Institution: University of Nottingham

Unit of Assessment: UoA 16 - Architecture, Built Environment and Planning

a. Overview

Driven by the desire to improve the Unit's research excellence, the former School of the Built Environment was incorporated into the Faculty of Engineering in 2009. The benefits to this Unit include: provision of strong research leadership and a reinforcement of research culture; access to excellent analytical, experimental and computational facilities and associated support staff; access to a team of dedicated research and business development staff; training and development programmes for academic and research staff. Research activities within the Unit have also been consolidated into three groups focusing on architecture and related applied research and two groups focusing on engineering and more fundamental research.

The results from these changes are evident in: recruitment of talented academic staff; increased industry and research council income; improvements in the quality of staff output; indicators of esteem, including best paper prizes, invitations to deliver keynote lectures and to sit on editorial boards, industry advisory boards and research council panels.

Further success through to 2020 will be ensured through: active recruitment of talented academic and research staff; mentoring early career staff and developing leadership skills; increased engagement with funding bodies and research partners; internal reviews of papers and grant applications.

b. Research strategy

Future Plans as at RAE 2008

At the time of RAE 2008, research within the then School of the Built Environment was managed by a small research committee, comprising the Head of Research (Riffat), Administrative Manager, Director of Architectural Research (Hale) and Heads of its five Research Groups: Building Services (Riffat); Sustainable Technologies (Riffat); Environmental Design and Tectonics (Ford); Urban Design (Heath); Architectural Humanities (Hale). Future plans focussed on strengthening collaboration, including with the newly established Centre for Sustainable Energy Technology (CSET) at the University's Ningbo Campus in China; consolidating and further developing research partnerships and networks; enrichment of established research groups; development of new research areas and facilities. This latter was exemplified by the newly created Environmental Design and Tectonics Group, following from the appointments of Ford and Stacey and the proposal to create a new Creative Construction Centre, centred around a new prototyping hall, digital printing and fabrication facilities.

Research Restructuring Post-2008

The School of the Built Environment migrated from its former Faculty of Law and Social Sciences to the Faculty of Engineering, which is now comprised of five teaching and learning Departments, of which Architecture and Built Environment is one, and five multi-disciplinary thematic Research Divisions, each comprising a number of related Research Groups.

The base disciplines of academic staff within ABE tend to focus on either Architecture or Engineering, with several straddling the two. Staff with an Architectural bias are typically members of one of the three Research Groups (from UoA 16) that belong to the Infrastructure, Geomatics and Architecture [IG&A] Research Division (whose remaining three groups are returned to UoA 15), whereas Staff with an Engineering bias are typically members of one of the two Research Groups (from UoA 16) that belong to the Energy and Sustainability [E&S] Research Division (whose remaining three groups are also returned to UoA 15):

- Infrastructure, Geomatics and Architecture Division: "Architecture, Climate and Environment", "Architectural Humanities", "Architecture and Tectonics".
- Energy & Sustainability Division: "Environmental Physics and Design" and "Heating, Ventilating, Air-Conditioning and Refrigeration (HVACR) and Heat Transfer".

The Faculty supports a rich culture of collaborative research, with broad ranging initiatives involving staff from multiple Groups and all Divisions. Indeed this culture of collaborative research

is actively promoted, with all Groups being positioned within Divisions that have Groups from elsewhere within the Faculty with complementary interests. For example, the Architectural groups in IG&A are complemented by Human Factors and the Nottingham Geospatial Institute, and the engineering groups in E&S are complemented by Thermofluids.

With this research structure in place, the Faculty then reviewed the strategic research priorities, research objectives and methodologies for the achievement of those objectives.

Strategic Aims and Objectives

The Unit aims to engage in fundamental and applied research of the highest quality, across multiple disciplines and throughout the range of relevant scales (from nano to city), to improve society's environmental, social, cultural and economic sustainability. Our objectives in pursuance of this aim are to:

- Recruit and support exceptional people
- Work in partnership with key stakeholders for mutual advantage
- Invest strategically in our unique environment
- Maximise the impact of our innovation for all stakeholders

Together with a review of the research funding landscape resulting from national and international priorities, this strategic aim and associated objectives have guided the setting of thematic grand challenges, recent appointments in response to them, restructuring in terms of the formation and composition of Research Groups, and the setting of new Research Group Strategies through to 2020. In the following we focus on our Research Groups; the rationale for their formation (if appropriate), their foci, their progress since 2008 and their future plans. Division and Faculty level strategies have also had considerable influence on our approaches to and resources for People, Infrastructure, Facilities and Collaboration; of which more later.

Our Research Groups

A number of our Research Groups have evolved since RAE2008 in response to: national and international research priorities in smart and sustainable cities, energy using behaviours, advanced structures and nanotechnologies; the University's Research Priority Areas of *Energy* and *Operations in a Digital World*; a desire for truly interdisciplinary research and to achieve a critical mass of activity within the groups.

Architecture, Climate and Environment (ACE, Prof. Riffat): is formed from the majority of the Sustainable Energy Technologies Group, the environmental design component of the former Environmental Design and Tectonics Group and the technology oriented part of the former Building Services Group. ACE aims to inform the sustainable practice of architecture and engineering to enhance the quality of the built environment; focussing on *Energy in the Built Environment* and *Climate Responsive Architecture* through eight overlapping themes: Sustainable Building Design, Energy, Cooling, Materials, Daylighting, Education, Simulation, Tradition and Heritage.

Collaboration with partners in academia, the construction industry and with CSET at the University's Ningbo Campus underpins much of this group's work. Progress is evidenced by a growth in funding (in excess of £6M for this REF period) from the Research Councils, TSB, EU (incl. Marie Curie), Royal Society, Carbon Trust, DECC, and Industry; receipt of numerous Awards (e.g. *Rushlight*, *UK Engineer Technology and Innovation*), two new technology transfer licences and three new patents. A highlight is the £2.5M Creative Energy Homes (CEH) project: a key resource to study micro-smart grids, energy storage, demand-side management and occupants' acceptance of innovative technologies. CEH is yielding results that inform both national policy and high quality research outputs, recognised recently through the ICE's *Trevithick Prize*. The group co-organised and hosted the UK Passivhaus Conference (2012) and the AECB National Conference (2011) and continues to organise the well established International Sustainable Energy Technologies conference. Now in its 12th edition, ISET attracts a growing delegation as well as journal Special Issues for the best of its papers.

Further grant success will be ensured through targeted engagement with Industry and funding bodies and by capitalising on initiatives such as Horizon 2020. The group will continue to maximise dissemination and the commercialisation of its research innovations as well as policy, societal and economic impacts. These endeavours will be continually revised in consultation with the group's Industrial Advisory Group and affiliated Honorary Professors.

Architectural Humanities (Dr. Hale): focuses on the history and theory of modern and contemporary architectural culture, with three distinct areas of strength: architecture of museums; relationships between architecture, technology and human embodiment; architectural hermeneutics (architectural and urban interpretation, theory and criticism). The group also initiated in 2003 formation of the Architectural Humanities Research Association (AHRA). Progress since 2008 arising from intensified collaboration (inter)nationally is reflected by the co-organisation of the international conferences *Narrative Space* (University of Leicester) and *Critical Phenomenology* (Carleton University, Canada); a series of interactive digital exhibition projects with Computer Science at Nottingham and involving international artists (*Moving City*); and Hale's award of the *Azrieli Visiting Critic* at Carleton University's Azrieli School of Architecture. This group, which is strengthened by three new lecturer appointments (including Dr Parnell, the 2012 RIBA President's Research Award winner: PhD thesis), will further develop its programme of collaborative interdisciplinary research, facilitated though smaller (University and AHRC) and larger (ESRC and EC) funded projects to address key future challenges such as strengthening links with professional practice (in architecture and related design disciplines) in a more vocationally oriented academic environment, alongside supporting the role of the humanities in society through further interdisciplinary and international engagement.

Architecture and Tectonics (Prof. Chilton). Formerly part of Environmental Design and Tectonics, this Group undertakes research into the core of architecture, as a practice and a discipline, as well as into specific areas of materiality, be this fabrication and digital design or new materials and unconventional and lightweight structures. Progress in particular in digital fabrication is evident in the construction of the new Centre for 3D Design and most notably the Wolfson Prototyping Hall situated in the Energy Technologies Building, a capital investment of £7.2M. A research exchange with Philip Beesley Architects funded by the Canadian *SSHRC Partnership Development Grant* facilitated the *Prototyping Architecture exhibition* that was showcased at the opening of the Wolfson Prototyping Hall. The Group has also been strengthened by the appointment of six academic staff, with Prof Chilton and Dr Beccarelli bringing new structural design expertise (particularly in lightweight materials and structures).

Building on the expertise of the recent appointments, and collaborating with colleagues across the Faculty, the group will develop a vibrant programme of applied research around digital prototyping, additive manufacturing, lightweight materials and structural systems. There is strong potential for close industry engagement, particularly with respect to new low-carbon building components and assemblies, as well as for continued engagement with the *TensiNet Association.* Through *TensiNet* the Group has contributed to the development of two CEN Standards (via CEN TC 248 and CEN TC 250) and an EU COST project on novel structural skins (TU1303).

Environmental Physics and Design (ePad, Prof. Robinson): ePad aims to combine physical and design principles with decision support to improve social, economic and environmental sustainability at the range of scales. It is structured according to four overlapping themes, each with a leader: (i) Social, Building and Urban Physics (Robinson), is intersected with the remaining themes; (ii) Psychophysics and Pedagogical Research (Altomonte); (iii) Low Carbon Building Design and Simulation (Wu); (iv) Landscape, Architecture and Urban Design (Heath). This group is comprised of former members of Environmental Design and Tectonics, Sustainable Energy Technologies and Urban Design as well as seven new appointments, including that of Prof. Robinson to provide overall leadership to the Group.

Highlights since 2008 include: development with a portfolio in excess of €2M of urban energy and environment simulation software and publication of the associated book "Computer modelling for sustainable urban design"; the €1.6M EC-funded EDUCATE (Environmental Design in University Curricula and Architectural Training in Europe) project to overcome barriers to the integration of environmental sustainability in architectural teaching and practice; development of new models of human behaviour and comfort, attracting three journal best paper prizes. Further grant success and the quality and impact of research and its outputs will be maximised through engagement with funding bodies (UK and EU Smart Cities Stakeholder Platforms, EERA JP and MSI on Smart Cities, JPI Urban Europe) and research partners (domestic and overseas, supported through a new IEA Annex on behavioural modelling).

HVACR and Heat Transfer (Prof. Yan): Evolving from the former Building Services Group, this new group extends beyond buildings to include the indoor environments of transport vehicles,

marines and aeroplanes. The key foci are i) thermal management and heat and mass transfer relating to the integration of HVACR and battery thermal management technologies for hybrid and electric vehicles; ii) efficient passive and active cooling technologies based on both conventional and novel (e.g. micro-nanofluid two-phase flow mechanisms) for thermal management; iii) multi-disciplinary research into biomimetic functional surfaces for these efficient cooling technologies; iv) multi-scale modelling and analysis of HVACR systems in buildings, vehicles, marines and airplanes. Progress in these themes is indicated by a number of awards including a Royal Society International Project Grant (£25k), several European FP7 Marie Curie grants (>€1M: FP7-IIF (332304), FP7-IIF (272410), FP7-IRSES (295224), FP7-IRSES (294905), FP7-IIF (298340)) and the commitment by FAW (China) of £1M to establish a new joint laboratory at Nottingham on low carbon vehicle thermal management & heat transfer.

In addition to their specific priorities, all groups are strongly encouraged to further their international engagement, actively recruit the best researchers, mentor early career academic and research staff, to share ideas and progress through informal presentations and to conduct internal reviews of papers and grant applications. This latter is reinforced through formalised Faculty-managed grant application peer reviews.

c. People:

Our aim is to recruit exceptional people and support them to attain and sustain excellence in all their academic endeavours. The Faculty strategy and Department and Division priorities guide every academic appointment. During the REF period, the Unit has successfully recruited two professors (Robinson and Chilton) and promoted two academic staff to professors (Gillott and Yan) – together with other professors present at the Unit in 2008 (Ford, Heath, Riffat and Stacey), they have been providing research leadership and guidance to other research and teaching staff, particularly those of the newly recruited, in various capacities. Emphasis is placed on nurturing staff at the beginning of their career to ensure that they excel at both teaching and research. The balance between these is moderated by our workload model which enables an equitable distribution of research, teaching and administrative duties. All new appointments benefit from reduced teaching and administrative commitments during their first three years at the University, financial support for equipment and consumables, guaranteed PhD studentships and mentoring.

All category A returned staff have permanent contracts and consist of 8 Professors, 2 Associate Professors and Readers, 6 Associate Professors and 8 Lecturers coming from well-balanced age groups, ethnic backgrounds and genders and with various research expertise relevant to the UoA 16. The demographic profile of the current REF Unit enables the Unit to effectively carry out the present priority research projects and well prepare for future research foci and themes as well as easily plan for the succession of the Unit research leaders (e.g. through University and Faculty level research leaders programmes, described below).

***Support and development of academic staff**:* The University is committed to the continued development of its academic staff, ensuring that a clear and viable upwards trajectory is identified for them and that they are assisted along this path through mentoring, networking opportunities, pump-priming their research activities and development training. To this end we have developed and implemented divisional and group based grant application mentoring systems to improve success rates at all staff levels. The faculty's formal ethical review practice adopted since 2010 and research groups' internal reviews of research outputs ensure the Unit's research to be both ethical and of high standard and good integrity. We have also developed a formal research leadership programme for Faculty academic staff, of which around one third of the initial cohort are from this UoA. This focuses on leadership foundations, networking, team working and building and 360°-assessment. This complements the Nottingham Research Leaders Programme, which is designed to support and advance key academics in their strategic research leadership roles, so that they deliver world leading research with impact, in pursuance of the University's Strategic Plan. The University was awarded the 2009 Scientist Best Places to Work in Academia Award, is a Stonewall University Champion and the Faculty of Engineering was the first such Faculty in the UK to receive an Athena Swan Silver Award in 2011 in recognition of good employment practise for women working in SET in higher education and research. Since RAE 2008 we have also implemented a formal induction process to help new staff settle in the new environment and a formal academic/research leave process to encourage staff to develop their research careers and new

collaborations. The latter is exemplified by Altomonte's six-month research leave (1 Aug 2012 - 31Jan 2013) to the Center for the Built Environment at UC Berkeley. Our promotions procedure ensures there is equal opportunity to all staff to progress, taking account of their career profile and pathway. In this REF period we have promoted 7 staff from Lecturer to Associate Professor and 2 from Associate Professor to Professor. Personal Development and Performance Review (PDPR) is the process employed by the University to ensure staff develop and are rewarded appropriately in line with the wider Faculty and University objectives. All staff set and monitor their own objectives within Faculty priorities, and drive their own development and performance improvement, with the support and guidance of their manager and reviewer. Our practice is that Staff meet their reviewer every 3 months to monitor and discuss their progress against key indicators.

Support for researchers' career development: The University is committed to embedding the principles of the Concordat to support the career development of researchers in its policies and practices. This agenda is driven by the University's Research-only Staff Group (RoSG) and the Engineering Research Staff Group (ERSG) which is represented on the faculty research committee. We have developed formal processes to support early career researchers, guidelines for research staff promotion and induction processes for all new research staff. We also have a bridging funding system to retain researchers at the end of fixed term contracts prior to the start of new grants and have introduced a formal Fellowship strategy with modules in CV preparation, fellowship proposal writing and interview practice, now being delivered twice per academic year.

Recruiting and developing the most gifted PhD students*:* Recruiting high quality PhD students and training them to a high standard is a core function of the Faculty, which benefits from the key role these students play in contributing to our research outputs. To encourage applications from HEU undergraduates, the Faculty runs a high fliers scheme, and funds summer internships to encourage our top flight UG students to pursue research degrees. The latter has enabled approximately 45 top class UG students (ca. 4 for UoA16) per year to undertake research placements across the Faculty, of which around 35 have gone on to study for PhDs at Nottingham and elsewhere. To attract the best overseas students we have implemented the "Dean of Engineering Scholarship Programme" which provides for 20 full and partially funded overseas PhD scholarships each year, of which typically 4 are awarded to UoA16. The successful candidates always have a 1st class UG degree and many also have a high MSc, MA or MArch distinction.

4 of our academic staff have completed PhD studies during the REF period and in total our staff have supervised some 150 doctoral students (including 5 EngD Students). To ensure PGR students receive the best possible supervision, each is usually assigned 2 supervisors with complementary expertise. The Faculty has also developed a structured Engineering Postgraduate Research Training Programme. A key element is the process of reflective audit. Each doctoral student is required to complete a 'training needs audit', in collaboration with their supervisor, within six weeks of registration. This audit covers research, professional and technical training needs, and is a compulsory part of progression. The Faculty holds a research student Progression Board at least twice yearly to review PGR students' performance and formally approve progression to the next year. The board is informed by training records, evidence of completion of supervision record forms (at least 10 per year) and the result of a formal progress assessment based on a written report and viva with an independent Internal Reviewer at the end of the first and second years. Research divisions also run their own colloquia and have an annual poster competition. All research students also take part in the 2-day Annual Faculty Research Student Conference, which includes specific sessions on thesis writing, preparation for the viva, getting published and career pathways for PhD graduates. Finally, as part of the University Graduate School, the Engineering & Science Graduate Centre runs a structured programme to support graduate career development.

d. Income, infrastructure and facilities

Income: During the REF period, the Unit has obtained 18 awards from UK Research Councils/Royal Society, 23 from the European Commission, 28 from government bodies and 45 from industry and other funding organisations. These awards have led to a total funding of £9.7M to the Unit. The Unit has also obtained a further £1.9M for infrastructure (Creative Energy Homes, Nottingham H.O.U.S.E and their associated monitoring equipment) and around £300k of in-kind contributions for research equipment (from Siemens). Exemplars of these grants are outlined in the following section (e). With respect to commercial exploitation, we have also been awarded 6 new patents and concluded 2 licensing agreements. This intellectual property has leveraged additional

income of £200k.

Infrastructure and facilities: Our Sustainable Research Building (SRB) (~550m^2) houses laboratory facilities ranging from a solar simulator, solar thermal systems/PV panels, air conditioning units, a micro-scale (5.5kWe) combined heat and power (CHP), wind tunnels for research into efficient cooling/jet impingement, external airflow and natural ventilation and infiltration in buildings, laser Doppler anemometer (LDA) to a thermal management and heat transfer research laboratory for low carbon vehicles. The SRB also accommodates some 90 PGR students and demonstrates a range of building-integrated low and renewable energy technologies with live data monitoring and display, such as solar thermal/PV panels and micro-wind turbines on the roof, self-cleaning windows and thermal heat storage with phase change materials. Additional laboratory spaces (ca. 200m^2) are provided by the Marmont Centre, including research facilities for solar desalination, ground source heat pumps, domestic biomass heating/CHP, building material testing, a climate chamber, an acoustics laboratory to study sound transmission and auralisation and a suite of well-serviced computers which are equipped with building simulation software such as ANSYS FLUENT, EnergyPlus, TAS and AutoCAD. The Creative Energy Homes consists of seven prototype houses designed and constructed to various degrees of innovation and flexibility to support testing of different Modern Methods of Construction (MMC), energy efficient design and renewable/sustainable energy systems such as solar thermal/PV, air source heat pumps, micro-CHP (1kWe fuel-cell CHP and 1kWe Stirling engine CHP), natural ventilation and heat storage with phase change materials and waste water collection/recycling etc. Equipped with advanced monitoring and smart metering equipment, they provide the ideal infrastructure for research on energy demand reduction, user behaviour, retrofit and zero-carbon emission housing. A new Centre for 3D Design, created after RAE2008, provides specialised facilities for digital fabrication technologies, with laser cutting and 3D printing equipment. These facilities are now providing strong support to the Unit's research.

We are also partners in the new 2700m^2 Energy Technologies Building (ETB): with a BREEAM rating of Outstanding, the £7.2M ETB, as a part of the University's £90m infrastructure investment over the REF period, accommodates 760m^2 of laboratory space dedicated to energy technologies, including the in-situ testing of building integrated renewable energy systems, advanced materials and innovative façade technologies to reduce energy demand and regulate indoor comfort. Furthermore, the new 400m^2 Wolfson Prototyping Hall has been used for the fabrication, testing and exhibition of full scale mock-ups of building components and assemblies, including façade prototypes.

Our integration into the Faculty of Engineering has had a significant positive impact on the quality and availability of infrastructure and resources. We have been given full access to the Faculty's IT and research facilities and equipment, particularly those in the Centre for Advanced Measurements in Engineering Research Applications (CAMERA). CAMERA includes high speed cameras, laser and phase Doppler anemometers and particle image velocimetry, a suite of materials testing machines, infrared cameras, advanced microscopy, a large-scale wind-tunnel and fuel characterisation / preparation equipment which are now routinely used by the Unit staff to support their research, for example, on experimental fluid mechanics, heat transfer and micro-scale biomass heating/CHP. We now also have full access to the Nottingham Nanotechnology and Nanoscience Centre where a suite of state of the art instrumentation for nano and micro scale analysis can be used to support our research related to detailed advanced characterisation of materials/samples. The Faculty also now provides a centralised Engineering Workshop and a large IT support team (in addition to our own dedicated technicians) and additional laboratory spaces and PGR research offices.

e. Collaboration or contribution to the discipline or research base

Since RAE 2008, major investments in the Faculty's Research and Business Development Team have been made (from 6.2 FTE to 9.2 FTE and now fully faculty funded rather than from HEIF). This group works closely with academic staff and the University's Business Engagement and Innovation Services and Research and Graduate Services Divisions to identify and communicate opportunities, facilitate introductions and provide contract support. Strategic decisions are made with reference to Faculty, Division and Group strategies.

Academic Research Collaboration: The Faculty develops interdisciplinary academic

collaborations amongst its research groupings through a number of different routes to deliver excellence in multi-disciplinary research and knowledge transfer. The production of the built environment is an intrinsically interdisciplinary pursuit and this culture of interdisciplinarity automatically extends to and indeed pervades our research endeavours. Exemplars include:

- *Midlands Energy Consortium* (MEC): we are founding members of this £3M interdisciplinary consortium of Nottingham, Birmingham and Loughborough Universities to research: solar, wind and biomass energy; clean fossil fuels and carbon abatement technologies; demand reduction and management in buildings; sustainable societies: economics, policies, practices and impacts; sustainable transport, advanced engines and systems. The MEC also coordinate the Midlands Energy Graduate School to unify related doctoral training and hosts the Energy Technologies Institute, a public-private partnership established to speed up the deployment of new low-carbon energy technologies in support of the UK's energy and climate change goals (Riffat, Gillott, Liu);
- *CALEBRE*: Consumer Appealing Low Energy Technologies for Building Retrofitting, a £2.1M EPSRC/E.ON collaboration (EP/G000387/1) with Loughborough, Oxford, Ulster, Herriot-Watt & Warwick Universities (Gillott);
- *H.E.R.B.: Holistic Energy-Efficient Retrofitting of Residential Buildings*, a €8.6M FP7 project between 17 European academic institutions and industry led by University of Nottingham (Riffat, Gan);
- *EDUCATE*, a €1.6M EU project (Contract no. IEE/08/635/SI2.528419) led by University of Nottingham with 8 EU partners including the AA (UK), Catholic University of Louvain (Belgium),Technical University of Munich (Germany) and University of Rome La Sapienza (Italy) to promote the integration of sustainable environmental design in teaching and practice (Altomonte, Ford);
- *Effective Adsorbents for Establishing Solids Looping as a Next Generation NG PCC Technology*, a £757K EPSRC project (EP/J020745/1) led by University of Nottingham with Leeds and UCL and 5 industrial partners including E.ON to develop and demonstrate novel and cost-effective solids adsorbents looping CO2 capture technologies (Liu);
- *Passive and Hybrid Downdraught Cooling (PHDC)*, a Nottingham-led €907k FP6 project (Project reference: 38418) which involved eight academics and industry partners from Europe, China and India, to undertake post-occupancy evaluations of exemplar PHDC projects and prepare design guidance and performance evaluation tools (Ford);
- *GROMIT* project: GROund coupled heat pumps MITigation potential, a £0.8M NERC collaboration (NE/F017715/1, NE/F020368/1, NE/F018568/1) with Reading University, the British Geological Survey and 2 industrial partners (Gan);
- *Towards Pervasive Media* (incorporating Moving City), a £201K EPSRC project (EP/H024867/1) with the University's Schools of English and Computer Science to develop a series of interactive digital exhibitions (Hale);
- *Heritage Conservation Guidance*, a RMB250K project with Tianjin University, China to prepare regeneration guidance for Tianjin's heritage sites (Heath & Zhu).

We have also developed active research co-operations with many leading international universities outside Europe such as in: North America, where we have had research exchanges (e.g. Altomonte to UC Berkeley; Hale to Carleton); China, where we have had a number of collaborative research projects (e.g. Yan with Jinlin University; Heath, Zhu and Tang with Tianjin University; Riffat with Shanghai Jiaotong University, Liu with Tsinghua and Southeast Universities and CAS institutes); Asia where we also have active research collaborations (e.g. Liu with the IITs at Delhi and Bangalore).

Industry/Practice Research Collaboration: Our industrial partners are a key part of our strategy to maximise the impact of our innovation. The Unit has a distinguished panel of *Honorary Professors* and *Special Design Professors* (including Clegg, Cucinella, Guthrie, Macfarlane and Timberlake) who together with an *Industry Board* provide advice on research strategy and research priorities, PhD student training and industry collaboration. They help to ensure the relevance to industry of our research projects. In this REF period we have continued or established collaborations and partnerships with numerous industrial partners. Exemplars include: the £414k TSB funded collaboration project with EnvirUp Ltd, Nottingham City Homes Ltd, Church Lukas Ltd, Eurocell Profiles Ltd and N. E. P. Energy Services Ltd; the £286k TSB funded collaboration project

with Ashwell Biomass Ltd, GAST Group, Strawsons Energy, and EPS Ltd; the £250k E.ON Retrofit Research House project funded by E.ON.

With houses sponsored by national and international companies (including BASF, E.ON, Saint-Gobain, Tarmac) the *Creative Energy Homes (CEH)* project is a particularly significant example of industry partnership; in this case to examine best practice for new and refurbished residential development.

Leadership in Academic Research: During the assessment period 19 plenary addresses were given along with 63 keynote speeches. Exemplars include:

- Eco-Urbanism Forum, Shanghai EXPO 2010 (Heath);
- Sustainable Energy & Construction Forum, Shanghai EXPO 2010 (Riffat);
- Global Humanitarian Forum, 2008; European Energy Conference, 2012 (Robinson);
- International Conference on Bionic Engineering, 2008 and 2010 (Yan);

Over 115 invited papers, speeches, lectures and seminars were given in the assessment period with 4 best paper awards being received, exemplars include:

- Building and Environment Journal Best Paper Award, 2009 & 2010 (Robinson);
- Trevithick Prize for Best Research Publication, ICE 2010 (Gillott & Rodrigues).

We have received 14 prizes, awards and honours and secured 5 incoming and 6 outgoing fellowships; including:

- Solar Decathlon Europe Sustainability Award (Gillott, Ford, Rodrigues);
- RIBA President's Award: Outstanding university-based research: commendation (Ford);
- RIBA President's Research Award: PhD thesis (Parnell);
- UK Engineer Technology and Innovation Award, 2009 & 2010 (Riffat, Gillott);
- Visiting Senior Research Fellowship to Bath (Robinson).

Our staff hold 34 positions on Editorial Boards, amongst which are:

- Int. Journal of Space Structures (Chilton);
- Architectural Research Quarterly (Ford);
- Journal of Urban Design (Heath);
- Journal of Applied Thermal Engineering; Int. Journal of Ambient Energy (Riffat);
- Int. J. Low Carbon Technologies; Sustainable Cities and Society (Riffat: Editor-in-chief);
- Journal of Building Performance Simulation (Robinson);
- Journal of Bionic Engineering; Nature: Scientific Reports (Yan).

We sit on 12 research council review or assessment panels, including:

- RIBA Research Awards Panel Member (Ford & Hale);
- French National Research Agency Panel Member (Robinson);
- EPSRC College of Peers and Panel Member (Yan).

Members of academic staff also hold key leadership roles and are current members of 24 research, industry and professional organisations, institutes and advisory bodies including:

- TensiNet Association; Int. Association for Shell and Spatial Structures (Chilton);
- DCFS UK Low-Carbon Task Force for Schools (Ford);
- Architectural Humanities Research Association, Steering Group (Hale);
- World Society of Sustainable Energy Technologies, CIB (Riffat);
- JPI Urban Europe; EERA JP on Smart Cities (Robinson);
- European network of biomimetic functional surface with fluids interaction (Yan).