

<b>Institution:</b> University of Bolton
<b>Unit of Assessment:</b> 12-Engineering
<p><b>1. Unit context and structure, research and impact strategy</b></p> <p><i>1.1 Overview</i></p> <p>Since its creation in 1996 in order to integrate the University of Bolton's materials (textiles and polymers) and engineering research strengths, the Institute for Materials Research and Innovation (IMRI), a research centre within School of Engineering, has forged a reputation of 'internationally leading' amongst academic and industrial sectors. The Institute has two main themes (a) advanced materials and (b) communications engineering, and within each of those is a particular line of enquiry, in which the lead researchers specialise. The major strength of the Institute is the multi- and interdisciplinary activities, as demonstrated in Figure 1 showing schematically how different areas interface with each other. Also depicted in Figure 1 is that advanced materials area has remained the main scope of the Institute's research as it has looked to maintain the status of its being considered world leading in specific areas, which was acknowledged within the previous REF2014. Although during restructuring in 2017 some previously successful areas (Renewable Energy) ceased to exist, new ones (Communications Engineering) emerged.</p> <div style="text-align: center;"> <p style="text-align: center;"><b>Advanced Materials</b></p> <p style="text-align: center;"><b>Communications Engineering</b></p> </div> <p style="text-align: center;">Figure 1. Research themes and areas</p> <p>Despite restructuring, the research aims have largely remained the same as in REF 2014 as the Institute is committed in their pursuit of producing excellent research where the impact is felt far beyond the realm of academia. Adopting an interdisciplinary approach therefore assisted in maximising the potential pathways to impact, which will be reflected in the details below where several staff members may operate between research themes. Engaging with key stakeholders and utilising public engagement to maximise the potential benefit have formed the bases on which the IMRI has looked to uphold its prestigious reputation for responsive yet excellent research since the previous submission</p> <p>The academic success of IMRI is demonstrated by:</p> <ul style="list-style-type: none"> <li>• &gt;400 publications in refereed journals, &gt;300 conference contributions;</li> <li>• £2.52m research income;</li> <li>• 56 postgraduate students achieving the award of PhD</li> </ul> <p><i>1.2. Research and Impact Strategy</i></p> <p><i>1.2.1. Vision</i></p> <p>Our aims are to deliver scientifically informed solutions to emerging technological engineering problems, maintain/develop a world lead in the respective fields and align all the research with teaching courses in a way that enables most recent non-confidential research to be disseminated through teaching programmes.</p>

### 1.2.2. Achievements of aims during the assessment period

#### Strategic plans

The University, after committing to changing its strategy to become a 'Teaching Intensive Research Informed University' in 2015, made a commitment to align all the research activities with teaching courses, which led to major restructuring in IMRI and Engineering.

To replace researchers who moved to other institutions during restructuring, the University has appointed one new professor (*Sheriff*) with expertise in telecommunications engineering and seven new lecturers during the period May 2017 – December 2019 with research interests complementary to the sustainable and emerging research areas: one with biomedical and smart devices (*Sanami*), four with construction materials (*Paschalis, Wang, Ilori, Oti*), two with communications and electronics engineering (*Anoh, Gu*) backgrounds. While not all of these of these new appointees have been included in this REF submission, they will contribute to development of these areas and will be trained as future leaders in their respective fields. In the Fire Safe Materials area, *Ebdon* a visiting Professor at Bolton since 2010, with expertise in polymer chemistry, was appointed as a Professor at 0.2 FTE contract since 2014 to replace the position formerly held by the late Prof Dennis Price.

In order to engage with industry and key stakeholders to maximise the research impact, the University of Bolton has been part of the Knowledge Centre for Materials Chemistry (KCMC) since 2008, currently hosted by the Centre for Process Innovation (CPI). *Weclawski*, with a materials engineering background, was appointed as a research fellow in 2018 for two years with joint funding from CPI and the University with a primary aim to liaise with industry to initiate and deliver industrial projects. *Weclawski* is currently being mentored to take up a permanent position within IMRI.

To embed research into teaching, the MRes course in Environmental Management started in 2018 with *circa* 90 graduates in 2019. Six more MSc programmes also commenced in 2020 covering the key research areas above.

#### Research Themes (see Figure 1) – focus and achievements

Our research themes foster a significant level of interaction between academic staff in terms of initiating joint projects, co-supervision of PhD students, writing co-authored papers, arranging joint group meetings and attending PhD progress assessing panels across the institute. The main activities, lead researchers (names provided in parenthesis), highlights and future directions of different research areas are outlined below.

##### (i) Advanced Materials

**Composites:** Composites being light weight materials while are gaining popularity in high performance applications, are susceptible to combustion leading to reduction/failure in mechanical properties. The research in fire safety of composites (*Kandola*) has established Bolton as the only UK (and EU) expertise in this area [REF 3b: Fire Safe Materials: Industrial impact]. Notable research in the area of assessing fire hazards are: the toxicological study of the carbon fibres/nanoparticles released during simultaneous fire and impact exposure of composites; structural damage to carbon fibres during heat/fire exposure; sensing in carbon fibre composites for early detection of fire. For developing fire-safe composites, the projects include designing sandwich structures from co-blended unsaturated polyester/vinyl ester resins with phenolics as layered structures for marine applications; surface treatments by chemical and/or nano-particulate ceramic coatings.

The research into structural mechanics (*Myler*) has led to the development of finite element-based predictive wear models for James Walker Seals based in Cumbria. The research was complemented by a KTP with Hylomar Ltd., which resulted in the successful development of predictive models for non-setting sealants with various additives. Additionally, engagement with key stakeholders within the automotive industry has given rise to work on the simulation and testing of the mechanical behaviour of composite reinforced aluminium foam crash systems with the Keating Berus supercar team.

**Fire Safe Materials (textiles and polymers):** The FSM area of research (*Kandola, Horrocks, Ebdon, 4 post-docs and 10 PhD students*), which has been a major activity since 1980, has continued to maintain its position of excellence within the field since the last REF submission 2014 through multidisciplinary projects which include the development of carbon fibres from lignin/ polymer blends, the development of novel environmentally sustainable fire retardants (FRs) with a focus on surface modification and appropriate application techniques including atmospheric plasma, the use of conventional FRs with novel synergists in fibre-forming polymers and biopolymers, the evaluation of FR properties of chemically/physically modified polymers and their mechanisms of action, and mechanical property changes of fire retarded polymers during and after exposure to heat / fire and associated modelling. The group has published 48 papers in peer reviewed journals, one edited book on "Handbook of Technical Textiles and 2 chapters in advanced texts. The group co-hosted the 16<sup>th</sup> European conference FRPM'17 in Manchester in July 2017, attracting 280 delegates.

**Smart Materials:** A series of new smart materials developed (*Geng*) include heating/ethanol-response of poly (methyl methacrylate) with gradient pre-deform property for temperature sensors, nitrogen-doped carbon nanotubes for electrical capacitors, photocatalytic nanomaterials N-La co-doped TiO<sub>2</sub> and 3D TiO<sub>2</sub> nanotube arrays for environmental technologies, the composites of graphene oxide, carbon nanotubes and Zn<sub>x</sub>Cd<sub>y</sub>S for high-purity water preparations, g-C<sub>3</sub>N<sub>4</sub>/Gd-N-TiO<sub>2</sub> Composite for solar cells, etc. 23 papers have been published in this area.

Theoretical research in smart materials has also been undertaken through an exploration of a number of issues associated with the problem of calculating and detecting electromagnetic quantum induced stresses in ENZ-type (epsilon-near-zero) dielectrics, a class of meta-materials with unique optical and optoelectronic properties for a wide range of applications (*Walton, Reviews in Mathematical Physics, 2018*).

The research in organic piezoelectric, photovoltaics and triboelectric materials until 2018 kept a focus on renewable and energy harvesting applications (*Siores, Emeritus Professor now, Soin until 2018*). The world's first 3-D spacer fabric based piezoelectric fibre-containing textiles was developed, which resulted in the successful filing of a UK patent (GB2516987(A)). The technology was nominated for Royal Society of Chemistry Emerging Technologies Award (2015) and ITMA Future Textiles Award (2014, 2015). The work has since progressed onto the development of triboelectric nanogenerators in the UK, which display significantly higher power densities.

The use of advanced SPM techniques of Kelvin probe force (KPFM), electrostatic force (EFM) and piezo force microscopy (PFM) has enabled a fundamental understanding of the charge development and transfer in triboelectric nanogenerators. The surface charge control strategies of perovskite additives, ion-injection and interfacial-charge injection have led to 29 articles in high-impact journals such as RSC Energy & Environmental Science, Nano Energy, Chemical Communications and ACS Applied Materials & Interfaces.

**Construction Materials and information modelling:** The recent restructuring has engaged civil engineering disciplines with the other engineering areas and the strategy was to attract new staff in this area. One such new recruit (*Paschalis*) is currently active in reinforced concrete and ultra high performance fibre - reinforced concrete structures allied to sustainable building materials. This compliments constitutive modelling of building structures, the use of finite elements for both structural and geotechnical design (*Boulbibane, 2 papers*). Another newly recruited lecturer, *Oti* with experience in building information modelling (BIM) in applications such as sustainable appraisal of structural buildings/component materials, harnessing performance data from building management systems for energy use optimisation etc, is now exploring the area of decommissioning of nuclear power stations (2 papers published) to contribute to demands by UK government to significantly reduce costs in the coming decades. With over 25 publications on subjects around BIM, his collaboration on the International Council for Building (French name: Conseil International du Bâtiment) Task Group 90 (TG90), led to the publication, 'Research roadmap for information integration in construction'. The TG90 collaboration while commenced in his previous employment, has continued at the University of Bolton to yield the Roadmap.

**Biomedical Engineering:** The work in medical textiles has been Bolton's strength since the 1990s. The research in the REF period concentrated on development of a new biomaterial fibre, Alchite

(3 publications) and another highly absorbent and MRSA resistant biomaterial (3 publications) for wound dressing (*Miraftab, retired 2016*). This work has been taken up by *Sanami*, working on design and construction of a pioneering collagen extrusion machine for production of continuous collagen fibres intended for tendon regeneration. The novel production technique allows commercialisation of this fibre into three-dimensional biomimetic constructs used in humans and animals. Another area has been compression bandages where a single-layer compression bandage has been developed which replaces the conventional four layer bandaging regimen for treating venous leg ulcers (*Anand, Rajendran, Emeritus professors since October 2017 and June 2018, respectively*).

Another line of research is design and development of a new Hip stem with negative Poisson's ratio properties for improving total hip replacement devices through, improved match in terms of both; structure and mechanical properties of bone tissues, leading to a reduction in detrimental stress shielding effects, promotion of new bone in-growth and extension of device life by remedial expansion of the stem in response to device loosening (*Sanami*).

Since REF2014 the BioMEMS and micro-sensors area has been commended for the major developments of surface acoustic wave single mechanism based 'lab-on-chip' devices as well as flexible and transparent electronics which then facilitated the development of biomedical devices which were capable of diagnosing and detecting viruses from home using the ZnO thin film-based technology (*Luo*). >90 journal papers, 5 special journal issues and two patents on utilisation of ZnO thin films for home diagnosis and virus detections have been published.

Another notable achievement is development of a new and innovative dielectrophoresis-assisted adsorption technology (*Geng*), which effectively removes biological pollutants (such as waste antibiotics, *E. coli*, etc.) and organic pollutants (such as ammonia nitrogen, compounds containing heavy metal ions, etc.) from water. The technological advances has since opened new pathways to impact through its potential to create ultra-pure water which can then be used across numerous different settings such the medical sector and environmental industries.

Recent recruit in 2018, *Furat Al-Faraj* has further developed work (published 2 papers) on water contamination and filtration. This relates to the sustainable land area and the effects of potential climate change (*Osman*) in parts of the Middle East and northern Africa. The work complements that of *Oti* who joined the School in September 2018 developing sustainable construction theme. Based on this expertise, in 2018 a Master's degree by Research in Environmental Management (90 graduates) was developed for the General Authority of Meteorology and Environmental Protection, Saudi Arabia.

#### (ii) *Communications Engineering (CE)*

This developing area, initiated by pioneering work in RF and antennas technologies (*Chan* until 2019), *Bati*), was strengthened with the appointment of a Professor (*Sheriff*) and two lecturers (*Anoh, Gu*) in 2019, following a strategic decision by the University to invest in advanced information and communication technologies. *Sheriff's* research on advanced mobile and wireless communications is complemented by *Anoh's* investigation into smart cities and smart grid technologies, *Gu's* research on wireless sensors and modulation techniques, and *Bati's* study into low power wireless charging. *Walton* also studies classical descriptions of single-cycle laser pulses and their interaction with charged point particles, motivating a phenomenological quantum description of compact laser pulses that offer new opportunities for transferring quantum information securely by entanglement for technological applications such as quantum computing and encryption.

#### 1.2.3. Future strategic aims

Our future research strategy is to maintain the international/national status of our well established research areas and further develop the emerging ones by simulating multi- and interdisciplinary collaboration within the unit as well as external organisations. In particular, we will achieve this by:

- expanding our composites research to include additive manufacturing. This will be achieved by investing in new types of composite fabrication processing to include both polymer and metal systems working in collaboration with Advanced Manufacturing Research Centre (AMRC) now with a base in the NW of England;

- Utilise the 'National Centre for Motorsport Engineering', which has the capability to fabricate and test specialist vehicles from concept to a roadworthy prototype;
- align our research in fire safe materials (textiles and composites) with performance automotive structures and motorsports composites and develop next generation of fire safe vehicles;
- maintain the international lead of the 'Fire Safe Materials' research by increasing the critical mass of full time researchers and expanding collaboration with the civil engineering area;
- further develop mechanisms/practices to disseminate our research outcomes of commercial interest. One of the identified routes is to work more closely with Centre of Process Innovation with which Bolton is already in partnership through KCMC;
- establish the recently started Communications Engineering research area. This will be achieved by exploiting the opportunities made available through Greater Manchester's significant digital economy to develop strategic links with key technology providers based in the region. The regional strategy will be complemented by an international strategy, which intends to further develop collaborative ties with China, in particular, where established links are already in place;
- align our research in biomedical devices with the dental and health science areas; and
- build on research capacity recently established in the field of environmental science and engineering, to support international goals around carbon, climate change, pollution and flooding

## 2. People

### 2.1 Staffing strategy & Staff Development

#### 2.1.1. Staffing strategy in relation to research strategy

*Academic:* The staffing strategy of the School of Engineering is focused on recruiting the highest calibre academics who share our vision of inter/multidisciplinary working, liaising with industry and ensuring a best fit of their research interests with the areas of our strategic focus. Our recent strategy to invest in communications engineering led to the recruitment of one professor (*Sheriff*) and two lecturers (*Annoh, Gu*). To replace the staff retired or relocated to other institutions, 6 new lectures were appointed as detailed in Section B2a and summarised here: Biomedical: (*Sanami, Furat Al-Faraj*) Construction Materials: four (*Paschalis, Wang, Ilori, Oti*); Fire Safe Materials: 1 professor (*Ebdon*, 0.2 FTE) and 1 research fellow (*Weclawski*). Since 2017 Bolton significantly invested in motorsport engineering by developing new BSc and MSc courses and appointing 7 permanent academic staff with many years of industrial experience. The latter so far have been concentrating on establishing the courses in line with our TIRI agenda, hence have not contributed to research and included in this REF submission. They will though contribute to the next REF.

*Research Assistants:* The University's recruitment and selection policies comply with the European Charter and Code, and are in line with the requirements of the Concordat. All research positions are job-evaluated, and each role aligned to the university's current pay and grading arrangements, which ensure that all researchers are rewarded irrespective of the type and duration of contract. Our recruitment and selection processes are designed to attract a wide range of candidates from within the UK and internationally and vacancies are advertised on a number of websites. All person specifications for research posts have the requirement that the researcher has the capability and capacity to develop into an independent researcher.

#### 2.1.2. Career Development Support

*Academic:* Career development is formally supported through the Annual Performance Review process in which the Head of School meets each staff member to review performance and assist with research and career development. The University has a 'Staff Enhancement and Achievement Map' (STEAM) programme, where staff members have access to professional mentoring from TIRI Professors and other experienced academic colleagues through the University's Mentoring Academy.

Some staff members are also members of University's committees including Senate, Board of Studies Research Degrees and Research and Knowledge Exchange Committee to ensure that School's interests are taken into account. The University, through its Research and Graduate

School run staff development workshops covering, for example, research degree supervision, grant-writing, leading research teams and public engagement.

All new academic staff have a mentor who gives advice for writing research proposals. Successes include an EPSRC First Grant award (*Halacheva, 2015*) and a Newton fellowship (*Soin, 2018*).

The University runs competitions for awards up to £5k for staff to conduct preliminary work, which will lead to a full grant proposal, these include Jenkinson's (internal funding for small project to pump-prime research activity) and Ryley awards (small grants to employ graduate interns for experiencing research). The University organises annual TIRI (Teaching Intensive Research Informed) conference, which features keynote and innovative research lectures, and personal and professional development workshops.

*Research Assistants:* The University has a PDP process for post-doctoral researchers, which in 2<sup>nd</sup> year of the employment encourages them to start to make their own applications for funding to develop their future as independent researchers. The post-doctoral and research fellows are encouraged to teach on MSc courses, are involved in supervisory teams for PhD students (with support from a series of supervisor development workshops) and are encouraged to be on standing panels set for monitoring students' progress. All post-doctoral and research fellows are supported with and expected to write research proposals as a part of their career development scheme. At the end of their fixed term contract, they are supported to be retained within the group or are helped to find positions elsewhere.

### 2.1.3. International staff appointments and visiting scholars

During the REF period *Kandola* was invited as a guest Professor in Université de Lorraine, Saint-Avold Cedex, France (2017) and Zhejiang University, Ningbo (2018 -2020). *Luo* is Visiting Professor to the Zhejiang University (China), Southeast University and Hangzhou Dianzi University (China). *Sheriff* has been a Visiting Professor since 2017 in College of Electronics and Information Engineering, Sichuan University, and since 2019 at Beijing University of Chemical Technology (BUCT), China. *Geng* has been a Guest Professor at Minzu University, China. *Sanami* is an honorary lecturer and researcher at the University of Manchester.

During the REF period, the School hosted a number of visiting researchers, including Li from Marine Chemical Res Institute, Qingdo (2018), Ban from Guizhou Normal University, Guizhou, China (2018-19), Atakan from Istanbul Technical University, Istanbul, Turkey, (2017), Kayanak from Anadolu University, Eskişehir, Turkey, Vendrame, Università degli Studi di Padova, Italy, (2018), Jovic, EMPA, Switzerland (2015), Abbache, University of Abderrahmane Mira – Bejia, Algeria (2014), Matzen from BAM, Berlin, Germany (2014), Majka from Cracow University of Technology, Krakow, Poland (2014).

## 2.2. Research students

The PGR programme is overseen by the Dean of Research & Graduate School; he/she is responsible for admissions, registration, progression and implementing QAA/HE compliant Research Degrees regulations. We have different PhD routes, including the PhD-by-Published-Works award, which was pioneered by IMRI specifically for senior managers in industry and commerce, enabling them to position work-based projects within an academic framework. There are two potential routes depending on how many publications the candidate has made; a retrospective route for those with publications and a prospective route for those who have started to publish research.

### 2.2.1 PGR Recruitment

The PGR recruitment and selection policies comply with the European Charter and Code. All funded PhD vacancies are advertised on websites including *findaphd.com*, which attract applicants across EU and beyond. We adhere to the same rigorous, fair and transparent selection and recruitment policies, including the University's Equality and Diversity policies, for appointing PGRs as for other staff grades. Applicants must submit a research proposal so that we can assess research interest and capability; all short-listed candidates are interviewed by staff members. Research & Graduate School staff provide fees advice, funding advice, visa advice and process

registration etc. Research student numbers remain at healthy levels, sustained by internal and external studentships and partnerships with external funders.

### 2.2.2. PGR training and support

The University supports its research students and requires participation in personal and professional development addressing Vitae's Researcher Development Framework. In the first year Research & Graduate School runs the Postgraduate Skills Record sessions, the attendance to which is mandatory. Participation in external, discipline-focussed postgraduate courses, attendance (and participation) at internal and external research conferences and seminars and training in specific approaches, techniques, etc., is encouraged and supported. An annual University research forum enables all research students, PDRAs, research staff and administrators to contribute, encouraging presentations and discussions on the national context, university policy and strategy, individual research projects, etc. Research student representatives are members of school and the University's research committees, to ensure that their views are heard; PRES (Post Graduate Research Experience Survey) is used to capture and respond to the student voice. The Students' Union also has established a Postgraduate Research Students Society which runs a short conference annually, usually in January of each year.

### 2.2.3. Progress monitoring

At 4 months from enrolment students (6 months for part time students) submit a detailed research proposal and work plan (R1), which is assessed by an independent panel comprising two staff members from school and one external to the School, chaired by member of Board of Studies Research degree committee. Written feedback is provided. Initial PGR registration (unless the student has an MSc or an Honours degree with 2(i) or first class), is usually for "MPhil with possibility of transfer to PhD". At 18 months mid-term progress or MPhil to PhD transfer documents (R2) submission require a substantial scientific report and presentation to a monitoring panel which is similar to that of R1. Written feedback is provided. Annual progress reviews are conducted to check that each stage is completed in time and the student presents his/her research in internal/external seminars/conferences.

The University's Board of Studies for Research Degrees (BoSRD) oversees all PGR approval, monitoring, and transfer recommendations.

## 2.3 Equality & Diversity

The university is passionate about ensuring diversity & equality within the workplace. As such the UoA is committed to key Equality & Diversity and the University position is set out on the University's website (<https://www.bolton.ac.uk/equality-and-diversity/>). In doing so, the School looks to actively promote a culture of respect for people ensuring that the work, teaching and learning environment is free from any form of discrimination. All staff within the School have undertaken the mandatory training on equality & diversity, which informs staff on all equality and diversity matters so that they are able to act accordingly should they encounter any instance of bullying, harassment, victimisation or discrimination.

The University's strategy on equality and diversity is reflected by the backgrounds of the submitted staff and those recently appointed. Of the 18 staff, 3 are female, 12 from ethnic minorities. The University's Equal Opportunities and Diversity Policy is available to all staff via its website and all new staff are taken through the policy at induction. All staff, including research staff, have access to Vivup, the University's Employee Assistance programme (EAP) provider which offers 24 hours support and counselling on personal and work related matters; this has been in place since 2011. The University has a policy on bullying and harassment and how incidents must be handled through its staff grievance and disciplinary procedures. Research staff have the same intellectual property rights as other staff, unless the particular funding body has imposed special requirements. The University's REF Code of Practice is published on the web pages (<https://www.bolton.ac.uk/assets/hosted/CoP-REF-2021-Aug-2020-revised-clean.pdf>) and specifically identifies how equality and diversity is catered for within the REF processes.

## 3. Income, infrastructure and facilities

### 3.1 Research funding portfolio

Research income in key research areas during this REF period remained consistent to previous REF period years. However, anticipated increase in overall income was affected by the restructuring of the IMRI and the fact that almost all new appointments made were at junior level, where the ability to attract large grant is limited. Across the REF period total income was 2.52M, the breakdown of funders being: 9% from Research Councils, 20% from EU, 60% from UK government (including Dstl) and 3% from charities, 8% from international collaboration and smaller funds made up the balance.

The flagship grants within different areas include:

*Composites:* Lignin-based carbon fibres for composites (BioBased Industries Joint Undertaking under the EU's Horizon 2020 programme, 2016–20: €556,250); flame retardant natural fibre-reinforced biocomposites (Innovate UK, (2013-15: £202K); In structural composites by Dstl, MoD to study effects of impact and fire on composite materials containing nano additives (2016-20: £177,457), designing carbon fibre composites with improved structural retention on exposure to fire and impact (2018-20: £121211); sensing in carbon fibre composites for early detection of fire (2018 – 21: £126211) and to develop vinyl ester resins for fire safe marine composite (2014-15: £30K).

*Fire Safe Materials:* In the textiles area the research in developing environmentally sustainable surface treatments and techniques for chemical functionalization of textile surfaces and industry (2014 – 20; £135K). Research in novel fire retardants has being funded by industry: William Blythe UK (2014 -17; £67.5K), LANXESS (previously Chemtura), US (2013-15: \$97K) and SCG, Thailand (2016 -2017; £34K).

We had 4 Knowledge Transfer Partnership (KTP) awards for developing novel FR intumescent coatings (2018 –20; £147717, with Sherwin Williams), FR polyurethane foams (2020 – 22: £ 176,142, with Vita Cellular Foams Ltd.), non-setting sealants (2017 – 19: £ 142,398, with Hylomar Ltd.) and SAW and FBAR microsensors (2019-20, £147k, with with Passion for Life Healthcare(UK) Limited) and wireless sensor for fire prevention (2017-2018, £113k, with TBA Textiles Ltd).

*Halacheva* (left Sept 2017) was awarded EPSRC's First Grant (EP/M02881X/1) in 2015. *Soin* received a Newton Fund - DST NRF (South Africa) Early Career Researcher fellowship (2019, ECR180426324617, £10K) award, which though was moved to another institution when Soin took up a lecturing post there.

### 3.2 Consultancies and professional services

Engineering staff are extensively involved in consultancy for industry demonstrating our engagement with industry. Fire Safe Materials has done work for £200K over this period with William Blythe, ICL, MEL Chemicals and SAB Miller. *Kandola* has been invited by a resin manufacturer (Scott-Bader) as an expert advisor for their FST technology roadmap workshop for future strategy development (2019). *Horrocks* was invited as an expert witness in a US company law suit (2015-18). His arguments based on evidence generated in the university's fire lab helped the company win its law suit. *Luo* provided consultancies for Rolls Royce on indicative sensing (£8k) for high temperatures and wireless sensors for harsh environmental monitoring (£20k).

### 3.3. Investment in infrastructure and facilities

The Engineering facility was greatly enhanced by a £15M investment in a new, purpose built, three storey, 6000m<sup>2</sup> floor space building, opened in 2018 to support the university's engineering provision. The building has 2000 m<sup>2</sup> of ground floor containing 1500m<sup>2</sup> of dedicated physical laboratory space, available for both teaching and research activities. The facilities include: new composites manufacturing and testing facilities, additive manufacturing laboratories, CNC metallic manufacturing, high 800W rolling road and admissions testing, fabrication centre for manufacturing vehicle bodies, chassis and surface scanning.

We have a suite of advanced laboratories and workshops for conventional and novel material preparation/processing, including nano-, micro- and macro-composites and for testing small and



medium-sized structures (impact and other physical/mechanical properties), plus a well-equipped fire research laboratory, which is unique within the UK. We have a Class 1000 clean room to accommodate advanced coating facilities for thin film materials and devices (magnetron co-sputtering, atomic layer deposition and evaporator). For fibre, thin film solar cell and smart device research, we have a bicomponent filament melt extruder as well wet extruder, an electrospinning unit built with full environmental control.

Further to these facilities specific to School of Engineering, relevant large university infrastructure investments which includes the dentistry and biomedical sciences Queens building sharing facilities at postgraduate level. The building houses facilities for testing and fabricating dental composites. Also this includes autoclaves, tissue engineering and regenerative medical processes.

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

##### 4.1 Research collaboration and examples of interdisciplinary research

The research carried out within IMRI is often interdisciplinary and collaborative. Examples of major international research projects (with names of principal investigators in the parentheses) include:

- The EU project (*Kandola*) on lignin based carbon fibres for composites comprises academic and research organisations (University of Limerick (Ireland), Chalmers University (Sweden), DITF Denkendorf (Germany), Fraunhofer IFAM (Germany), IVW (Germany), Centeblex (Belgium)), has collaborators from all sectors of carbon fibre from polymer processor (Tecnar GmbH), fibre producer (Dralon GmbH), composite producer (Eirecomposites, Ireland), technologist (C-Tech Ltd, UK) and end user (Centro Ricerche FIAT SCPA, Italy).
- Dstl project under UK-France PhD scheme (*Kandola*) is in partnership with Ecole des Mines d'Alès and Laboratoire National de métrologie et d'Essais' (France).
- The project under 'Personnel Survivability' theme to flame retard Nylon-Cotton fabrics (*Kandola*) is funded by Natick (US Army) and is in collaboration with MTIX Ltd., UK
- LANXESS (previously Chemtura), USA funded a project to develop novel surface coatings for composites (*Kandola*).
- SCG, Thailand based company funded a project in the area of flame retardant polymer nanocomposites (*Kandola*)
- *Luo's* collaborative work in the area of SAW, FBAR and micro sensors in China has been funded by NSF, China (RMB 800K, 2019-2022) and a Key project of Sci.&Technol., China (RMB15M, 2019-2022) .
- *Kandola*, as vice chair of the COST (European Cooperation in Science and Technology) action MP 1105 (FLARETEX, 2012-2016), with membership of 21 European countries, has networked with other researchers for developing consortia for recently submitted and future EPSRC, TSB and EU project proposals.
- *Osman* has undertaken joint research with colleagues at Liverpool John Moores University, UK; Lulea University of Technology, Sweden; National University of Ireland; University of Khartoum, Sudan; and the Prime Minister's Office, Baghdad, Iraq.
- *Myler* (since 2016) works with SimPeds-SimEngineering based at Boston Children's hospital in collaboration with Harvard University on medical simulators and their interface with medical training procedures. He also works with Ras al Khaimah, UAE (2018) on *optimization for depth of cut and surface roughness for control depth milling in Titanium Ti6AL4V with Abrasive water jet cutting*.
- *Oti* collaborates with Universities of West of England, Coventry and Oxford Brookes. He has research links and industry support from establishments such as Wood Nuclear (part of Jacobs) and SUEZ Recycling and Recovery UK Ltd.

Much international collaboration takes place between individuals. Over the REF period, staff have hosted numerous visiting international researchers as detailed in Section C.1c. In addition to this, on average four undergraduate/post graduate students per year for 4 – 6 months from European countries (ENSICAEN Caen, Polytech' Montpellier, Polytech' Nantes, France) as internees, working on on-going research projects and adding value to the projects, while getting trained on

research skills. *Sheriff* has established a Joint Innovation Laboratory in Information and Communication Technology and Applications (JILICTA) with the College of Electronics and Information Engineering, Sichuan University, in order to foster research collaboration in terms of joint projects and publications, and student exchanges. *Geng* has been collaborating with the University of Alicante (Spain) to develop functional nanomaterials for electrochemical applications and has been the external examiner of PhD Defence of the Materials Institute of the university since 2012.

#### 4.2 Collaboration with research users

Collaborating with key stakeholders across industry has been at the heart of Bolton's research strategy as to maximise the pathways to impact for the economy and society.

The Fire Safe Materials group has worked with many industrial partners on joint projects where experimental strategies were developed to observe effect of fire retardant materials on flammability of their polymers/ products in order to assess their commercial potential. Examples include William Blythe, LANXESS, SCG, Innovia films, Devan Chemicals, Avocet, Uniroyal, Tata steel etc. The research findings apart from regular consortium meetings and scientific conferences have also been presented in various workshops including Knowledge Transfer Networks.

The success of the Fire Safe Materials research has resulted in the research expertise being highly sought out to consult on issues where their world leading knowledge will add value to the understanding of critical issues. *Kandola* has been invited by a major UK resin manufacturer (Scott-Bader) as an expert advisor for their FST (fire, smoke and toxicity) technology roadmap workshop for future strategy development. *Horrocks* was invited as an expert witness in a US company law suit. His arguments based on evidence generated in the fire lab coupled with his previous research helped the company win law suit. The group also helped European Flame Retardants Association (EFRA) to produce a video on fire safety standards, which was filmed partly in the Fire lab at Bolton and *Horrocks* gave expert advice. The BBC formally approached *Horrocks* to present an opinion on the fire safety of children's Hallowe'en clothing and his comments on flaws in fire testing regulations for those materials, led to direct changes of the fire and safety standards for children's fancy dress costumes in the UK. Until April 2019 *Horrocks* chaired a small private company NWtextnet that assists UK textile companies with technology transfer, applied research and dissemination. *Horrocks*, *Kandola* also deliver custom designed short courses to industry, e.g., at Yalova, Turkey (2019), IPECO, Holdings Ltd, UK (2015).

*Al-Faraj* collaborates with Universities of Salford and Lund, Sweden. *Paschalis* works closely with other Institutions such as the University of Brighton.

#### 4.3 Contribution to Society

A number of staff members and PhD students developed and coordinated the 'Messy Science' event, as part of Manchester Science Festival from 2010 to 2016 and participated in the Food and Drink Festival from 2014 to 2016. Many staff members have contributed to schools, youth clubs and groups in a range of activities such as the two week summer schools as part of the STEM Advantage Scheme in partnership with British Army and Royal Air Force, local schools, Bolton Interfaith Group along with engineering employers in order to promote science and engineering among young generation.

*Horrocks* secured funding from the Cotton Industry War Memorial Trust (£24K) for the creation of an archive on the history of the Lancashire Cotton Industry at the University. This will comprise a recently purchased private document collection together with the University's own text collection based on its many years in textile education commencing during the 19<sup>th</sup> century. The aim is to catalogue and integrate both historical collections and archive them electronically using professional software. A major outcome is the creation of an e-portal, which will enable access to the collection as well as link with others located within the North West region.

#### 4.4 Academic leaderships

The School of Engineering includes among its staff: two Fellows of Royal Society of Chemistry (*Kandola*, *Ebdon*), Fellow of the Institute of Mechanical Engineers (*Myler*), Fellow of the Institute of Water (*Al-Faraj*), Fellow of Institute of Materials Minerals and Mining (*Sanami*). *Horrocks* was

awarded Honorary Life Membership of the Royal Society of Chemistry based on his continuing contribution to chemistry over a 50+ year period. He is also Fellow and Honorary Life Member of the Textile Institute. All staff are members of different professional bodies.

*Kandola* is Member of EPSRC College (2003- present) and has served on EPSRC prioritisation panels. *Rajendran* was the Chair for Professional Qualification Award Committee of the Textile Institute for four years until 2016. He also represented the Textile Institute Council for a decade until 2018 in recognition of his devotion to the furtherance of scientific knowledge concerning fibrous and biomedical materials, for which he has been honoured with a prestigious medal and award by the Textile Institute.

#### 4.4.1 Editorship and scholarly activities

*Horrocks* is a member of the Editorial Board of Journal of Fire Science and *Kandola* of *Molecules*. *Kandola* has been guest editor of 2 special issues of Polymer Degradation and Stability (2015, 2018) and Polymer (2016) Journals. *Horrocks* has been guest editor of *Fibres* (2018). *Kandola*, *Horrocks* and *Ebdon* have been referees for major international fire science, polymer and composites journals.

*Luo* is editor and editorial board member for Scientific Reports, Sensors, Electronics (ISSN 2413-4155), International Journal of Computational Materials Science & Surface Engineering, Active & Passive Electronic Components, International Journal of Nanomanufacturing and Chinese Journal of Sensors & Actuators.

*Geng* is Associate Editor for Carbon Materials Group, *Frontiers*; and *Advances in Renewable Energy*. *Geng* has been a guest editor for International Journal of Hydrogen Energy. He has also been referee for top journals in Chemistry or Materials Science such as the Journal of American Chemical Society, Journal of Physical Chemistry, Carbon, Chemical Communications, Advanced Materials, Advanced Functional Materials, Journal of Materials Chemistry, Chemistry - European Journal, etc.

*Myler* acts as a reviewer for the Royal academy of Engineers grants panel. He has been a referee for journals such as Polymers, Journal of Materials Engineering and Performance, Journal of Machine Intelligence and Data Science and Composites Part B.

.Al-Faraj is a reviewer and editorial board member of the Journal of Bioscience and Applied Research. Paschalis is a reviewer for the Engineering Structures Journal and the Construction and Building Materials Journal.

#### 4.4.2. Conference Chairs and Invited Speakers

*Kandola* co-hosted the 16<sup>th</sup> European conference FRPM'17 in Manchester in July 2017, attracting 280 delegates. *Kandola* has delivered 24 invited lectures, some examples include RSC conference - Fire Retardant Technologies, UCLAN Preston (2014); International Symposium on Flame Retardant materials & Technologies (ISFRMT), China (2014, 2018); E-MRS 2014 Fall Meeting, Warsaw, Poland (2014); 7th Asia-Europe Symposium on Processing and Properties of Reinforced Polymers (AESp7), Madrid, Spain (2015), International Conference on Value Addition and Innovation in Textiles COVITEX, Faisalabad, Pakistan (2015, 2017); Eurofillers, Montpellier France (2015); EuroNanoForum Riga, Latvia (2015), European Meeting on Fire Retardancy and Protection of Materials, FRPM 15 and 19, Berlin, Germany (2015); Turku, Finland (2019); Asia-Oceania Symposium on Fire Safety Materials Science and Engineering (AOAFSM), Suzhou, China (2015, 2017); International Conference on Lightweight Design of Marine Structures, LIMAS, Glasgow and London (2015, 2017), Functional Textiles and Clothing Conference, FTC Delhi, India (2018), 30<sup>th</sup> Annual Conference on recent Advances in Flame Retardancy of polymeric materials, BCC, San Antonio, US (2019). *Ebdon's* invited lectures include RSC Preston, UK (2014), FRPM 2015, RSC Surrey 2016, Thermoplastic Compounding conference Dusseldorf (2019). *Horrock's* plenary lectures include International Antimony Association, Brussels (2018); International Workshop on Nanostructured Materials, Stockholm (2016; SCI, UK (2018). He was also invited to give the SCI Levinstein lecture in October 2016.

*Luo* has organized many international meetings as conference (co)chairman (Chair of 8th Int. Conf. on Manipulation, Manufacturing & Measurement on nanoscale, 13 August 2018, Hangzhou, China. Co-chairman of 2nd Int. Conf. on Electronic Info. Technol. & Comput. Eng. EITCE 2018,

**Unit-level environment template (REF5b)**

12 Oct. 2018, Shanghai, China. Chairman on Int. Conf. on Manipulation, Manufact. & meas. on nanoscale, 2018, Aug. Hangzhou, China; co-chairman of 1st to 3rd Int. Conf. on Nanomanufacturing, committee member of Int. Conf. on Micro & Nano-Eng., MME, session chairs of many Int. conferences.), He has delivered over 20 Keynote/plenary speak and invited talks in the international conferences.