of Assessment: 13

1. Unit context and structure, research and impact strategy

Unit context and structure

The fabric of society and the shaping of the built environment is significantly impacted by the accelerating pace of urbanisation globally. Salford's research responds to the fast-changing realities in our cities by creating new knowledge in emerging fields, such as smart cities, hypermobility and the increasing integration of information systems and technology into all areas of urban life. We expand original and multidisciplinary academic thought on planning, design, construction and evaluating sustainable urban environments, focusing on the interface between the physical design, construction, functioning and development of future urban spaces, and the lives, health, behaviour and movement of the people who inhabit cities. With key industry and policy stakeholders we deliver global impact in the form of sustainable methods and processes of construction, energy efficiency and digital innovation. By seeking to understand the key questions underpinning the development of cities as equitable, resilient and liveable spaces for all, and how citizens, individually and collectively, will shape urban futures, we make unique and valuable contributions to the discipline.

Research is delivered by 5 groups that cluster staff around globally defined, multidisciplinary challenges. The submission spans 42.03 FTE staff, listed below against their primary affiliation, noting that many collaborate across groups:

- **Acoustics Research Group (ARG; 12.2 FTE: Cox**, **Davies W**, **Elliott**, **Fazenda**, **Hargreaves**, **Hughes**, **Li**, **Meggitt**, **Moorhouse**, **Torija-Martinez**, **Umnova**, **Von-Hunerbein**, **Waddington):** 60+ years of research in acoustic measurement, architectural and building acoustics, audio engineering, computer modelling of sound, environmental noise and soundscapes, materials for acoustics, psychoacoustics and vibro-acoustics, with established excellence in public engagement.

- **Applied Buildings and Energy Research Group (ABERG; 8 FTE: Al-Maiyah**, **Farmer**, **Fitton**, **Ji**, **Oladokun**, **Paraskevas**, **Swan**, **Taleghani):** smart homes and smart meters, retrofit, sensor technology and energy efficiency including whole building testing through Energy House facilities.

- **Disaster Resilience (DR; 3 FTE: Fernando**, **Ingirige**, **Keraminiyage):** globally relevant interdisciplinary work to enable countries and communities to plan, prepare for and recover from, natural and man-made disasters. This includes capacity building for disaster mitigation and reconstruction, post-conflict reconstruction and community engagement, waste-management and collaborative learning/training environments, including VR and immersive technologies through our THINKLab facility.

- **Infrastructure Research Group (IRG; 6.83 FTE: An**, **Aziz**, **Ekundayo**, **Fleming**, **Higham**, **Underwood**, **Yousif):** aims to achieve greater efficiency from existing housing and transport infrastructure and providing novel solutions for new construction including lean project delivery and socially-responsible procurement. **IRG** also encompasses Digital Built Environment development, including Building Information Modelling (BIM) and Geographical Information System (GIS).

- **Smart Urban Futures (SURF; 12 FTE: Davey**, **Davies N**, **Elkadi**, **Fois**, **Gyau**, **Hayes**, **Kenawy**, **Lee**, **Poppelreuter**, **Sherriff**, **Trillo**, **Wootton):** aims to understand contemporary societal and ecological challenges and future factors underpinning climate-change resilient cities. This includes urban ecology, future mobility, food security and adaptation to changing environments.

All staff are core members of a Research Group and are encouraged to become associate members of other groups/centres across the University to support interdisciplinarity. This facilitates active participation in the development of thematic research strategies, making explicit research synergies and ensuring research cohesion. Recognising existing collaborations within the University around built environment themes, two staff are submitted into UoA13 from the Arts, Media and Communication Research Centre (**Davey**, **Wootton** in **IRG**), one from the Centre for Social and Health Research (**Sherriff** in **SURF**) and one from the Ecosystems and Environment Research Centre; **SURF**: **Fois**).

ARG is situated within Salford Innovation Research Centre (**SIRC**); a multi-disciplinary environment focusing on engineering, robotics and autonomous systems, computer science and advanced materials research. The other four groups are located within the Centre for Urban Processes, Resilient Infrastructures & Sustainable Built Environments (**UPRISE**). Both **SIRC** and **UPRISE** are Research Centres within the School of Science, Engineering and Environment.

Major achievements 2014 – 2020

Our REF2014 environment submission was rated highly, with a profile of 50% world-leading and 37.5% internationally excellent quality. Throughout this period, we have successfully built on our longstanding excellence in built environment and acoustics research, securing investment in our unique, state-of-the-art facilities, supporting our staff to grow as research leaders and translating research into practice internationally and within the UK. We achieved the following three strategic aims:

1. ***Continue to invest in our unique facilities as the underpinning support for all research and impact activities***

The Energy House facility was established in 2011, (£5m, £2.5m from ERDF), to address the retrofit and decarbonisation agendas. Throughout this REF period, this has delivered innovation around retrofit of existing homes (£520k, BEIS), building performance and digital control technologies that led to the development of the Smart Meters Smart Homes Lab (£270k; HEIF and in-kind), detailed further in Section 3. The team has used research outcomes to advise on decarbonisation strategy (GMCA Low Carbon Buildings and Retrofit Strategy, Leeds City Region Retrofit Strategy, BEIS Retrofit Advisory, **Swan**), and standards for building performance and assessment and delivery (SAPSIG advisory for UK regulatory energy model for homes, Building Regulations, PAS2035 retrofit delivery standards, **Fitton**).

This success has culminated in Energy House 2.0 (EH2); a £16.5m investment (£8.2m secured from ERDF in 2018 to **Swan**, **Fitton**, with £3m Office for Students and £5m University funding). EH2, to be completed in 2022, has been specifically designed to replicate the conditions of 95% of the global populated areas of the world, creating unique research infrastructure to answer issues of energy and building performance and the decarbonisation agenda at an international scale. EH2 will bring together established research excellence in whole building efficiency and retrofit, modern methods of construction and building types and future energy systems issues.

2. ***Continue to lead built environment sector developments and set the international research agenda through excellent collaborative research***

Our research leads to innovations and improvements across built environment industries and we have undertaken projects with a range of companies to co-develop solutions. We have received £13.87m of competitively awarded funding, placing us 7th in the sector for total income reported to the 'Architecture, Built Environment and Planning' cost centre, 2013-19 (HESA). Reflecting our priority of Industry Collaboration we are 4th in the sector for total income from UK industry, commerce and public corporations 2013-19 (HESA).

Our research outputs receive considerable attention from the discipline and contribute to wider social and economic impact. Since 2014, 26% of our outputs were rated in the top 10% most cited

publications worldwide (field-weighted) and outputs held within our University of Salford Institutional Repository (USIR) authored by our 43 staff were downloaded ~296k times during this REF period. Our research generates measurable impact: 11 outputs are utilised in policy documents nationally and internationally, and 5 outputs are utilised in patents (see section 4). Our highest altmetric-scored output (**Torija-Martinez; ARG**) was the result of an interdisciplinary collaboration combining the technological, economic and environmental acoustics aspects of an electric aircraft. Published in *Nature Energy*, it is ranked in the top 5% of all outputs scored by Altmetric and has been referenced in 3 policy documents and 12 news articles.

Responding to international priorities, we have been involved in 21 EC funded consortia (H2020 and FP7). We have acquired GCRF awards (See Section 3) including the £1.2m 3-year EPSRC 'MOBILISE' (**IRG**) project that aims to construct a collaborative multi-agency platform for building resilient communities in Sri Lanka, Pakistan and Malaysia; and ESRC's £856k 3-year 'TRANSCEND' project that extends into the area of risk-sensitive urban development and equitable resilience. These projects have accelerated **DR's** plans for generating impact in the form of policy making at an international level; examples include collaboration with international governmental and non-governmental stakeholders and thinktanks, including the Construction Research Institute of Malaysia, the Institute of Policy Studies, UNICEF and the Climate Change Secretariat of the Ministry of Environment in Sri Lanka.

Our expertise in digital built environments, especially '*building Information modelling and management*' (BIM) continues to contribute to national developments, specifically the UK Government and construction industry's commitment to drive digital transformation for improved efficiency, productivity and whole-life value of built environment assets. **Underwood** has been involved in developing and delivering the UK BIM Strategy with the goal to raise digital skill levels in the construction industry through chairing the 'UK BIM Academic Forum' and a national BIM4Education initiative project to develop the UK BIM Framework and the BS EN ISO19650 series of standards (published in 2019, this is the international standard for managing information over the lifecycle of a built asset using BIM).

3. Grow inter- and multidisciplinary research to address complex built environment challenges

Our Research Groups are fully engaged in cross-disciplinary discourse and research among built environment professions, industry and academic bodies. To continue to appropriately and effectively address multi-faceted, real-world problems we have formed a staff base with expertise across many disciplines associated with the built environment, including: acousticians, architects, architectural historians, architectural technologists, building economists, building physicists, building service engineers, civil engineers, construction managers, cultural theorists, land surveyors, material scientists, planners, quantity surveyors, structural engineers and psychologists.

Success through interdisciplinary approaches can be illustrated through funded projects tackling complex environmental challenges. For example, IGNITION (**Elkadi** ERDF, €4.5m, with £1.2m to Salford) is a joint research project led by the Greater Manchester Combined Authority (GMCA)'s Resilience Unit and 10 other partners with the University providing core expertise in urban green infrastructure. Researchers from **SURF** and the Environment and Ecosystems Research Centre (EERC, returned to UoA7) are researching solutions into improvements to the urban environment towards meeting sustainability targets such as water usage and clean air.

Research group areas of focus and achievements

Acoustics Research Group (ARG)
ARG focuses on the global challenges of decarbonisation of the built environment, clean transport systems and healthy living and ageing. Led by **Cox,** the group spans expertise in audio technology, engineering acoustics and vibration, environmental acoustics, with work contributing to new ISO standards and guidance used in buildings, product design and noise assessment

methods. These have been adopted as standard practice by government bodies, test houses and manufacturers, particularly in construction, automotive and aerospace sectors. **ARG** has received £3.8m of external funding to undertake 40 projects in this REF period.

ARG's work with creative and broadcast industries focuses on improving accessibility in sound broadcasting. **ARG** is a primary partner in the BBC Audio Research Partnership, set up in 2011 to bring together the world's top audio research groups to develop the next generation of audio broadcast technology. As part of this partnership, **ARG** has participated in major research projects this REF period: EPSRC £457k (2012-15) 'Perception and Automated Assessment of Recorded Audio Quality' (**Cox** as PI, **Fazenda and Li**); EPSRC £2.6m (2013-19): S3A Future Spatial Audio for an Immersive Listener Experience at Home (**Cox**, **Davies**, **Fazenda**); and EPSRC, £1.27m, (2016-19) 'Making Sense of Sounds' (**Cox**, **Davies W**). These have developed and demonstrated new ways to make sense from large amounts of everyday sounds, focusing on real-world non-music, non-speech sounds and soundscapes to enable more productive interaction with sound data and improve the lives of people in their sound environment.

We are also developing new health technologies (hearing devices) and acoustic methods within medical diagnostics, for example, EPSRC £288k (2019-24; **Cox**) 'Challenges to Revolutionise Hearing Device Processing'. This research is using innovative approaches in speech technology and machine learning to revolutionise the function of hearing devices, particularly addressing current functional deficits around hearing speech in noise in different environments e.g. the home or public spaces.

The €5m EU FP7-Transport CARGOVIBES (Attenuation of ground-borne vibration affecting residents near freight railway lines; **Waddington**), assessed new measures to ensure acceptable levels of vibration for residents living in the vicinity of freight railway lines to facilitate the extension of EU freight traffic on rail. This project delivered a guideline on the evaluation of adverse effects, for use of engineering companies doing environmental impact studies and for use by policy makers seeking to balance costs and benefits of rail traffic. Other notable **ARG** initiatives include: an EPSRC-funded (£556k) project on embedding measured data within a computational framework for vibro-acoustic design (**Elliot**, **Moorhouse**) and a Knowledge Transfer Partnership (KTP) project with Farrat Isolevel, which applied methods for characterising vibration sources developed by **Elliot** and **Moorhouse** to buildings and a PhD studentship on Acoustic metamaterials for harsh environments (**Elliot**, **Umnova**).

We have received numerous national and international awards including: Institute of Acoustics – Tyndall Medal, Engineering Medal, Honorary Fellowship, and Young Persons' Award for Innovation in Acoustical Engineering; EPSRC Connected Nation Pioneer award; IET's Leslie H Paddle scholarship; Acoustical Society of America Science Writing Award; and Audio Engineering Society Silver Medal. They are named inventors or have been instrumental in the development of 2 patents and 1 policy (see section 4). Research impact in this area (REF3) describes how the standard methodologies and guidance developed by **ARG** have been used in buildings, product design and noise assessment. Direct commercial exploitation of the research by a range of manufacturers in construction and transportation (automotive and aerospace) has a collective value of over £1 billion.

Applied Buildings and Energy Research Group (ABERG)

The former area of '*energy to building research'* was coupled with '*impact of building on health and welfare of individuals and communities'* to form 'building performance' and is led by **ABERG**. **ABERG's** strategy has been to support energy transition in the UK and globally, by developing outward-facing partnerships (with private, public and the third sector), to focus on delivering strong evidenced-based mechanisms to support changes in domestic and small commercial energy systems. **ABERG** has received £1.9m to deliver research using the innovative capabilities of our Energy House and Smart Meters Smart Homes Lab (see section 3). Example projects include: £244k 2-year (**Swan**) retrofit optimisation with Radbot to assess the use of smart controls to establish the performance of sustainable retrofit in homes; and the £521k 21-month 'DEEP' project

(**Fitton**) to demonstrate energy efficiency, working with Leeds Beckett and Loughborough Universities.

Impact in the Group (REF3) addresses the Climate Emergency declaration, that requires a change to how we consume energy in buildings. Our work delivers solutions in support of energy and emission savings in new and existing homes, supporting innovators to rapidly bring products to market. **ABERG** has been involved in delivering 35,000,000t of CO_2 emissions savings and helped test 22 energy-saving products, leading to business revenues of £1.03m and the improvement of 1,842 homes across Greater Manchester.

ABERG received the 2017 Green Gown Awards for 'Sustainability Excellence', the 2015 'Love Energy Award: Star of the Future' for delivering the green agenda and were runners-up in the Guardian Universities Awards 2019 for 'Business Collaboration'. Research has received coverage on national TV (including BBC News and Channel 5's Gadget Show), radio (including Radio 5 Live) and national press (including Guardian, Mirror and Telegraph).

Disaster Resilience (DR)

DR undertakes national and international research into *'disaster management and resilience'* and the strategy within this period has been to extend research to cover the full lifecycle of disaster planning. Working closely with low- and middle-income countries (e.g. India, Malaysia, Sri Lanka) vulnerable to natural disasters or the impacts of climate change we have helped improve resilience to extreme weather events. **DR** influences national and international advocacy/policy-making initiatives, sustaining lives and livelihoods through development schemes that do not exacerbate climate change impacts/factors. Investigating the phases of preparedness, mitigation, recovery and rehabilitation was facilitated by £3m of funded research from UKRI, EU and charities/trusts, e.g. the GCRF/EPSRC £1.2m (2017-2021) 'A Collaborative Multi-agency Platform for Building Resilient Communities' with 18 project partners including the Cabinet Office, Asian Disaster Preparedness Centre and Rural Development Foundation, Pakistan.

Impact emerging from this area (REF3) exemplifies our focus on building resilience through digitally enabled multi-agency collaboration involving relevant government agencies and communities. We have developed advanced technology solutions that allow the sharing of disconnected data on vulnerability, hazard prediction and exposure, enabling collective decision-making that reduces risk.

Infrastructure Research Group (IRG)

IRG has attracted £1.7m from major funders to support the '*delivery and maintenance of housing, highways and railways infrastructure*' globally. Research leads to solutions particularly around maintenance and operation, safety and reliability, long-term prediction relationships, analytics, data integrity and information quality. In Vietnam, Jordan, the Philippines and Turkey (see section 4) this has led to secure, sustainable and resilient energy supplies and developing energy efficient and carbon neutral buildings. With UK infrastructure clients and contractors, projects have aligned to the UK Government's roadmap for energy efficient, carbon neutral buildings, improved traffic management, '*digital architecture'* and minimising risks through evidence-based design, construction and maintenance.

The €6.49m EU FP7 Design4Energy project (2013-17) (**Underwood**, with **Fernando**, **DR**) developed an innovative integrated design methodology to allow stakeholders to optimise the energy efficiency of buildings, both at individual and neighbourhood levels. Digital built environment research has included a combination of UK/EU government funded research, KTP and knowledge exchange projects, e.g. **Underwood** worked with the Beijing Construction and Engineering Group to pilot improved efficiencies through new BIM-based collaborative work practices.

Sustainable Urban Futures (SURF)

SURF has acquired £3.38m to investigate the interface between the physical design, construction, functioning and development of urban spaces; and the lives, health, behaviour and movement of humans who live in cities, focusing on '*smart urban futures*'. In the £4m ERDF 'IGNITION' project (2018-21), Salford was awarded £1.2m (**Elkadi**) to construct a nature-based solution living lab on our Salford campus (raingardens, street trees, living green roofs/walls), to evaluate impact, develop innovative financing solutions and tackle socio-environmental challenges. The project experiments with integral national building specification (NBS) models that would be attractive to differing investors. The findings of this project are already feeding into numerous initiatives to ensure that the green infrastructure in Greater Manchester is increased by 30%, enabling Manchester to be a leader in NBS in cities.

The Cutting Crime Impact project (co-ordinated by **Davey** and **Wootton**; €3.1m, H2020, 2018-2021) is an 8-country partnership supporting law enforcement agencies and relevant local and security policymakers to reduce the impact of crime and prevent crime from occurring through improved urban design and planning. This leads from previous work, which forms the basis of our impact in this area (REF3), to develop ProtectED: a spin-out, not-for-profit Community Interest Company focusing on student security and welfare. ProtectED is the UK's first Code of Practice and accreditation scheme and is providing training and accreditation across the UK. This evidence-based approach to addressing student security is recognised by the professional security sector and has impacted the work of the government regulator of the UK security industry, security professionals and British Council representatives. It was awarded the 2019 Security & Fire Excellence prize for 'Contribution to Standards' and won the 2020 Outstanding Security Performance Award for 'Customer Service Initiative'.

Future research and impact strategy

Vision: *To be a leading global research community focused on designing and embracing disruptive technologies to addresses the multifaceted challenges within our communities, towns, and cities, and how we interact with them as individual citizens*.

Group aims:

- **ARG** – incorporating vibration and acoustic design into new product development, new construction materials, decarbonisation and 'Industry 4.0'; and expanding further into medical and psychoacoustics, e.g. design for accessibility for people with atypical cognition and studying the effects of noise on mental health

- **ABERG** – reinforce existing and foster further international collaboration and grow the team to fully utilise the potential of Energy House 2.0 laboratories

- **DR** – expand work across South East Asia on using technology to prepare communities against flooding and utilise this knowledge to inform flood defence policy and practice in the UK

- **IRG** – use robotics and artificial intelligence to design and construct new productivity and performance platforms

- **SURF** – focus on supporting social and economic infrastructure as part of the construction of technologically driven climate-change resilient cities

Objectives:

- ***Increase investment in research infrastructure*** and maximise opportunities from current developments. Alongside EH2, we are constructing a £65m School of Science, Engineering and Environment building to open in 2022/23. This will facilitate

interdisciplinary solutions significant to infrastructure decarbonisation challenges. The next phase of the Campus Masterplan (2020-24) focuses on investment in a state-of-the-art Acoustics building to further our global acoustics research and impact linked to the aims of **ARG**.

- ***Increase the diversity and number of staff*** by developing early career researchers, particularly women, through the three-year research plan process and making strategic external appointments to expand expertise

- ***Increase the number of postgraduate researcher (PGR) enrolments and completions*** through growth in domestic and international recruitment. This will allow us to boost our knowledge base, enrich our scholarly community and grow the next generation of scholars

- ***Increase the value and duration of external research funding*** to provide a stable and sustainable income stream. This will be achieved through the three-year research planning process and increased collaborative research grant applications with international partners, that will enhance our reach and reputation internationally

- ***Expand the impact of our research*** for a diversity of non-academic users across industry and the public sector through continued staff development in this area.

Supporting research integrity, open access and open research

Overarching research governance is delivered through the School Research and Enterprise Committee (SREC), chaired by the Associate Dean Research and Innovation (ADRI). SREC includes Research Centre (professorial) leads to monitor, manage and report on research integrity across the School. All projects involving primary data collection require approval from the School Ethics review panels and Approvals committee. SEE has piloted the University's new ethics review scheme to streamline and provide prompt feedback for ethical approval and to ensure transparency and visibility of ethical and integrity considerations.

To ensure data are sustainably accessible and discoverable and to enhance the integrity and efficiency of data sharing, validation and re-use, research outputs are deposited and made available open-access as pre-prints or final 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 programmes have access to Open Access funding to support Article Processing Charges (OA Gold). Institutional Open Access Funds are available based on internal peer review of the paper by the Research Centre Director and ADRI. Agreements with several academic journal publishers reduce or remove the cost of publishing open access in their journals: 49 outputs have benefitted from Gold OA support via institutional funding or publisher deals.

2. People

Staffing strategy

Our ongoing aim is to recruit staff into our 5 key areas who have established research track records and international presence or are early career researchers (ECRs) with exceptional research promise. This strategy is to ensure our academic staff will provide an excellent PhD supervision experience, undertake high quality research and generate real-word impact from research projects.

We are returning 43 staff: 13 Professors (30%), 6 Readers (14%), 7 Senior Lecturers (SL; 16%), 9 Lecturers (L; 21%) and 8 Research Fellows (RF; 19%). As approximately one third are Professors, we have in place strong leadership to set group strategy and effective mentoring for junior staff. With 30% of the group at mid-career level and 40% ECRs there exists a pipeline to develop future research leaders ensuring the sustainability of the Research Groups.

Twenty-three researchers (53% of submitted staff) have been recruited since 2014 strengthening capacity in each of our research groups: 4 Professors (2 IRG, 1 DR, 1 SURF), 2 Readers (1 DR, 1 SURF), 2 Senior Lecturers (1 ABERG, 1 IRG), 7 Lecturers (3 SURF, 2 ARG, 2 IRG) and 8 Researchers (4 ABERG, 3 SURF, 1 ARG). This has expanded our range of expertise, for example: **Fois**, **Gyau** and **Trillo** together link human geography, heritage conservation and international sustainable urban development (**SURF**) and **Al-Maiyah**, **Oladokun** and **Taleghani** increase capacity around thermal comfort and building energy efficiency (**ABERG**). We have increased the number of female staff through recruitment (6/23; 26%), which has resulted in a modest increase in the proportion of women submitted to this REF: from 18% in REF2014 to 21% now. In contrast we have a higher representation of staff from a BAME background (28%) compared to the University's academic staff population overall (13%).

Through our Athena SWAN action plan (**Hayes**, **Lee** and **Swan** have roles on the SEE Athena SWAN Self-Assessment Team) we have taken steps to ensure that our internal processes create an inclusive environment, e.g. female representation on all selection and recruitment panels and mandatory training appropriate to staff roles, e.g. recruitment and selection, widening participation, ethics, unconscious bias and equality and diversity. This includes REF-related processes, for which we ensured male and female representation in the Unit submission team. In line with our REF2021 Code of Practice, the attribution of REF2 outputs to staff has been subject to an equality impact assessment. Our REF2 submission is close to the gender ratio of our submitted staff, with 18% of outputs attributed to a female author (-3% compared to the proportion of female submitted staff) and 35% of outputs attributed to staff from a BAME background (-3% compared to our proportion of BAME submitted staff).

A central aspect of our future staff strategy is to improve the low proportion of women in our Research Groups and also seek to develop initiatives to address this more widely within built environment and engineering research disciplines, through engaging with young people from diverse backgrounds to encourage interest in pursuing careers in these areas.

Formal staff development mechanisms

Research workload is set by the School under guidelines from the University. All staff undergo the University's annual 'Performance and Development Review' (PDR) process, which includes a research review as part of the overall academic workload and opportunities to request training/support. Since 2019, all staff are invited to submit a three-year plan, detailing their current level of research activity and plans, which are peer-reviewed and feed into PDR processes. The outcomes of this peer review inform research development needs and workload allocations as part of an improved, transparent process for research resourcing.

Academic staff can seek a review against the 'Academic Career Path' criteria annually and apply for promotion to Reader/Professor via the annual University Professorial Promotions Committee, which includes external verification of their research profile. These opportunities have supported 14 staff to progress in their careers during the current REF cycle: from SL/Reader to Prof: **Aziz**, **Davey**, **Davies W**, **Swan, Underwood** and **Waddington**; from L/SL/RF to Reader: **Elliott**, **Fazenda**, **Fitton** and **Trillo***;* from L to SL: **Al-Maiyah** and **Fleming***;* from RF to L: **Hargreaves** and **Kenawy**. Three researchers hold fractional posts (0.2-0.83FTE) including 2 Professors with parental responsibilities.

Reflecting our commitment towards developing home-grown talent, 40% of our submitted staff are Salford alumni; with 3 recruited to Lecturer positions during this REF period after receiving their PhDs and 4 of these have been Research Group Leads. Research development for newly appointed staff and ECRs is supported through: i) reduced teaching loads during their first year; ii) workload and fee-waivers for staff wishing to undertake PhDs; (e.g. **Ekundayo**, **Fitton**, **Fleming**); iii) the annual Vice-Chancellor's Research Scholarship Scheme providing £2k financial support and 10% additional research workload allocation (e.g. **Hargreaves**). We support new members of staff within 2 years of appointment and those returning from maternity/long-term sick

leave with a separate internal Research Centre fund of £30k, allocated annually, to provide start-up and pump-priming support.

Our Research Groups operate a voluntary research mentoring policy for all staff. We determined that this opt-in approach best supports effective delivery of tailored support and the development of meaningful mentor-mentee relationships. All researchers are given the opportunity to be appointed a senior research mentor to provide guidance in developing their research career, including project development, grant applications, publication peer review and developing partnerships/collaborations. Over REF2014 30 mentoring relationships have been supported, equating to 70% of all submitted staff. This led to successful promotions, e.g. for **Trillo** (Lecturer to Reader, supported by **Elkadi**).

Supporting the development of high-quality grants, outputs and impact

The University's Research & Knowledge Exchange Directorate (RKE) provides research bidding support in the form of a dedicated support office and mechanisms for internal peer review. In addition to RKE's training, **SIRC/UPRISE** organise discipline-specific sessions for staff including: research impact, writing successful proposals, research ethics, writing retreats and sandpit events to support interdisciplinary collaboration. Sessions are arranged at different times to support staff attendance (including PT, research and contract staff and staff with parental responsibilities).

In 2018/19, we created 9 impact action plans across our 5 groups to develop concepts and technologies around resilience, wellbeing, sustainable use of energy and materials. These will contribute to priorities such as the circular economy agenda in the built environment – spanning cities, transport systems and infrastructure – to work together to deliver solutions for new forms and challenges of (urban) living. Our School Impact Coordinator meets regularly with impact action plan holders to monitor progress against objectives.

Across the REF period £320k of central University and SIRC/UPRISE internal funding has supported pump-priming of projects, research/networking visits or conference attendance. This includes development of strategic feasibility projects, e.g. **Moorhouse** awarded £5k to commercialise a PhD project in building acoustics; **Torija-Martinez** awarded £10k to design a drone microphone for quiet audio recording. This project is currently being tested within a partner organisation and an application for funding will be made to Innovate UK; **Elliott** awarded £5k to develop a prototype sound source for acoustic measurement, which led to a patent application for condition monitoring). **Poppelreuter** awarded £2k to support work on her book '*Before 1939: German-Speaking Women Architects in American Exile*', which crosses sociology, history and architecture as an interdisciplinary project.

We actively create opportunities for staff to interact for productive intellectual exchanges and peer support. Our bi-monthly 'Architecture Matters' lecture series, running since 2018, includes lunchtime/evening talks by our academics and invited speakers for our staff and postgraduate students to engage with topical debates in our discipline (e.g. Stephen Hodder, previously president of RIBA and Martin Kirkpatrick from Buttress Architects, Manchester). We have established a SEE monthly Professoriate forum to feed into SREC and the ADRI organises weekly all-staff research meetings as an informal mechanism to discuss upcoming opportunities. As the SEE unification process completes we will also implement an ECR network to ensure that this community has a voice at SREC.

Ensuring an excellent postgraduate research (PGR) experience

Our PGRs are integral to our research activity and culture and we have significantly grown the size of this community. We supported 248 PhD awards (~35 annually); a 92% increase from REF2014. We recognise that the majority of our PGR completions are male (76%), and we have taken initial steps to increase female academic leadership though promoting/appointing 2 female professors, **Davey** and **Lee**, to improve the proportion of female PGR supervisors available as role models.

Of our PhD awards, 32% domicile in the UK/EU, 68% are international (with Nigeria representing 10%, and Saudi and Iraq 7% each) and 69% identify as BAME. To support our large international cohort, we provide additional English language support and social events (see below). We offer diverse PGR modes/pathways that enables us to flexibly accommodate differing student needs. These include FT, PT, PT split-site, FT and PT distance-learning, PhD by Published Works and research based professional doctorates. Of the total completions, 19 (~8% of the total) were professional doctorates (Table 1).

Table 1. Disaggregated doctoral completions.

	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
PhD	45	37	28	37	35	33	14
Prof Doc	1	3	3	2	5	2	3
Total (REF4a)	46	40	31	39	40	35	17

PGR students are aligned to their supervisor's Research Group upon enrolment and invited to participate in all School and Research Group seminars and guest lectures with the overarching aim of nurturing future talent. PGRs are provided with opportunities to deliver a controlled amount of teaching, through assisting in tutorials/labs and/or dissertation supervision in an hourly paid capacity as part of their development: 12 PGRs took up this opportunity in 2019/20. PGR representatives are elected from the student body to partake in School committees to ensure that the PGR voice is heard.

In addition to the Salford Postgraduate Research Training (SPoRT) programme and University-level events (see REF5a), UPRISE and SIRC provide opportunities for PGRs to develop research skills, capabilities and a broader understanding of their fields. The Research Centres provide around 18 research seminars annually under the 'Academics Talk' programme, covering areas such as research methodology and methods, qualitative and quantitative data analysis, plagiarism in research, critical thinking, ethics and establishing a career post-PhD. Review of this provision is conducted annually based on attendance, supervisors' views and student feedback.

Biennially, UPRISE convenes the International Post Graduate Research Conference, now in its 14th year. PGRs present their work to build confidence in presentation and communication and network with researchers from different institutions/countries. In 2019, 50 papers were presented, with representatives from 7 countries and 11 universities. We combine each conference with an industry day to facilitate industrial engagement and network-building. To support engagement across the School, we have hosted 3 'Passion for Flash' events, a TED-style public speaking competition for all students undertaking research. For the past 4 years, our Research Centres have administered the '4-Minute Thesis' challenge, where prizes are awarded for 'PechaKucha' style presentations.

Our CIB Student Chapter (part of the 'International Council for Research and Innovation in Building and Construction') has, since 2009, hosted an annual International Food Festival to promote discourse between international students and staff. More recently, the Student Chapter has produced a bi-monthly CIB newsletter and hosted a bi-weekly coffee event to support an improved PGR community. In 2017, our Student Chapter won the prestigious CIB Sebestyén Future Leaders Award. To assist these student-led activities, £5k is budgeted annually by the School.

A £20k budget from internal Research Centre funds is available annually for PGRs (including PT, distance learning and split-site) to attend conferences to present their work. Students can access £500 annually and are advised to participate in at least 1 international and 1 national conference during their programme of study. Our PGRs have access to a dedicated space that houses 30 workstations, research equipment/facilities and technician support. This facilitates peer-to-peer learning and social engagement between students and is located near offices of academic staff, with shared communal facilities ensuring greater cohesion and engagement.

As a result of our nurture-based approach to the PGR experience and clear expectations for development our alumni destinations include notable academic positions at leading universities

and companies, including: *Alshdiefat* (Philadelphia University, Jordan), *Amadi* (River State University, Nigeria), *Bayer* (Lancaster University), *Haidar* (University of Liverpool), *Nawi* (Universiti Utara Malaysia), *Padillo* (Universidade Federal de Santa Maria, Brazil), *Turo* (Catholic University of America, USA), *Venegas* (Universidad Austral de Chile) and *Zami* (King Fahd University of Petroleum and Minerals, Bahrain); and in esteemed roles in leading organisations including: *Bew* (Chair of the Government's BIM Task Group and now honorary Visiting Professor), *Sheaffer* (Apple Inc.), *Stephenson* (BBC) and *Synodinos* (Airbus).

Support for our Research Technicians to develop their careers

As signatories to the Technician Commitment, we actively encourage our technical staff to engage in research and provide support for their chosen career pathway through the PDR process. Professional/technical staff can seek a regrade through our HR processes or apply for a new post as a promotion opportunity when research input would be taken into account. **Fitton**, appointed as Technician in 2011, was recruited as Lecturer in 2014 following his notable input into research outputs/projects and promoted to Reader in 2019. The outputs he authored as a Technician formed 4/14 submitted in 2016 for a PhD by Published Works. Other examples include:

- *Benjaber* (energy technician) contributed to 5 journal and 1 conference outputs
- *Narish* was recipient of the Higher Education Academy's Technician of the Year in the Built Environment in 2014, gaining national recognition for continued support in research-led teaching
- *Rattigan* (thermal lab technician) contributed to a journal paper in 2019
- *Wong-McSweeney* (acoustics technician) was lead author of 2 journal papers in 2016.

3. Income, infrastructure and facilities

Research income

Our income totals **£13.9m** with an average of £1.9m per year during this assessment period. We have a balanced portfolio across funder types indicative of alignment to funder priorities that address local, national and international agendas. Income is predominantly from 3 sources: £4.9m (35% of total) from UK government/industry sources; £4.8m (34%) from Research Councils with £4m from EPSRC, £597k from AHRC and £1497k from ESRC; and £3.65m (26%) from European programmes, EU industry or other sources. This income has supported **202 projects** with 106 (52%) delivered in collaboration with an external partner (academic and/or industry).

Selected European programmes include:

- **H2020 €9m BuildHEAT 2015-20 (Sherriff**, **Swan)** sought to reduce heating consumption in the residential sector in Europe through developing a set of reliable, energy efficient and affordable retrofit solutions and testing these in 3 multi-family houses, located in Rome, Zaragoza and Salford. This involved the whole construction chain in the process of creating retrofit solutions, including investors to consider new financing models to facilitate the entry of new technologies into the market and addressed technical, behavioural, cultural and economic approaches.
- **H2020 €7.3m 'EU-Circle' 2015-18 (Fernando**, **Ingirige)** involved 20 project partners from 8 countries. Salford led the assessment of the effects of cyclonic pressures and consequent flooding in Bangladesh, developing appropriate adaptation measures to strengthen the operational resilience (modelling the assemblage of critical infrastructures of communications, water, power, buildings, sanitation and health). Onwards impact led to an initial multi-agency collaboration idea between Government and private sector infrastructure operators in Bangladesh to provide solutions as a cohesive group in response to cyclonic pressures on infrastructure.
- **FP7 €7.2m PROSECO 2013-17 (Fernando)** 'Collaborative Environment for Design of AmI enhanced Product-Services Integrating Highly Personalised Innovative Functions with Minimal Ecological Footprint along Life Cycle and of Their Production Processes',

designed a novel methodology and a comprehensive ICT solution for collaborative design of product-services (Meta Products) and their production processes. The effective extension of products with new services in different sectors (automotive, home appliances, automation equipment etc.) was achieved by means of Ambient Intelligence (AmI) technology, Lean and Eco-design principles and applying Life Cycle Assessment techniques. New Meta Products, using AmI, will be capable of acquiring knowledge to add highly personalised innovative functions, thus enabling new business models.

- **FP7 €6.49m Design4Energy 2013-17 (Fernando**, **Underwood)** developed optimised design methodologies for energy-efficient buildings integrated into neighbourhood energy systems. It explored how the developed tools, provided in an interactive virtual workspace, enabled team members, clients and architects to investigate the impact of energy and cost of their design through exploring what-if-scenarios. The consortium of 17 institutions included VTT, Fraunhofer, Solintel and Technical University of Dresden.
- **FP7 €3.6m CROSS-DRIVE 2014-16 (Fernando**) 'Collaborative Rover Operations and Planetary Science Analysis System based on Distributed Remote and Interactive Virtual Environments' created the foundations for collaborative distributed virtual workspaces for European space science. Whilst space exploration missions produced huge data sets of potentially immense value for research, planning and operating future missions, the lack of integration and the fragmentation of the expert teams, data and tools meant that the scope for unlocking this value was being missed. The project improved data analysis and exploitation of space-based observations by providing and standardising new methods and systems for collaborative scientific visualisation and data analysis, mission planning and operation. This used data from Mars atmospheric analysis, rover landing site characterisation and rover target selection during real-time operations, collected in view of the ESA ExoMars 2016 TGO and 2018/2020 rover missions' scenarios.
- **H2020 €3m 'Cutting Crime Impact' 2018-21 (led by Davey, Wootton)**. Salford led the research, design and development of bespoke tools tailored to needs and operational contexts of end-users: focusing on predictive policing, community policing and crime prevention through urban design and planning, and on measuring and mitigating citizens' feelings of insecurity. Partners include law enforcement agencies and universities across 8 countries. The success of the project has led to the introduction of human-centred design and development processes within partner police forces.

Research Council awards include:

- **EPSRC £5.4m, £1.4m to Salford, 2013-19** – '*S3A Future Spatial Audio in the Home*' (**Cox)** was a collaboration between three universities (Salford, Surrey and Southampton) and BBC R&D. The project produced the soundtrack to 'The Turning Forest,' the first public virtual reality piece by the BBC that won the 2016 'TVB Europe Award for Best Achievement in Sound.' The project was piloted on BBC Taster as a way of exploiting 'Internet of Things' to create spatial audio. Through the research, BBC R&D has created production tools for the reproduction method used for the '2020 BBC Proms' and research on accessibility has led to two trials within BBC One's 'Casualty' which improved the sound for the hearing-impaired in scripts for a central character.
- **ESRC/GCRF £4.6m, £855k to Salford, 2019-22** – '*Transformative Science and Engineering for Nuclear Decommissioning (TRANSCEND)*' (**Fernando**) investigates socio-technical systems required for enabling a transition towards a more risk-sensitive and transformative urban development approach in Sri Lanka, Pakistan and Malaysia.
- **AHRC £1.2m, £457k to Salford, 2012-16** – Perry (leaver) was a Co-I on the '*Cultural intermediation: connecting communities in the creative urban economy*' project led by the University of Birmingham to study community cultural budgeting and how intermediaries can support projects that respond to community needs around their cultural activities within current public sector funding mechanisms.
- **EPSRC £1.2m, 2017-20** – '*Collaborative Multi-Agency Platform for Building Resilient Communities' (MOBILISE)*' (**Fernando**) is being used by the Disaster Management Centre and National Building Research in Sri Lanka, Provincial Disaster Management Centre in

Pakistan and Sarawak Multimedia Authority in Malaysia to conduct evidence-based intervention for disaster risk-reduction and response.

- **EPSRC £556k, 2016-19** – '*Embedding measured data within computational frameworks for vibro-acoustic design*' (**Elliot**, **Moorhouse**) is led by Salford with the University of Cambridge plus 6 industry partners including Dyson and Bentley Motors. The project developed methods to provide more reliable and complete models for the vibro-acoustic response of mechanical equipment and vehicles, forming the basis for an International Standard ISO20270: 2019 and subject of an international webinar for training engineers by Siemens.
- **AHRC £189k, 2018-21** – '*Monitoring Object and Visitor Environments (MOVE)*' project (**Al-Maiyah**, **Elkadi, Fitton, Kenawy**) aims to develop a visual live-environmental dashboard of data that will assist museum curators in achieving stable and controlled indoor conditions to address seasonal and unpredictable weather patterns.
- **AHRC £148k, 2018-20** – 'IT Indian Heritage Platform' (**Gyau**, **Trillo**, **Udeaja**) project sought to enhance cultural resilience in India by applying digital technologies to the Indian tangible and intangible heritage.

We have led 11 KTPs, totalling £1.7m and related funding from Innovate UK. Examples include:

- **Virtual Incident Training Simulation Platform £301k 2018-19 (Fernando)**. Led by Evidential Ltd., this project aimed to create a fully immersive and adaptable platform for use as a training experience for Emergency Services across the world, contributing to safer environments. Using Augmented and Virtual Reality the platform gives a user the ability to create their own scenarios and the inclusion of artificial intelligence technology would create unique experiences each time.
- **KTP with Farrat Isolevel Ltd. £208k 2017-20 (Moorhouse)** provided a measurement methodology for the prediction of structure-borne noise and vibration, whilst the University of Manchester supported by enhancing Farrat's capability to characterise vibration isolation materials for use with these models.
- **KTP with Links Project Management LLP £154k 2013-16 (Underwood)**. This 30-month project enabled the industrial partner to develop a business-wide BIM strategy towards Level 2 BIM compliance. The project enabled the business to improve the management of information, reputation, leading to an increase in contract awards, turnover and profit. External recognition of the project has been received through invited presentations at leading industry events (e.g. 'BIM Show Live'); being shortlisted for the RICS 'BIM4SME's' awards in 2015 and was 'Highly Commended' at the 2017 'North West Regional Construction Awards.' The KTP Associate won the 'Institutional and National Student Employee of the Year Award' 2015.

Selected UK government/industry funded projects include:

- **Saint Gobain Retrofit project £133k 2014-15 (Swan)**, was designed to allow a major products manufacturer to combine a number of project lines into a single sustainable retrofit offer and assess their performance to provide an evidence base to support predicted performance of the retrofit. Further, the project validated the 'Quick U-Building' method of dynamically assessing the fabric performance of homes against established methods, leading to development of a patent.
- **BEAMA Controls Studies £65k 2015 (Fitton)** involved conducting a series of studies on the performance of heating controls in domestic properties for Siemens, Honeywell, Danfoss, Peglar and other controls manufacturers jointly through their industry association of British Electrotechnical and Allied Manufacturer's Association (BEAMA). The project's output led to a change in the Standard Assessment Procedure (SAP), the UK's regulatory assessment model to establish the projected energy performance of domestic properties.
- **The Centre for Digital Built Britain £50k 2018-19 (Underwood)** Pedagogy & Upskilling Network project brought together a network of over 50 collaborators drawn from research, practice and other relevant areas to develop a digital competency management

ecosystem, designed to support a digitally enabled, agile, competent and productive workforce.

Research infrastructure and facilities

We have continued to develop our research facilities to support our thematic growth areas (see section 1). Our key research facilities supporting UoA13 include:

Energy House and Energy House 2.0 (**ABERG**)

This facility advances on 'Energy House 1.0' (2011), a typical 1919 Salford terraced house reconstructed within a laboratory in which climatic conditions can be maintained, varied, repeated and patterns monitored and energy loss or retention studied. It has delivered ~£900K research funding since 2014, including collaboration with major companies such as Saint Gobain, Viessmann, Honeywell, Siemens, Danfoss and funded projects with Honda, Good Energy, Octopus Energy and Electricity Northwest. 'Energy House 2.0', with £11.5m funding (£8.2m ERDF and £3.3m HEFCE plus University match-funding), will construct a 2-chamber 720m^2 facility to become the world's first all-weather buildings research centre, covering diverse temperatures (-20C to +40C) weather conditions to reduce test times for new products from years to weeks for differing building types. 'Energy House 2.0' has already generated opportunities with housebuilders (Barratt Homes), product manufacturers (British Electrotechnical and Allied Manufacturer's Association) and electricity distribution network operators (Electricity Northwest) who have expressed interest in early involvement at the opening and operation of the facility.

Smart Meters Smart Homes Lab (**ABERG**)

The UK's first 'smart meters' facility (opened in 2018) acts as a research base for industry by supplying data and advice on smart meter performance/usage and as a laboratory to test future energy services and 'Internet of Things' products. It was co-created with support from Innovate UK and 12 industry collaborators, with £180k HEIF funding for staffing and ~£40k matched support from industry for smart meter, heating systems, renewables and batteries equipment, some of which is not commercially available. It has been used by companies such as Octopus Energy, Hildebrand and Schneider Electrical and a number of start-up companies for commercial research projects, including Chameleon (£40k 4-month; **Fitton**) and Hildebrand (£56k 2-year; **Fitton**) on the use of smart meter data to assess homes and businesses.

Acoustics facilities and equipment (**ARG**)

Audiobooth (**Cox** EPSRC £1.4m 'S3A'; 2015): is a new £30k low-noise soundproof laboratory that allows for spatial audio experiments that combine 3D-audio, augmented and virtual reality systems. This facility was pivotal in the delivery of further projects, including the EPSRC £1.2m 36-month (Salford awarded £399k; **Davies**) 'Making Sense of Sound' project and commercial research conducting performance assessments of the latest generation of the Qualcomm aptX codec (£52k over a 3-month period). The aptX codecs tested at Salford are now installed on an estimated 7 billion devices worldwide.

Acoustic camera (**Cox**): since 2015, **ARG** has had permanent loan of the £160k EPSRC acoustic camera, which has been used on research projects including the detection of sound leakages in buildings. Notably, the camera was used in support of the production of BBC 4's 'Sound Waves: The Symphony of Physics' programme in 2017 to demonstrate how a violin works.

Other improvements to **ARG's** measurement capabilities have involved investment of £250k from commercial and HEIF funding on various equipment, including a microphone calibration system, robot for loudspeaker measurement, head and torso simulator and 40 channel data acquisition system. The robotic turntable resulted in £15k-£30k annual commercial income for a range of loudspeaker and microphone directivity testing contracts. The calibration equipment was used to support work by the National Physical Laboratory and by Sound Level Meter manufacturers (e.g.

Casella UK). The 40-channel measurement system was used extensively for research, commercial work and student support, including the EPSRC £496k 30-month 'EMBED' project, £208k 3-year KTP with Farrat Isolevel (**Moorhouse**), and £42k 3-month iCASE studentship with QinetiQ (**Elliot**).

THINKlab (**DR**)

THINKlab was set up in 2006 as a Centre for Innovation Excellence to facilitate cross-disciplinary research using digital innovation as a key enabler to deliver solutions to our industry partners. Technical facilities include the lab is equipped with a 4K rear-projected stereo capable Powerwall, touch tables, and a range of XR facilities, including AR and VR headsets, motion tracking and haptics, a VR workbench driver and projection system, a 3D-scanner and 3D-printers and dedicated technical support. The facility is used for developing advanced technology platforms for smart city applications, collaborative engineering, multi-agency collaboration environments, serious game applications and interactive learning and training environments and community spaces. The facility has been an important vehicle for supporting the co-creation and development of large-scale, interdisciplinary, international, strategic, technology-led research and industry partnerships and projects.

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

Since 2014, we have developed 5 international policies/patents, been awarded 48 prizes for our research and made 58 media appearances. Our staff hold 86 roles in leading professional organisations, 6 posts as visiting academics, sit on 10 funding review panels, took on 120+ roles as conference/symposia organisers, 2 journal editorships, 24 editorial board memberships and 200+ external examining roles. We gave 88 invited keynotes at academic conferences, 57 invited addresses at industry events, 72 guest lectures and were involved as peer reviewers for 150+ journals/publishers. We have convened 11 international fee-paying conferences, hosted over 250+ free seminars/workshops at Salford and welcomed 23 residential academic visitors from leading universities over sabbatical periods.

Industry collaborations

As a result of Research Group strategies to embed collaboration at the heart of all our research, we have worked with 600+ companies and academic institutions. We have 20 active research MOUs in operation (e.g. our Highways England MOU has secured 10 funded projects worth £262k since 2014, demonstrating the ongoing value of our collaboration):

- **ABERG** have worked with product manufacturers, including Saint Gobain (e.g. £133k 5-month refurbishment project; **Swan**), Knauf, Stelrad, Siemens, Honeywell, Resideo, Ideal, Honda Motor Europe, Electricity North West in the Energy House and in the field on commercial and grant-funded research projects, generally focused on building and system performance. The development of the 'Smart Meters Smart Homes Lab' (see section 3) was in partnership with Landis and Gyr, Kaifa, Secure, Octopus, Good Energy, Hildebrand, Chameleon, Geo, NIBE and Viessmann. Notably, **ABERG** has worked with 170+ SMEs as a direct result of their SME engagement strategy. Demonstrating wider leadership, **ABERG** lead/participate in industry-academic networks, such as the International Energy Agency Annexes, SAP Scientific Integrity Group, the Building Performance Network and Local Government networks (GMCA), supporting energy and building projects locally and nationally.

- **ARG's** work is rooted in industry. For example, the EPSRC £496k 30-month 'EMBED' project (**Moorhouse;** embedding measured data within computational frameworks for vibro-acoustic design) includes Bentley Motors, Dyson, Wave Six and Bruel & Kjaer as industrial partners; and the EPSRC £288k 5-year 'CLARITY: challenges to revolutionise hearing device processing' project (**Cox**) on improving hearing aids has collaborations with Amazon, Honda and Action on Hearing Loss. Other partnerships include Alstom, Arup,

BBC, Boeing, Bombadier, Daimler, Deutsche Bahn, Farrat Isolevel, Ministry of Defence, Music Tribe and NASA.

- In **IRG**, collaboration with major UK infrastructure clients and contractors in its 3 key areas of development across 37 funded projects include: 1) Railways - Balfour Beatty, China Ministry of Transportation, Eurostar (UK) Ltd., London Underground Ltd., Network Rail, Rail Safety & Standard Board, Risktec Solutions Ltd., Serco Assurance Ltd., Tube Lines Ltd.; 2) Highways - Akins, Balfour Beatty, Costain, Highways England (10 projects worth £262k), WSP, Jacobs; 3) Housing - Arup, BAE systems, Currie & Brown, Ernst & Young, Faithful & Gould, Guinness Trust, Infrastructure UK, Mott McDonald, Seddons, Sir Robert McAlpine and Turner & Townsend.

- **SURF** has a strong connection through work with communities and industry. Locally, members have engaged with local authorities and collaborate with GMCA, Transport for Greater Manchester, British Cycling, the Environment Agency and the Royal Horticultural Society (see 'IGNITION,' see section 1). Collaborators include United Utilities, Royal Horticultural Society, Groundwork, City of Trees, Northern Rail, Seddon Construction and Salford Art Gallery and Museum. Internationally, **SURF** is building a profile with private-sector organisations, national governments and agencies in countries including in South East Asia, Egypt and Russia (e.g. British Council £52k 1-month project to subjectify UK and Russian smart cities; **Elkadi**).

Academic collaborations

We have developed meaningful collaborations with a host of universities nationally and internationally. The Unit's international standing and connections are demonstrated by staff holding 6 honorary positions nationally and internationally in recognition of their contribution to the discipline:

- **Elkadi** is International Guest Professor at Karlsruhe Institute of Technology, Germany and Honorary Professor at Taylor University, Malaysia
- **Hayes** is an Honorary RA at the University of Liverpool
- **Torija-Martinez** is Visiting Fellow at the University of Southampton
- **Trillo** is Visiting Fellow at San Diego State University, USA
- **Umnova** was Visiting Professor at the University of Burgundy, France, 2015-2017.

Our staff have performed over 200 PGR external examiner roles, demonstrating the breadth and value of our contribution to our discipline (including **Lee** at Queensland University of Technology, Australia; Universiti Pendidikan Sultan Idris, Malaysia; University of Witwatersrand, South Africa); and given 72 guest lectures, demonstrating our international presence (e.g. **Keraminiyage** in 2016 at the University of Moratuwa, Sri Lanka, on 'New Trends, Challenges and Uses of Standard Forms for Construction Contracts: UK perspective;' **Fois** in 2017 at the Universidade Federal do Rio Grande do Sul, Brazil on 'The Global Countryside: Rural Change and Development in Globalization'); and hosted 23 residential academic visiting researchers at Salford, demonstrating the attractiveness of our facilities and relationship (including Prof Penamora, Columbia University, USA in 2014; and 6 post-doc RFs from China Academy of Building Research, China, in 2017).

Examples from 2 Research Group collaborations include:

- **ARG**: the aforementioned £288k 5-year 'CLARITY' project (**Cox**) has partners from Sheffield, Cardiff and Nottingham Universities; the £1.4m 'S3A' project (**Cox**; see section 3) has partners from Southampton and Surrey Universities; the £496k 'EMBED' project (**Moorhouse**; see section 4) is delivered in conjunction with the University of Cambridge. Other examples include joint PGR supervision with the Universidade Federal de Santa Catarina, Brazil (**Fazenda**); and joint publications with the Universities of Essex and York (**Williams**).

- **ABERG** work with a number of universities in terms of networks and live projects, e.g. Leeds Beckett and Loughborough on the £521k 21-month 'DEEP' project. In terms of networks, they were one of the founding members of the Building Performance Network (with Leeds Beckett, UCL, Oxford Brookes and Sheffield Universities) and involvement in International Energy Agency Annexes (Leuven, Innsbruck, Ghent, Liege, Concordia, DTU, Ecole des Mines, Savoie Mont-Blanc, Strathclyde, West of England, Lincoln, Wollongong, Tsinghua, Aalborg, Chalmers). At a regional level, **ABERG** has helped established an Energy Innovation Agency with the University of Manchester and Manchester Metropolitan University to support the energy transition at the city-region; and has supported external PhD projects from University College London and Lancaster by providing access to facilities.

We augment our expertise through the appointment of honorary Visiting Professors who are aligned to our Research Groups and provide us with connections to national/international networks. We review appointments biennially to ensure engagement is meaningful. Our appointments include:

- 4 from public sector organisations: Mark Farmer (**IRG;** author of the Government's Review of the UK Construction Labour Model: Modernise or Die in 2016), Dr Mark Bew (**IRG;** Chair of the Government's BIM Task Group and PhD alumni), Mike Ormesher (**ABERG;** Director at British Board of Agrément) and Anke Woessner (**SURF;** Head of Urban Planning Department, Karlsruhe, Germany)
- 3 from leading construction organisations: Steven Hodder MBE (**SURF;** Partner at Hodder Associates, former RIBA president and 1996 Stirling Prize winner), Claire Handby (**SURF;** Director in Real Estate Practice at Deloitte) and Trevor Mole (Property Tectonics, overarching Chair across all Visiting Professors, providing a critical-friend approach across all research in the Unit);
- 2 from academic institutions: Professors Yong Zhang and Hua Feng Zhang (**IRG;** University of Science and Technology, China)

Contributions to professions and learned societies/disciplinary advances

Many staff are members of one or more of the built environment professional institutions and play a significant role in shaping agendas:

- **Fitton** (**ABERG**) is leading an EU patent application for a heat flux sensing device
- **Moorhouse** and **Elliott** (**ARG**) contributed to the development of ISO 20270:2019 Acoustics - characterisation of sources of structure-borne sound and vibration; a Gas Strut Air Spring patent in the USA (US20180045264A1); and Harman Becker Automotive Systems, Germany, referred to their work as part an Acoustic Thermometry patent in the EU whom supply Mercedes Auto, along with other car manufacturers, with systems to control vehicle road noise by using the car audio system
- **Underwood** (**IRG**) chaired the UK BIM Academic Forum that led the development work that fed into BS EN ISO 19650 series (see section 1) for managing information over the whole lifecycle of a built asset using BIM.

Our work has been recognised through 48 prestigious prizes, including:

- **Cox** received the Acoustical Society of America's Science Writing Award in 2014 for 'The Sound Book,' which presents a tour of the world's most amazing acoustic phenomena in exotic noises – creaking glaciers, whispering galleries, musical roads and a Mayan pyramid that chirps like a bird
- **Hargreaves** was awarded the 2016 Tyndall Medal by the UK Institute of Acoustics in recognition of his contribution to and excellence in acoustics research and teaching
- **Higham** received the Emerald Literati Award for Excellence, Highly Commended Paper 2016 ('Life Cycle Costing: evaluating its use in UK practice', *Structural Survey,* Vol. 33:1,

pp. 73-87) and again in 2017 ('Sustainability and investment appraisal for housing regeneration projects', *Structural Survey*, Vol. 34:2, pp. 150-167)
- **Moorhouse** was awarded the 2018 the Institute of Acoustics Engineering Medal in recognition of his outstanding contribution in the field of acoustical engineering;
- **Poppelreuter** was awarded the 2016 'Milka Bliznakov Research Prize' by the International Archive of Women in Architecture, Blacksburg VA, USA for 'Refugee and émigré Female Architects before 1940'.

Our staff influence a variety of agendas through the 86 international/national committees and panels on which they sit, including:

- **Elkadi** was appointed as board member of the CIB (International Council for Research and Innovation in Building and Construction) in 2019, replacing leaver *Ruddock* who held this post since 2013
- **Moorhouse** convenes on the International Standards Organisation (ISO) committee TC43/SC1/ WG57
- **Poppelreuter** is a Council Member of the Historic Building Council in Northern Ireland
- **Sherriff** is Trustee of the Fuel Poverty Research Network and committee member of the Cycling Society Research Network
- **Swan** is Chair GMCA Low Carbon Buildings Group and Member of the Westminster Sustainable Business Forum
- **Underwood** is Chair of UK BIM Academic Forum and actively engages with the UK BIM Alliance, Scottish BIM Delivery Academia Group, Behaviours4Collaboration Group, Constructing Excellence Digital Construction Group, Nuclear Institute Digital Special Interest Group, Northwest Regional BIM Hub and Constructing Excellence Manchester Committee
- **Umnova** is a member of the UK Acoustics Network funded by the EPSRC.

Staff sit on 10 funding review panels in our discipline:

- **Fazenda**: EPSRC, ESRC, AHRC, CONICYT (Associative Research Program, Chilean National Commission for Science and Technology Research) and Deutsche Forschungsgemeinschaft (German Research Foundation)
- **Ingirige:** EPSRC, ESRC, NERC, Leverhulme Trust and Newton Fund
- **Ji**: EPSRC
- **Moorhouse:** EPSRC and KULeuven, Belgium
- **Swan**: EPSRC and Royal Society.

We make representation on 18 external boards/advisory committees, including:

- **Davies:** Irwell Catchment Partnership Board
- **Fitton**: BRE SAP Scientific Integrity Group, International Energy Agency and UK Building Regulations Advisory Committee on Energy
- **Swan**: Green City Challenge Board for Greater Manchester and Low Carbon Buildings Group.

Ten of our returned staff have chartership status in leading professional, statutory and regulatory organisations, engaging widely within each network: **Al-Maiyah** (CIBSE, SLL, ICOMOS); **Elkadi** (affiliate RIBA, FRICS); **Fitton** (MRICS); **Higham** (MRICS, MCIOB), **Ingirige** (MRICS); **Ji** (CEng); **Kenawy** (EES); **Moorhouse** (CEng); **Paraskevas** (CEng, IET, CMath, IMA); **Swan** (CMgr FCMI) and **Underwood** (MCinstCES, CPsychol).

Journal editorships: Our staff are Editors-in-Chief for 2 international journals (**Keraminiyage** for Journal of Financial Management in Construction and Property; **Underwood** for International Journal of Digital Innovation in the Built Environment), act as Associate/Review Editors or are Board Members for 24 peer-reviewed titles (including **Davies** for Journal of Tourism Futures;

Moorhouse for Applied Acoustics; **Torija-Martinez** for Journal of the European Acoustics Association; **Umnova** for Journal of the Acoustical Society of America and Journal of Sound and Vibration) and regularly carry out peer reviews for 150+ publications in our disciplines.

Conferences and CPD events: Our 88 academic keynotes delivered include: **Moorhouse** in 2016 at the Hellenic Acoustics Association's Annual Conference in Athens, Greece; **Ingirige** in 2019 at the Interflood Conference, Singapore on 'Urban Flood Management and Stakeholder Engagement Across Collaboration Chains with Specific Focus into Challenges faced within South and South East Asian Region.' 57 keynotes at industry events include:

- **Elkadi** (2020) at The British Council event in Manila, Philippines on the 'Assessment of Universities Industry Partnerships'
- **Poppelreuter** (2020) at the Public Record Office in Northern Ireland (invitation by the Historic Environment Record of Northern Ireland delivered 'Belfast Architecture of the 1930s')
- **Swan** (2017) at the Green Economy Event for the British Electrotechnical and Allied Manufacturer's Association at the House of Commons
- **Torija-Martinez** (2019) at the Acoustics Technical Noise meeting organised by NASA and Penn State University, USA
- **Underwood** (2020) to the Chartered Institution of Civil Engineering Surveyors and Chartered Institute of Arbitrators.

We have hosted 11 conferences, including the 3rd International Intelligent Music Production (2017, **ARG**) and the 2019 Smart Meters Conference (140 attendees; **ABERG**). We have run seminars/workshops (250+ events), for example, since 2018 **Lee** ran a series of breakfast briefings to showcase our research to industry – our 'Construction Standards' event following Grenfell attracted 95 attendees with our honorary Visiting Professor Mike Ormesher (British Board of Agrément) as guest speaker; and our 'Post-Brexit Construction' event with guest speaker Professor Noble Francis (Construction Products Association) attracted 120 attendees; in 2019, **Umnova** hosted the Symposium on Acoustics of Nanopourous Materials (funded by the UK Acoustics Network); **Underwood** hosted the EU BIM Task Group for a Vietnam delegation; and **Aziz** hosted the 'Big Data Scenarios in Facilities Management event (sponsored by CIOB and RICS). Our staff have been involved in 120+ steering committees of conference/symposia (including **Underwood** at 8th International Congress of Architectural Technology 2019, University College Lillebaelt, Denmark and 7th International Congress of Architectural Technology, Ulster University, Northern Ireland; and **Williams** at 2019 International Conference on Immersive and Interactive Audio, University of York).