Institution: Brunel University

Unit of Assessment: 15 General Engineering

a. Overview

Engineering at Brunel University was set up at the founding of the institution to tackle problems that were fundamental to future economically important technologies, and more immediate industrial needs. To this day we maintain that vision.

This submission draws together staff from electrical, electronic, civil, manufacturing, and biomedical engineering, its applications, and its supporting sciences. This forms a coherent unit with critical mass of currently 67 academic staff, 22 research staff, and 37 support staff. We are arranged in four themes:

Sensors and Systems: 19 staff (1 member of staff also in Biomedical Engineering).

The Sensors and Instrumentation Group develops and exploits detectors, instrumentation, and data analysis methods. They apply their work to high energy particle physics, space science, medical imaging, and remote instrumentation and control. Data processing techniques include grid computing, genetic programming and visualization. The Electronic Systems Group develops algorithms and measurement techniques from scientific fundamentals, implementing intelligent electronic systems for efficient operation and control of industrial processes, and health care systems. The Power Systems Group develops computational tools for analysis, control, operation, management and design of electricity transmission and distribution systems.

Communications and Signal Processing: 13 staff.

Both groups collaborate on the themes of real-time signal processing and transport and delivery over heterogeneous networks. The Media Group work on image and video compression, visual media processing, speech and audio processing and recognition, media search and retrieval, and 3D imaging technologies. The Wireless Networks Group specialise in ad-hoc networks, cognitive communications, cross-layer optimisation, interactive broadcast systems, personal mobile grids, service discovery, applications in telemedicine, and wired and wireless integration networks.

Manufacturing Systems and Design: 22 staff.

The Manufacturing Systems Group specialises in manufacturing technology, enterprise engineering and engineering management. Their main expertise lies in fabrication, metrology, positioning and manipulation at the micro- and nano-scales using bench-top ultra-precision machines. Other expertise lies in supply chain management systems' modelling and simulation, agile manufacturing, e-manufacturing, and digital enterprise technology. The Manufacturing Design Group is transdisciplinary, linking manufacturing, materials, electronic systems, and environmentally sensitive and sustainable design. They specialise in the use of biomimetics to design and develop new materials and structures, design for efficient circuit fabrication using printing technologies, and smart manufacturing processes for low power electronics and embedded systems.

Biomedical Engineering: 14 staff (1 member of staff also in Sensors and Systems).

The Devices Group concentrate on bio-fluids processing, prototype implantable devices and sensing systems. Modelling and simulation is used to diagnose and interpret diagnosis data, predict bioprocesses, judge the impact of therapies and to optimise the design of medical devices and tools. The Bioprocessing Group uses continuous flow methods for purifying particles and cells, reactions, and filtration. Significant emphasis is placed on scale-up of novel counter-current chromatographic methods.

Operation

The Electrical and Electronic Engineering subject area (Sensors and Systems, and Communications and Signal Processing themes) is led by **Nandi**, Manufacturing Systems and Design by **Cheng,** and Biomedical by **Brett**. All three units are part of the School of Engineering & Design (SED). The School management team agrees strategy and makes recommendations for new appointments and infrastructure investment. The team comprises the Heads of Subject Areas, Director of Graduate Studies, and the Research Centre leaders. Although our principal activities are high quality research and teaching, we promote the application of our research through technology transfer. We acknowledge our role in the public engagement of science and engineering, and our staff take part in public activities and are active within their professional institutions.

b. Research Strategy

Our approach to engineering research and training is that:

- it is a fundamental discipline for exploring the world around us,
- it is an enabler of technologies relevant to society,
- our staff engage with both fundamental problems and economically relevant technologies,
- we are equally engaged with fundamental and industry-related problems,
- all staff are expected to engage widely with other engineering, science, health, economics, and social sciences,
- we prepare doctoral students to be flexible in the application of their new knowledge.

Vision and Strategic Plans

Our vision is:

to tackle challenges that are important to the economy, the environment, and society both nationally and internationally.

We aim to be a creative community that is inspired to work, think, and learn together to meet the challenges of the future. We aim to attract outstanding partners across a range of disciplines to complement and underpin the applied research and development activities. Our strategy is formulated to maximise interdisciplinary, international dialogue and to enhance both basic engineering science and applied engineering-led research via continued focused investment in our research infrastructure, allowing us to be receptive to new opportunities arising from the changing landscape of national and international priorities such as "green" technologies.

Our unified research strategy is keyed into the overarching University strategy developed through consultation with Schools and Research Centres. Research theme strategy is developed by a team led by Wrobel (Deputy Head of SED, Research) and consisting of Centre leaders, plus representatives of ECR and MCR staff. External views are given by our Industrial Advisors who include: Dr. M. Short CBE FREng (O_2-Telefonica), Prof. N Jackson FREng (Ricardo), D. Rayers (BBC Future Media and Technology), P. Jenkins (BT Innovate and Design), Dr. N. Jefferies (Huawei Technologies), Prof. C. Firth (Thales), Dr. C. Clifton (Sony Semiconductor and Electronic Solutions), Dr. M. Bradley (National Grid), Ms R. Ali (BP), Mr. A. Harper (Jaguar-LandRover), Mr. J. Laughlin (TSB), and Mr. J. Sellors (Lotus Engineering). Examples of how our Advisors interact with the management team are: their support for shifting the emphasis of the Power Systems Group to include distribution network technologies and starting an internal collaboration on building a network of researchers working on topics allied to the circular economy. Their advice has also been helpful in warning against starting certain activities as they were a poor fit with our strategy.

Drawing on our strategic review in 2013, the highlights of our five year research strategy (from 2014) are to:

- draw together our critical mass of staff to establish three (University-wide) multidisciplinary research institutes in 'Energy Futures', 'Environment, Health, and Societies', and 'Materials and Manufacturing',
- build a new facility for, and create the first impacts from, the Brunel-led National Structural Integrity Research Centre,
- ensure the long-term sustainability of our EPSRC-funded programme of joint work with power systems researchers in China,
- secure funding for a novel purpose-built micro and nano-manufacturing facility,
- invest in facilities to co-locate sensors for health and biomedical researchers,
- secure funding for a new computing facility for big data analytics in the engineering sector,
- expand staff and facilities in our Communications and Signal Processing, and Biomedical Engineering themes,
- expand levels of international inward investment by industry for our research infrastructure,
- create mechanisms to further enhance multidisciplinary collaboration between the themes.

Our plans are designed to deliver constant and consistent improvement to 2020, and require significant additional inward investment. The strategy pursued from 2008 has improved our success rates across all types of funder, and we will sustain these levels of improvement through to 2020. The fundraising activities are an integral part of the campaign to celebrate the University's 50th anniversary in 2016. Highlights from the specific strategies for the four themes are:

Sensors and Systems:

- Expand power systems research based on the success of our recent smart grid activities.
- Build new facilities for Non-Destructive Testing instrumentation development as part of the National Structural Integrity Research Centre.
- Exploit our instrumentation for use in radiation detectors in harsh environments.
- Develop accelerator beam systems for proton cancer therapy with the Cockroft Institute.
- Exploit our big data analytics expertise and facilities in a wider range of engineering areas.

Communications and Signal Processing:

- Bring the departments of Mathematics and Computer Science into the same operational unit as Engineering and Design to create a larger, more coherent, and stronger fundamental base for our signal processing and data analytics research. This will benefit both the Communications and Signal Processing and Sensors and Systems themes.
- Expand our activities on real-time health, consumer, industrial telemonitoring applications.
- Develop multimodal interfaces enabling the users' interaction with new types of media content and multimodal sensorial input including but not limited to tactile and auto-stereoscopic video signals.

Manufacturing Systems and Design:

- Bring together the manufacturing and materials groups into a single entity or Institute to further improve the pull-through of basic research. An emphasis will be placed on pilot-scale studies and scale-up testing.
- Bring together staff from across Brunel working on supply chain research and integrate with our work on manufacturing systems.
- Develop the scientific approach and holistic understanding to ultra-precision and nano / micro machining and its implementation and application perspectives.

Biomedical Engineering:

- Bring together researchers from Sensors and Systems and Biomedical Engineering in a tight focus on problems related to ageing.
- Capitalise on current activities on bio-sensing for screening, monitoring and security.
- Expand work on interactive telemedicine and define clinical devices for first point of care.
- Develop design and manufacture through self-evolution of inorganic metastable materials and of biologically derived materials such as biopharmaceuticals and biofuels.

Achievements of the Specific Strategic Aims from RAE2008

Our RAE2008 submission was to UoA25 (General Engineering and Mineral & Mining Engineering). Our strategy was to i) consolidate the recent expansion of staff numbers in the four themes, ii) nurture ECRs to be successful MCRs, iii) diversify the income streams, iv) invest in new facilities and refurbishment of existing laboratories, and v) improve the impact of our research. We summarise the evidence in this section, with the detail described in sections c), d), and e). Since 2008, we have:

- spent a total of £8.13M on infrastructure refurbishment,
- promoted all 6 ECRs (RAE2008) (one to Professor),
- built the 12th largest Technology Strategy Board portfolio in the UK,
- entered into strategic agreements with TWI, Jaguar-LandRover, Renishaw, and ESAB,
- attracted £5.8M industrial inward investment.

The success of our RAE2008 ECRs is especially pleasing. They have won 26 grants totalling £3.87M, i.e. a yearly average of £107k.

The Research Support and Development Office (RSDO) provides the central support for each School's, and the University's overall, research strategies. Investment in RSDO staff since 2009 (from 11 to 15 people) and training has gone in-step with our substantial growth in the number, variety, and total income of grants. RSDO manages a Research Development Fund to support the development of major grant applications and the University's EPSRC Impact Acceleration Account. RSDO also supports the development of strategic research relationships with industry. For the protection and commercialisation of IP that originates from inside Brunel, RSDO arranges seed funding, sector-relevant management support, and patent filing.

c. People

i. Staffing Strategy and Staff Development

The University staffing policy is designed to promote world-leading research and sustain a vibrant academic environment. Significant emphasis is placed on giving staff new to Brunel (ECRs and established) support to ensure that they are able to be productive as soon as possible – this contributes to the sustainability and vibrancy of our research environment. For example, our RAE2008 ECRs have won 4 grants each since 2008. Our staffing strategy is:

- to provide the opportunities and reasonable means for all staff to fulfil their potential,
- to identify gaps in our portfolio as research areas develop within the four themes,
- to reward research groups demonstrating grant income success with new posts,
- incentivise and financially reward staff for winning grants,
- to provide mentoring at all levels.

Our recruitment policy places strong emphasis on hiring outstanding researchers whose work complements one or more of our existing research centres. Candidates are expected to have a record of publishing high quality research commensurate with their experience level. Typically about 50% of applicants to academic posts are from overseas. Our recruitment strategy is:

- for senior staff – to only appoint those with internationally leading portfolios
- for MCRs – to only appoint those with internationally competitive portfolios and the potential to become internationally leading
- for ECRs – to only appoint those with some international experience and the potential to be internationally competitive / leading,
- to advertise posts internationally and to target active groups, particularly for ECR posts,
- to appoint those with proven multidisciplinary experience,
- all appointees must be able to demonstrate that either they have taken steps to apply their work to a cognate academic area, or engaged with public or private sector organisations.

Evidence of How our Staffing Strategy Relates to our Research Strategy

Since 2008, 11 people have retired and 7 left for other posts. We have appointed 18 people (8 ECRs, 10 Senior) of these, 5 were in the **Sensors and Systems** theme, 2 in **Communications and Signal Processing**, 8 in **Manufacturing Systems and Design** and 3 in **Biomedical Engineering**. Of those who retired or moved on Watts and Da Via went to Manchester, Yang to UCL, and Yao is now Director of Strategy and Marketing at Huawei Technologies (UK). Success in research output and grant income have been such that 15 members of staff have been promoted since 2008, including two to Professorships.

The new staff appointed have been very productive and raised a total of £8.56M with 45 grants (32% of the total for the period). Further examples of their early productivity are: **T. Gan** has already won 7 grants, **Nandi** won the IEEE Award for Best Communications Letter in 2012, and **Taylor** rose from Lecturer to Professor. Our strategy for investment and staff support has attracted academics to move here, for example, **Boyd** moved from Melbourne Centre for NanoFabrication (Australia), **Meng** from UCL, **Ojeda** from Sheffield, and **Theodoridis** from TEI Athens (Greece).

We have a total of 14 staff with visiting positions elsewhere. Exemplars of those made since 2008 are: **Al-Rawshidy:** Yuan Ze University (Taiwan). **Nandi:** University of Calgary (Canada). **Owens:** Zhejiang Gongshang University (China). **Owens'** Visiting Professorship has assisted considerably in winning the bid to co-ordinate an EU programme for R&D collaboration with ICT between China and Europe.

Career Development Support

All staff are supported to attain the next level in their career. We undertake some activities which are subject specific whilst others are institution-wide and common across disciplines. For all levels of seniority, staff are mentored through the promotion process to help understand the requirements, preparation, expectations, and the final interview. The University process (overseen by Senate) actively rewards research excellence. As part of the process, the University organises workshops, led by the University Equality Champion, to support women intending to apply for promotion. The overall promotion process is subjected to an annual Equality Impact Assessment, which is used to drive improvements in the equity of the process.

Brunel University received an Athena SWAN Bronze Award in 2012, and is embedding the policy and practices across all disciplines. Newly introduced Athena SWAN Research Awards are

open to staff returning from maternity, adoption or paternity leave (>4 months) to support research leave, equipment purchase, or to employ RAs. Awards are made on the basis of an internally reviewed proposal. The University appointed 'Equality Diversity Champions' to provide leadership in creating and maintaining an inclusive culture. The University operates a vibrant Women in Science and Engineering group spanning the whole University and all grades (including PGRs). **Cole** and **Leslie** won STFC awards for encouraging girls to take up STEM subjects.

Specific Arrangements for Research Assistants (RA)
Brunel received the European Commission's 'HR Excellence in Research' award in 2011 in recognition of its commitment to the recommendations of the Concordat to Support the Career Development of Researchers. Brunel has a Concordat Action Plan and Working Group. RAs are offered programmes of personal and professional development through both the Graduate School and the Staff Development Unit as appropriate. Examples of courses offered are: 'Creating Research Impact', 'Understanding Patents, Licensing, and Standards', and 'Effective Public Speaking'. Before the end of their contract with Brunel, over 90% of our postdoctoral researchers secure further positions; typically 15% of our RAs go to academic posts, 70% to an industry or sector related to their post at Brunel, and 15% take other positions (including teacher training). Examples of recent positions secured are at: the Centre for Bio-inspired Technology at Imperial, National Grid, Eon, and Converteam. Of the RAs hired since 2008, 9 were British citizens, 7 were Chinese, 7 were European, 4 were Asian, and 2 were South American and African. Many of these staff were employed via our active programme of international recruitment, which stems from our international research collaborations.

Specific Arrangements for Early Career Researchers (ECRs)
On appointment, all ECRs are assigned a mentor, have reduced teaching and administrative responsibilities throughout probation, and are appraised annually by the Head of the appropriate Subject Area within the SED. ECRs receive priority in the allocation of our DTA and SED-funded research studentships. Start-up funding of up to £15k is available upon internal review of a short proposal. These awards are intended to initiate a project, acquire equipment, and to travel to conferences to create a network of collaborators. Three examples of successes due in part to the award of these start-up funds are that **L. Gan** went on to win an EPSRC First Grant award (£120k), **Nilavalan** leveraged additional support of £36k from TWI, and **Ojeda** won both a Royal Society New Investigator Grant (£15k) and a NERC CASE award (£84k).

Specific Arrangements for Mid Career Researchers (MCRs)
All senior lecturers are appraised annually by the Head of the appropriate Subject Area within the SED. The Staff Development Unit courses appropriate for MCRs include Research Ethics, Managing Research Staff, and Influence and Impact for Researchers.

Specific Arrangements for Senior Researchers (SRs)
Readers and professors agree their targets for the coming year with the Head of SED and their annual pay rise is linked to their performance. Senior academics looking for leadership roles are offered a six month programme to develop competencies in their areas. Seven SRs took part since 2008: **Ignatova**, **Khir**, **Kyberd**, **Makatsoris**, **Powell**, **Smith**, and **Taylor**. During this assessment period **Sadka** and **Vasegi** were awarded research leave.

ii. Postgraduate Research (PGR) Students

We celebrate the vital role PGRs play in sustaining research activities and stimulating adventurous new ideas. Since 2008 157 PGRs have completed in this UoA. We receive approximately 9 applications per place. Our strategy for PGR is to:

- attract and select students with the greatest potential for high quality research,
- create bilateral agreements with companies and research organisations to support PGRs,
- train students to be flexible in the application of their new knowledge,
- to develop the transferable skills of all PGRs,
- to enable all PGRs to gain international exposure,
- to enable PGRs to engage with an appropriate business or industrial sector,
- to give PGRs confidence in their abilities and achievements,

To support this strategy we have diversified the number and type of funding sources for the scholarships that we offer. In addition, the University has made a substantial financial commitment

directly as part of several partnerships. For example, for UK Nationals we have secured 15 scholarships from the Thomas Gerald Gray Charitable Trust, which are topped-up by the SED.

Since 2008, we have entered into 8 strategic partnerships (or similar agreements). For instance, TWI initially agreed to co-fund 5 PhDs in a pilot programme (2009-13) for NDT instrumentation, shared with Mechanical Engineering. Due to the quality of the students recruited and their work, TWI agreed to support a further 10 PhDs with a 40%-60% funding split between Brunel and TWI (2011-15). Similar agreements have been made with NPL, National Grid, and Renishaw. The TWI agreement grew into the partnership which won the National Structural Integrity Research Centre and is funding 10 PhDs per year at Brunel (with various companies).

Between 2002 and 2012 Brunel and Surrey jointly ran the EPSRC Engineering Doctorate Centre for Environmental Technology. To sustain the expertise generated and in accordance with the EPSRC's aims for the EngD Centres, from 2010, Brunel introduced an Industrial Doctorate Scheme for Sustainable and Environmental Technologies. The Research Engineers (RE) have the same working and financial arrangements with the supporting companies, and the Brunel Graduate School provides the transferable skills training. The model adopted is sustainable and the collaboration with Brunel is proving attractive to both the companies which were involved with the EPSRC-funded scheme and new ones. So far, 12 REs have embarked on the new scheme with the first due to complete their four year programme in 2014. Sponsors for this programme include: Buro Happold, Converteam, Mollart Engineering, NPL, and National Grid.

PGR Training and Support Mechanisms

Admissions are managed through the Brunel Graduate School. Specialist training, enrolment and progression is managed by the SED. Transferable skills are provided by the Graduate School, for example, ethics, research methods, and project management. The Graduate School is the hub for PGRs and plays an important role in bringing together the community through both academic and social activities, supporting the development of cross disciplinary links. The Graduate School also collaborates with other universities in London (particularly UCL and KCL) to provide a broader context for researcher development, i.e. opportunities for inter-disciplinary learning, collaboration and networking across institutions.

SED organises an internal Research Student Conference (ResCon). All PGRs must take part and it gives PGRs a chance to speak, present posters, and allows supervisors to see how their PGRs defend their work before they go to an external conference. ResCon2013 involved 200 presentations over a three-day period (130 talks and 70 posters). For progression to year 2 each PGR gives a talk, presents a poster at ResCon, and is interviewed. Travel funds are available to ensure that all PGRs present their main findings at an appropriate conference. Since 2008, 16 PGRs won conference prizes, 3 won thesis prizes, and 3 won full scholarships in open competition. Onward destinations of PGRs since 2008 include GlobalData UK, Naton Medical Group Inc (Beijing), Research Center for Drugs and Food (USA), and the National Agency of Drug and Food Control (Indonesia).

d. Income, Infrastructure, and Facilities

Since 2008, our strategy has ensured that we invested £10.8M in infrastructure and facilities across our four themes, plus the engineering computing facility. We currently operate a total of 4,200m^2 of research space (plus 1,500m^2 for offices and teaching) – the SED totals are 13,700m^2 and 4,000m^2 respectively. In 2009 SED opened a 4,500m^2 facility to house several groups and to provide state-of-the-art space for PGRs at a cost of £16M (SRIF3 / HEFCE). The strategic decision by the University to create this building freed up space for the SED to start a 10-year programme of refurbishment. The Heinz Wolff Building, housing the Biomedical Engineering laboratories received a £7M upgrade in 2010. SED workshop facilities are supported by 37 staff with 10 specialist technicians in research laboratories. SED has 4 dedicated administrative staff for research support. Our research and high performance computing facility is supported by 11 dedicated technical staff. Brunel is a Worldwide LHC Grid Tier 2 site and part of the European Grid Infrastructure. Our Tier 2 has currently 1300 cores and 650 TByte of on-line storage. It is internally networked at 10 GB/s and connected to JANET at 4 GB/s.

Since 2008, our staff have won 16 Industrial CASE studentships with 9 funded through the EPSRC (2 under the Dorothy Hodgkin Postgraduate Student scheme) and others sponsored by, Motorola Ltd., HealthSmart Ltd., Fortune TV, TMD Technologies Ltd. and Astra Zeneca. The total value of these awards was over £759k.

Sensors and Systems

SPECIALIST FACILITIES: the Sensors Development laboratories operate a high-rate Cobalt-60 gamma-ray irradiation facility for radiation tolerant electronic and sensor components for applications in particle physics, space science, and medical dosimetry. A 4T superconducting magnet for long-term testing of photodetectors. A micro-focus 40kV X-ray source for space science applications. Two Class 10,000 clean rooms for developing and evaluating fast scintillators (including fibres).and fluorescent quantum dots. The Power Systems laboratory operates a Phasor Measurement Unit, ELPROS Phasor Data Concentrator, frequency disturbance recorders, Schweitzer protection, automation, and Bay Control System, National Instruments Compact RIO system, a Moixa LVDC microgrid system, a small-scale embedded generator testbed for PV and wind, and a 96 core computing facility for power systems modelling and data analytics. The Electronic Systems laboratories are equipped with the capability of printing electronic structures on various materials, and Axxin instrument for real-time isothermal amplification of nucleic acids

INVESTMENTS SINCE 2008: high-performance computing and data centre refurbishment (£570k), high-rate Cobalt-60 gamma-ray irradiation facility (£86k), and power systems and control laboratory (£188k).

INCOME SINCE 2008: the grants won total £10.3M. Examples include: DEECON, an FP7 project that is developing a retrofit marine diesel engine exhaust cleaning system (€3.4M total, €1.1M Brunel, **Balachandran**), an FP7 project exploited HPC tools for smarter electricity distribution network operation (€6.5M total, €1.2M Brunel, **Taylor** and **Irving**), an STFC-funded project for the UK participation in the International Muon Ionization Cooling Experiment (£469k, **Kyberd**), and an NHS-funded project on erythropoiesis in health and disease (£372k, **Nandi**).

PLANNED INVESTMENTS: high-performance computing and data centre upgrade (£550k), upgrade of the Class 100,000 clean room (£130k), a real-time digital power systems simulator, and an upgrade of the Co-60 sources.

The current and planned investments will enable the members of this theme to:

- develop smart operation and management tools for future electricity distribution grids and a pan-European 'Super Grid',
- play a full role in designing and engineering sensors and instrumentation for the next generation accelerator at CERN,
- increase the quantity and quality of collaboration with health researchers on transdisciplinary problems for 'point-of-care' testing and diagnosis,
- exploit our expertise and facilities for big data analytics.

Communications and Signal Processing

SPECIALIST FACILITIES: the Wireless Networks laboratory has configurable booth-type cells for research and showcasing activities. Communications software for research includes: OPNET, OMNET, NS3, Virtual Photonics Incorporated, High Frequency Structural Simulator, and CST Microwave Studio, plus a 2x2 MIMO Wireless LAN testbed. The Signal Processing laboratory comprises 20 FPGA boards, 20 DSP systems, 1 Altera Cyclone IV, 2 high performance Xilinx Spartan 6 FPGA Boards, and a DVB-T/H Delay Diversity TV Transmission Network, Optical Spectrum analyser, optical sources and detectors, and 100 km of fibre and D-Fibre. The Media Communications laboratory operates facilities for capturing, processing and visualising 2D/3D information including a stereoscopic video projection system, an auto-stereoscopic Philips display as well as high-end multimedia-capable processors, NX-12 3D body scanner, a Minolta VIVID910 3D laser scanner, and a 6 camera Eagle Digital System for whole body motion analysis.

INVESTMENTS SINCE 2008: new laboratories in the £16M SRIF3 / HEFCE building (£194k),

INCOME SINCE 2008: the grants won total £2.3M. DTV4ALL, an FP7 project co-ordinated by Brunel that facilitated the provision of access services on digital television across the European Union (€2.9M total, €0.6M Brunel, **Itagaki**), an EPSRC First Grant on structured sampling operators for compressive terahertz imaging (£120k, **L. Gan**), and INSTINCT, an FP7 project co-ordinated by Brunel that focussed on realising the commercial provision of services in wireless networks (€9.3M total, €0.7M Brunel, **Cosmas**).

PLANNED INVESTMENTS: signal processing development lab upgrade (£62k), 4G wireless lab-scale test facility (£190k), antenna anechoic chamber (£80k), upgrade of the 3D image capture facility with holoscopic cameras and an autostereoscopic display (£47k).

The current and planned investments will enable the members of this theme to:

- place greater emphasis on integrating communications with e-health applications,
- develop state-of-the-art 3D capture and visualisation technologies and broaden the range of engineering applications,
- develop communications technologies to enable the UK to be a digital economy leader.

Manufacturing Systems and Design

SPECIALIST FACILITIES: The Materials research laboratory (shared with the Wolfson Centre for Materials Processing) is the only University research centre to achieve BS EN ISO 9001:2008 UKAS Quality Management 015 standard (including equipment calibration test certification). The principal electron microscope is a new Joel 2100 FEG-STEM for sub-nanometre imaging. It is equipped with X-ray analysis, electron energy filtering, electron energy loss spectrometry, tomography and cathodoluminescence capability (specimen holder connected by fibre optic to a remote spectrometer). This instrument is unique in the UK and only one of two in the world. The Electron Microscopy suite also includes: FESEM Zeiss Supra VP FE-SEM able to operate at UHV, with weak vacuum conditions and with uncoated specimens; scanning probe microscopy; atomic force microscopy, and a secondary ion mass spectrometer. The Analytical suite includes equipment for thermal, rheological, chemical and structural analysis including micro and nano characterisation, mechanical and related physical testing. The Manufacturing laboratories comprise a 5-axis UltraMill with 0.1µm accuracy and a 3-axis micro electrochemical machine, both make complex 3D components with nanometric surface roughness. A CNC diamond turning machine and a CNC precision lathe provide capacity for micro cutting. Two sub-nanometric 3D surface profilers for surface metrology, and a Mitutoyo Coordinate Measuring Machine for dimensional/form metrology measurements at 1µm accuracy. Also photopolymeric additive layer manufacturing using a Viper Si2 SLA system. The Cleaner Electronics laboratory comprises a Versastat electrochemical workstation (cyclic voltammetry, galvanostatic charge- discharge cycling, and electrochemical impedance spectroscopy), three-roll mill, bead mill, and viscometer, used for making functional inks and carbon slurry, Diamatix DMP 2800 printer for high precision jet printing of functional fluids and inks, and a Heidelberg Offset lithographic printer for high speed sheet fed printing of electronics.

INVESTMENTS SINCE 2008: Joel 2100 FEG-STEM system (£2.43M), ToF-SIMS instrument (£320k), Class 100,000 cleanroom (£230k).

INCOME SINCE 2008: the grants won total £9.9M. Examples include: an EPSRC-funded project on integrated design of closed-loop cooling systems (£419k, **Cheng**), an FP7 project with 6 SMEs to use ultrasonic detection and removal of fouling inside industrial and domestic pipes (€1.4M total, €0.6M Brunel, **T. Gan**), Micro-ECM, an FP7 project on electrochemical machining with emphasis on engaging with SMEs (€1.6M total, €0.5M Brunel, **Ivanov**), the EPSRC funded the upgrade of small equipment for ECRs (£476k, **Ojeda**), and the Leverhulme Trust funded a project to determine the chronological context of latent fingerprints on porous surfaces (£175k, **Reynolds**).

PLANNED INVESTMENTS: large-scale 3D fabricator (£39k), electron backscattered diffraction and energy dispersive X-ray analysis equipment (£440k), Nanotech ultra-precision lathe (£350k).

The current and planned investments will enable the members of this theme to:

- bring together their existing collaborations with the National Physical Laboratory and ESAB to build a long-term programme on metrology for embedding micro- and nano-scale manufacturing into industrial processes and to widen the range of industrial application areas,
- start joint research programmes focussed on the ‘circular economy’ with researchers in materials, mechanical engineering, systems biology, and supply chain management (Business School),
- develop work on ‘design for decommissioning and deconstruction’,
- offer practical solutions towards resolving the Energy-Water-Resource nexus.

Biomedical Engineering

SPECIALIST FACILITIES: the Pilot-scale zoned hazards laboratory comprises two ATEX-compliant Maxi CCC centrifuges (4.6 and 18 litre capacities). The pumping system is dedicated to liquid-liquid handling (up to 3 litres/minute flow rates). The whole laboratory is evacuated every few minutes with complete air-exchange extractions, and is remotely controlled from an explosion-proof Operator Room. Supporting facilities include HPCCC centrifuges, solvent handling systems (5 and

25 litre capacities), fraction analysis is provided by 2 HPLC units with both PDA and ELSD detectors, HPLC and a GC for analysis and a liquid-handling robot for the solvent selection process. We have stroboscopic photography for the visible coils of the Cantilever CCC centrifuge, plus a continuous countercurrent extraction rig, a toroidal CCC, and non-synchronous CCC instruments. The Membranes laboratory operates a uniaxial tensile tester, a dynamic mechanical analyser, differential scanning calorimetry and thermogravimetric analyser, laser Doppler vibrometer, and laser surface and scanning velocimeters. The Particle Systems laboratory contributes a modified Phase Doppler Anemometer for bipolar charge measurement of both liquid and powder pharmaceutical aerosols, fully instrumented electrospray booth (incl. a high frame-rate camera) to study electrically charged sprays for agricultural applications, and high sensitivity electrometers. The Biofluids laboratory has a high frame-rate camera (XPri) for studying the movement of mechanical cardiac assist devices, an Aloka ultrasound scanner for imaging the heart and arteries, pulsatile flow meters for in-vivo and in-vitro, catheter tipped pressure transducers, and an Instron to measure the mechanical properties of arterial segment invasively. The Robotics laboratory comprises liquid handling robots for automated PCR setup, and a Qubit Fluorometer for DNA, RNA and protein quantification, a unique in-house designed and built micro-drill for cochlea surgery.

INVESTMENTS SINCE 2008: surgical robotics facility (£64k), refurbishment and upgrade of the bioprocessing suite (£1.2M).

INCOME SINCE 2008: the grants won total £4.4M. Examples include: a project funded by the British Heart Foundation for evaluating the hemodynamics of a new intra aortic balloon (£460k, **Khir**), an FP7 project for the Microbe Innovation Programme to accelerate natural bio-based alternatives for carbon capture and storage in the energy-intensive industries (€3.6M total, €0.3M Brunel, **Garrard**), the TSB-funded project for scalable technology for the extraction of pharmaceuticals (£498k, **Sutherland**), and MRC and Wellcome Trust funded project for developing a 'lab-on-a-chip technology for point of care diagnosis of STIs (£1.36M, **Balachandran**).

PLANNED INVESTMENTS: Orbitrap mass spectrometer (£425k), upgrade of the Counter Current Chromatography facility (£220k), a new 'Health Engineering' facility (£1.45M).

The current and planned investments will enable the members of this theme to:

- improve quality of life by developing less invasive and better functioning medical devices,
- improve medical outcomes by developing precision and automation in surgical settings,
- collaborate more extensively with electronic systems researchers for point-of-care testing and diagnostics, and smart biosensors for screening, monitoring, and security.
- scale-up processes and protocols for extracting and purifying pharmaceuticals,
- better integrate health economics with our sensors and medical device researchers.

Of this income, £6.8M was from RCUK, £12.9M was from the EU, £2.3M was from the TSB and £5.8M from other sources, including charities and industry. The assessment period has seen a number of changes to the research funding environment, particularly the requirements of funding councils. The University has responded to this by fostering links with potential partners in research collaborations, supporting and encouraging interdisciplinary collaboration that is particularly relevant to research in General Engineering, and by providing a Research Development Fund to support development of major grant applications.

Major Plan

The **National Structural Integrity Research Centre (NSIRC)** is a major investment planned to integrate the work of the **Sensors and Systems** and **Manufacturing Systems and Design** themes. NSIRC also brings together researchers from Applied Mechanics in our Mechanical Engineering Department. Brunel leads NSIRC with a unique, integrated approach to research and PGR training. The total project value of £82M comprises £15M (HEFCE), £45M (industrial partners), and £22M (Regional Growth Fund). The initial partners are BP, Cambridge University, Lloyds Register, Manchester University, Network Rail, TWI, and UCL. It will be housed in a purpose-built 4,500m^2 facility at the TWI site outside Cambridge. NSIRC will advance the underpinning science, develop novel technologies, innovate in the value chain, conduct holistic product design, and demonstrate monitoring solutions for asset management. It will accelerate the translation of science into commercially relevant products and services. The investment in new

equipment will include: a guided wave inspection system, scanning electron microscope, remote and intelligent sensors and analysis tools for condition monitoring applications, an acoustic emission monitoring system, and electromagnetic testing.

Consultancy, Professional Services, and Patents

Our staff attracted £501k for consultancy work for industry. Examples include TEVA Pharmaceuticals, National Grid, the BBC, and TWI. In addition, **Brett** was the independent consultant of the Commission of the European Community's Research assessing existing research contracts on Robotics Applied to Surgery, and for cadaver trials in Brussels on ontological samples. **Angelides** has conducted extensive work for AT&T (USA). TMD Technologies Ltd (an SME in West London) regularly use our materials characterisation services which developed into a CASE award for **Ojeda**. A key example is how our partnership with ESAB has developed. ESAB asked the Manufacturing Systems Group to create a programme for their management on how to maintain their technological competitive advantage. This resulted in ESAB moving from their product-centric approach to being customer-focused. This is unusual in that a university was asked to develop a solution to create a business-critical shift.

Staff in this submission hold over 70 patents. The Brunel strategy is to file an application only if there is a business case for the invention, we do not file patents speculatively for all inventions our staff bring forward. As a result, many of our patents and licensing arrangements evolve from grants and consultancy activities. Exemplars of patents granted since 2008 are: **Balachandran:** 'Microfluidic Device' (MX2009007447). **Evans:** Lithographically Printed Cells' (GB2451603). **Ignatova:** 'Counter-Current Chromatographic Arrangement' (WO2010010366). **Makatsoris:** 'A Modular Flow Reactor' (WO2013050764). **Sutherland:** 'Centrifuge' (US2008207422).

e. Collaboration and Contribution to the Discipline and Research Base

Our strategy is to have every member of staff active in at least one network. This is implemented through programmes to enhance collaboration at different scales. These are differentiated to support staff at all stages in their careers. For example, our strategy for ECRs is to start by improving local collaboration and to ensure that they are helped by their mentor or other MCR / SR to engage in external networks or to create new ones. For more established researchers, we have a strategic agreement with PERA to co-ordinate European research networks on our behalf. We present some **exemplars**:

Local: To initiate collaboration across disciplines (and UoAs) Brunel organises 5 University-wide Collaborative Research Networks (CRNs). We contribute to three – Innovative Manufacturing, Ageing, and Energy and Environmental Sustainability. These CRNs bring together experts into multidisciplinary teams to address important 'grand challenges' through series of events and workshops. For example, Brunel appointed David Riley as Entrepreneur in Residence to implement a programme of engagement with staff to foster entrepreneurial culture and encourage commercial engagement. RSDO organise events to help stimulate research activity, including the annual 'Buzz' event, run in conjunction with RCUK, to develop proposal writing skills and to facilitate networking and cross-disciplinary research. Our EPSRC Impact Acceleration Account (£600k) is being used for research within the automotive sector, building upon the existing strengths in Brunel and their collaborative projects with industrial partners. Our aim is to draw upon researchers with expertise relevant to the automotive sector (particularly **Manufacturing** and **Electronic Systems**) but who are not yet working closely with the sector and create new partnerships with researchers in our Mechanical Engineering Dept and the Wolfson Centre for Materials Processing. This will achieve a demonstrable impact by creating strategic alliances across the automotive value chain at the institutional level. Another example of collaboration across UoAs in Brunel is that of **Cheng** with Karayiannis in the Mechanical Engineering Dept on an EPSRC project on the integrated design of closed-loop cooling systems for boiling heat transfer (this project is also in collaboration with Edinburgh). **Balachandran** has created a partnership with Brunel health researchers which has won funding from the MRC and Wellcome Trust.

National: Brunel operates a Knowledge Transfer Secondment Scheme. Exemplars of people seconded from industry since 2008 are John Scott (KEMA) to work with **Irving**, Alan McMorran (Open Grid Systems) to work with **Taylor**, and Michael Kemmler (BioFocus DPI), to work with **Sutherland**. Our collaboration with TWI has been built up over 10 years with multiple researchers. This relationship has culminated in winning the **National Structural Integrity Research Centre**

which now becomes a much wider collaboration of leading universities and companies. **Makatsoris** co-directs, with Bath University, the EPSRC-funded Directed Assembly Grand Challenge Network which aims to gain unprecedented control of the assembly of the building blocks of many functional materials, consumer and industrial products.

The Brunel repository of full text research outputs is ranked 12th of all UK universities by usage and content. We have an Open Access mandate in place, and a centrally managed Open Access Publishing Fund. Additional measures relating to the accessibility of research data are being put in place in line with RCUK requirements.

International: Brunel contributed to the discovery of the Higgs boson – this year's Nobel prize for Physics. Our **Sensors and Instrumentation Group** contributed to CMS, one of the two large detectors that saw the rare Higgs events. We helped to design, build and operate a high-energy electron and photon detector, the world's largest silicon particle tracker, and a grid computing and data analytics centre. **Taylor** collaborates with the University of Tennessee (USA) on electricity network measurements in the F-NET project for 1000 devices across North America and Europe. **Nandi** leads an international team developing methods for studying music processing in the brain during naturalistic music listening, funded by TEKES (Finland). Our **Materials Research Group** have been convenors and authors of New International Standards in Surface Chemical Analysis (ISO TC 201) and Microbeam Analysis (ISO TC 202). In collaboration with Liverpool University, **Cheng** co-leads the Global Sustainable Manufacturing Network – a group of UK/Sino universities and companies and the Korean Institute for Machinery and Materials. This is a 5-year Manufacturing Grand Challenge project co-funded by the EPSRC and the Korean Government. **Owens** and **Itagaki** have just started as co-ordinators of an EU-funded programme for R&D collaboration with ICT between China and Europe. The network identifies obstacles to reciprocity and encourages a more balanced relationship with China by supporting European nationals, companies and organisations willing to access Chinese research programmes.

The strategic partnership with PERA has assisted all 4 themes to win more than 20 EU FP7 proposals since 2008 with, for example: Tampere University (Finland), Turino Polytechnic (Italy), Aachen University (Germany), Steinbeis Innovation GmbH (Germany), Union Fenosa (Spain), EdF R&D (France), IBM (Israel), Fraunhofer IWES (Germany), KU Leuven, and Oslo University.

Visiting Scholars: Our collaborations have led to visits by 23 overseas scholars since 2008 (total of 54 for SED). Of these, 12 were visiting professors plus 11 other senior scholars. In addition, more than 40 visiting research students have visited Brunel for periods of three months to a year. Examples are: S. Li (Harbin Institute of Technology, China), J. Mula (Universitat Politècnica de València, Spain), E. Simolowo (University of Ibadan, Nigeria), and P. Stoa (SINTEF, Norway).

Examples of interdisciplinary research: A programme of internet-enabled diagnosis at the point-of-care led by **Balachandran** (Electronic Systems) resulted from a short-term consultancy request from St. George's Hospital. Following this contact, a project was developed for a 'Doctor on a chip', a handheld device capable of accepting a raw sample from a person and providing an STI disease-specific diagnosis in minutes. The treatment loop is completed with automatic electronic communication with a GP able to prescribe based on the reliability of the result from the device. **Nandi** (Electronic Systems) collaborates in a NIHR-funded team from Brunel, Bristol, Cambridge, and Oxford to study the regulation of gene expression during red blood cell development. **Hobson** (Sensors and Instrumentation) has developed new techniques validating medical dosimetry and in accelerators for proton-beam therapy. Members of the Wireless Networks and Signal Processing Groups have been collaborating with medics and health practitioners to create telemonitoring applications exploiting communication technologies.

Influence of Research Users: the most prominent example here is how the collaboration with TWI grew into a partnership. TWI assisted us both strategically and practically in re-organising parts of our research in Electronic Systems, materials, and applied mechanics to create a coherent programme on structural integrity across different application areas. The resulting strategy was supported financially within Brunel. The success and dedication of staff in implementing the strategy gave confidence to both TWI and Brunel to enter into a Strategic Partnership – resulting in winning and forming the **National Structural Integrity Research Centre**.

The long-standing relationship with GSK has steered the Bioprocessing Group's research strategy towards increasing the effort devoted to scale-up. This advice gave Brunel confidence to

invest in specialist infrastructure to support this work. Our relationships with Rolls Royce, Renishaw, CRDM (3D printing), and Mollart Engineering have shaped our strategy for engaging with the TSB. Our strategy is to support a wider range of our groups orienting part of their work towards higher TRLs. This has led to both a greater number of proposals and a higher success rate. The consequence is that Brunel now has the 12th largest TSB portfolio in the UK.

Leadership in the Academic Community – (Inter)national Advisory Board Membership: Since 2008, 14 of our staff are or have been members of advisory boards in the UK and overseas. Outstanding among these are: **Boulgouris:** Panel Member, Greek Universities Quality Assurance Agency. **Cheng:** Member, UK Manufacturing Professors Forum; Member, IMechE Academic Standards Panel. **Fisher:** Member, Technical Programme Committee, Khalifa University, Abu Dhabi. **Hobson:** International Advisor, MIT Sea Grant Programme, for NSF; and the Canadian Govt. **Mousavi:** Advisor, the World Health Organisation. **Owens:** President of the Advisory Board, Institute of Studies Brazil-Europe. **Sadka:** Member, Board of the European t-platform NEM.

Leadership roles in Research Councils, learned societies and professional bodies: Since 2008, 16 of our staff are or have been members of the EPSRC college. Other notable positions are: **Boyd:** Board of Directors, Materials Research Society (USA) and Executive Committee member, European Materials Research Society. **Agius:** Reviewer, Netherlands Organisation for Scientific Research, Physical Sciences Council. **Boulgouris:** Expert Evaluator, Swiss National Science Foundation. **Brett:** Founder and President, Technology in Medicine Section of the Royal Society of Medicine; Chair, IMechE Division on Engineering in Medicine and Health. **Cheng:** Member, review panel for the EU NMP Programme. **Hobson:** Member, STFC Particle Physics Grant Panel. **Khir:** Board Member, European Society for Artificial Organs. **Leslie:** Chair, Women in Physics Group, IOP. **Nandi:** Chair of the Awards sub-committee of the IEEE Technical Committee of Machine Learning for Signal Processing. **Ojeda:** Reviewer, NSF (USA).

International Conference programme chairs: Notable among these are: **Boulgouris:** IEEE Int. Conf. on Image Processing (ICIP), Belgium (2011). **Boyd:** Int. Union of Materials Research Societies Int. Conf. on Electronic Material, Sydney, Australia (2008). **Brett:** IEEE Conf. on Mechatronics and Machine Vision in Practice, Brisbane, Australia (2011). **Cheng:** 9th Int. Conf. and Exhibition on Laser Metrology, Machine Tool, CMM and Robotic Performance, London (2009). **Fisher:** 16th Conf. on Biopartitioning and Purification, Mexico (2011). **Ignatova:** Int. Symposium on Preparative and Industrial Chromatography and Allied Techniques, Brussels (2012).

Invited keynote lectures at international conferences: Notable exemplars are: **Boyd:** SPIE Photonics West, San Francisco, USA (2010); Int. Conf. on Research Facilities, Washington, USA (2011). **Cheng:** IMCC, Tianjin, China (2011). **Makatsoris:** 5th Int. New Exploratory Techs Conf. (NEXT), Turku, Finland (2008). **Nandi:** Int. Symp. on Communications, Control and Signal Processing, Rome, Italy (2012); opening of the Centre for Interdisciplinary Brain Research, Jyvaskyla U, Finland (2013). **Zobaa:** CIIEM, Spain (2011).

Election to membership or fellowship of learned societies: All staff in this submission are Members or Fellows of one or more of IEEE, IET, IOM3, BCS, EI, IOP, Soc Biol, RSC, or IMechE. Elections since 2008 include: **Agius:** Fellow, British Computer Society. **Bonser:** Fellow, IOM3. **Boulgouris:** Senior Member, IEEE **Brett:** Fellow, American Institute of Medical and Biological Engineers. **Cheng:** Fellow, IMechE. **Cosmas:** Senior Member, IEEE. **Leslie:** Chartered Physicist. **Nandi:** Fellow, IEEE. **Nilavalan:** Senior Member, IEEE. **Ojeda:** Fellow, RSC. **Sadka:** Fellow, IET.

Journal editorship: Examples since 2008 include Editor or Editor-in-Chief: **Al-Raweshidy:** The Communications and Networks J. **Boyd:** J. Laser Micro/Nanoengineering. **Cheng:** European Editor, Int. J. Advanced Manufacturing Technology. **Zobaa:** Int. J. Power and Energy Systems. Associate Editorships: **Bonser:** J. Bionic Engineering. **Boulgouris:** IEEE Transactions on Image Processing and **Cosmas:** IEEE Transactions on Broadcasting**.** Guest Editorships: **Khir:** Proc. IMechE Part H: J. Eng in Medicine. **Makatsoris:** Int. J. Manufacturing Research.

Fellowships, awards and prizes: Brett: Best Paper Award, IEEE Toowoomba (2010). **Cosmas:** Special Service Awards, IEEE Broadcast Technology Society (2010 and 2013). **Meng:** 1st International Audio/Visual Emotion Challenge Award, AVEC2011, USA (2011). **Nandi:** IEEE Communications Society, Heinrich Hertz Award for Best Communications Letter (2012).