Institution: University of Ulster

Unit of Assessment: 16 Architecture, Built Environment and Planning

a. Overview

The University of Ulster's Corporate Plan identifies the achievement of international excellence in chosen areas of research as a strategic goal (Corporate Goal 2) with 15 research institutes (RIs) comprising the structure within which research is delivered. The Built Environment Research Institute (BERI), one of the larger RIs, constitutes the submitted unit. Built Environment at Ulster is within the Faculty of Art, Design and the Built Environment, the Faculty comprising three Schools (Built Environment (SBE), Art, and Architecture), a Research Graduate School (RGS) and two RIs (BERI and Art & Design). The Faculty's Research & Innovation Committee is co-chaired by the RI directors. Coherency arises from complementarities and supportive management structures within the faculty and between SBE and BERI. SBE embraces all disciplines within the built environment, with the exception of architecture which at Ulster has a research culture focussed on design, the output from which is included in UoA 34 (Art and Design) rather than UoA 16.

Within BERI, specialisms are developed in four research centres, each lead by a director. At a strategic level, the research direction is set by the Director of BERI working with a management board that includes the centre directors and the heads of SBE and RGS. The Centre for Sustainable Technologies (CST) is concerned with energy efficiency, renewable energy, and sustainable materials combining theoretical approaches with measurement and modelling. The Centre for Research on Property and Planning (RPP) incorporates research in real estate, housing, planning and transportation with a focus on policy implications. Fire Safety Engineering Research and Technology (FireSERT) offers innovation in the design, assessment and protection of materials in fire, informs regulations and the enhancement of fire safety in the built environment and investigates human response to evacuation. The Hydrogen Safety Engineering Research centre (HySAFER) specialises in safety aspects of hydrogen as an energy carrier researching into issues critical to the introduction of hydrogen and fuel cells systems within the built environment.

b. Research strategy

Since submission of RAE 2008, the scale and complexity of change in the built environment has been significant. Exposure to the economic recession has increased risk but raises opportunities in informing future research. BERI's strategy, as articulated through its Five Year Plan, is to be responsive to these new conditions defined by complex economic, institutional, social, environmental and technological parameters. Alignment to strategies at a European and UK level on sustainability and technological development are exemplified by CST's focus on energy, costs and security of supply; RPP's interest in the security of urban environments, FireSERT's concern for a safer built environment through research on the fire resistance of materials and structures, and HySAFER's role in safety issues pertinent to fuel cell technologies and hydrogen.

BERI's strategy articulated in the RAE2008 submission was based on research that enhances the quality of the built environment and addresses the changing needs of society in a more sustainable manner. Specific objectives were to embrace research at the forefront of the built environment; to promote diversity in the breadth of the research portfolio coupled with specialisation in specific areas of excellence; to work in partnership networks; to share best practice; to engage with industry and end-users; to grow the research base, promote post-graduate activity and disseminate knowledge. The unit, through its extensive and highly varied activities, as articulated throughout REF5, incorporating research output, grants, dissemination, user-engagement and civic involvement, is confident that it has delivered on the 2008 strategy. Strategic goals of enhancing experimental facilities and supporting staff have been underpinned by University and government funding through the Northern Ireland (NI) Department for Employment and Learning (DEL).

Across the unit, a common focus has been enhancement of the quality of the built environment through the evaluation of issues of global significance, for example, the behaviour of fire in materials and structures (FireSERT), development of technologies for energy related CO_2 reduction in buildings (CST), advancement of research on alternative energy sources (bio-mass, solar energy, heat pumps), safety aspects of hydrogen and fuel cell technologies (HySAFER), the

retro-fitting of the existing stock (experimental houses), energy storage and policy/spatial planning (DEL Cross Border R&D funding), regeneration and security of urban areas (RPP). Sustainability has been a common thread with projects as diverse as housing and neighbourhood monitoring, marine spatial planning, value performance of buildings, clean coal technology, solar energy, heat pumps, fire resistance of materials and structures. BERI's research portfolio with major new grants notified over the assessment period in excess of £15.53M (EPSRC, CEC, Charities, Government) demonstrates the breadth of the research portfolio. Engagement with partners is a hallmark of BERI's modus operandi with models of collaboration including networks developed through European grants, the DEL cross-border R&D grant on energy storage and in the case of RPP joining partners to create a specific entity for cross-border spatial planning, the International Centre for Local and Regional Development (ICLRD). Industry and end-user collaboration has been extensive through Fusion (InterTradeIreland's all island technology transfer programme) and KTP projects. There are many examples of collaboration with external organisations, links which have facilitated significant growth in the PhD community through exploiting alternative funding sources.

The RAE2008 submission identified a number of new initiatives which have been implemented over the ensuing REF cycle. First, the emerging research in hydrogen safety has been recognised. Establishment of HySAFER as a separate research centre in 2008 has allowed BERI to play a leading role in the development of safety strategies to support the hydrogen industry, contribute to regulations, codes, and standards, and develop a framework for carrying out hydrogen safety engineering. Second, the 2008 RAE submission identified the proposal for a Real Estate Initiative (REI) supported by external industry/donor funding. While the economic environment has not been entirely conducive, this Initiative has received external donations in excess of £500K, funding which has been used to develop long-term research through PhD scholarships, engage with policy makers and undertake short-term industry-related research for the sector. Third, the 2008 submission highlighted CST's initiatives in energy in the built environment. This has been furthered over the REF cycle by the development of experimental test houses ("Terrace Street").

Future strategic aims and activities for BERI (and its research centres) will be highly influenced by the changed context from the global to the local. Economic conditions, public policy, government expenditure, societal expectations and environmental limits, such as climate change and natural resource availability, have all influenced the context within which the built environment operates with the research agenda needing to address the challenges posed. For example the fragility of urban systems is reflected in new research on urban security developed in the FP7 project (BESECURE). Risk and resilience is shaping the agenda with response to environmental conditions allowing built environment disciplines to offer research informed solutions, through for example FP7 project (COBACORE) on emergency planning. A key objective over the next five years, drawing upon the outcomes of such projects, will be articulating the challenges facing the built environment and devising appropriate technologies and standards for societal well-being. Central to this strategy is BERI's expertise in renewable energy and energy efficient technologies with further development flowing from the BIOMARA (INTERREG funding) and MERITS projects (FP7 smart grid enablers) and the EPRSC CALEBRE project on low carbon lifestyles.

BERI through the diversity of its research is well placed to engage with policy, planning, development, investment and governance issues. BERI will build upon achievements and integrate lessons of the past with a critical understanding of current conditions and, further, explore the options and requirements of a future economy, society and environment. Such innovation is exemplified by "Terrace Street", a retrofit project funded by the DEL Research Capital Investment Fund (RCIF) that directly embraces priorities of the NI Executive's Programme for Government with relevance nationally and internationally. Providing a test vehicle for developing new energy technologies and assessing economic and social impact, Terrace Street will evaluate strategies in terms of environmental impacts and energy consumption using products developed by CST (heat pumps, solar thermal and vacuum glazing), illustrate how retrofitting can make a positive impact on fuel poverty and demonstrate pathways to a low energy future. Likewise, critical issues concerning fire safety and protection will be addressed by FireSERT and over the next five years HySAFER will focus on innovative safety strategies for the indoor use of hydrogen systems (HyIndoor, FP7 project) and the storage of hydrogen devices (FP7 H2FC and EPSRC SUPERGEN projects).

Key drivers of research over the next five years reflect challenges that are central to economic well-being globally: climate change, reductions in greenhouse gas emissions, securing a supply of energy (energy/fuel resilience) that is affordable, reducing energy poverty and retrofitting the existing building stock. Major questions regarding the future well-being of urban environments require innovation in the policy agenda concerning how the public and private sectors develop funding/financing models (RICS project on PPP/PF2). Priorities formulated by international agencies, industry, governments, regulatory bodies and academia are key drivers, some proactive others reactive. Indicators for monitoring attainment of targets and success in achieving these key goals include international standing as measured through invitations to deliver invited papers, to participate in networks and research proposals, to engage with government and regulatory authorities, to deliver policy relevant research with community benefit. Internal drivers within the University include the establishment of a new faculty (August 2007) combining Built Environment, Architecture and Art an initiative that is stimulating collaboration across planning, regeneration and creative industries and spawning inter-disciplinary PhD research that reflects external stimuli through for example the Design Council and the NI Department of Culture, Arts and Leisure.

New and developing initiatives are inter-linked to these drivers, funding streams, the recruitment of research contract staff (RCS) and PhDs. Examples that will characterise the BERI portfolio over the medium term are: urban security, an expanding area of research, being developed through FP7 projects over the period 2012/13-2015/16 (BESECURE and HARMONISE), risk and resilience in the built environment a theme being advanced through COBACORE (FP7), the funding gap surrounding urban and infrastructural schemes through RPP's research on vehicles (PPPs, Tax Incremental Financing). CST as a founding member of the Competence Centre for Advanced Sustainable Energy, an Invest NI-industry collaboration, will, with partners (academic and industrial), use stimulus funding to lever match funding and undertake industrially relevant research in energy efficiency and renewable energy in buildings; offshore energy; biomass and bio fuels. Energy storage, initially benefitting from DELNI funding (2009-2011) and further research awards (FP7, EINSTEIN, MERITS; INTERREG, SPIRE; Northern Periphery Programme, SULA and OCTES) is a central focus of BERI's developing initiatives and research agenda projecting forward. Innovation will focus on the design, development, characterisation and simulation of new generation modified hybrid energy storage phase change materials and renewable energy applications (CST). Continued grant funding will facilitate development of methodologies to predict large-scale fire behaviour and advance research on fire safe materials and structures (FireSERT). Postgraduate research will be supported through diverse funding sources (HyIndoor, SUPERGEN) as will the recruitment of additional RCS, within the administrative/technical structure. Paralleling these initiatives is the development of research infrastructure including built environment facilities as part of the University's new £250M Belfast campus scheduled for 2018 completion.

c. People, including:

i. Staffing strategy and staff development

The University's Organisational Development Strategy (2011-2015) acknowledges that the key to enhancing excellence in research is the ability to attract, develop, retain and reward high performing staff. Indeed the University's policies and practices to support recruitment and career development received the HR Excellence in Research Award from the European Commission. This good practice extends to the Built Environment where complementarities between BERI and SBE have provided coherency between the research agenda and staffing strategy. The Director of BERI and the Head of SBE share common principles regarding the benefits of research-informed teaching. This has facilitated a recruitment policy based on demand, new emerging topics and strengthening the research base in strategic areas identified in BERI's Five Year Plan. Central to the strategy is making appointments in growth areas within SBE and complementing strengths within BERI where the infrastructure exists to support appointees. The Director of BERI sits on interview panels for new appointments within SBE. Over the assessment cycle new academic staff appointees have been allied to funding streams and developments in the research infrastructure base, for example in CST Anderson (biomass), Ming Huang (energy storage) and Mondol (solar), in FireSERT Choi (structures) and Zhang (fire materials), in HySAFER Brennan and Tretsiakova-McNally (safety) and in RPP Davison (transport) and McCord (real estate markets). Based on the continuing sustainability of research initiated under the DEL cross-border R&D grant, readerships were created in CST (Griffiths) and HySAFER (Makarov) and a lectureship in RPP (Ritchie).

Integral to the staffing strategy, the BERI Membership Committee, chaired by the Dean, meets twice yearly to review achievements against benchmarks and receive requests for membership.

The University's Staff Development works closely with BERI, all staff including RCS participate in Development Appraisal Review (DAR) either on a biennial or annual basis; professors are required to align annual objectives to progression criteria. Specific research requirements identified by DAR are addressed through personal development plans with training, infrastructure or other support provided through either SBE or BERI's recurrent budget, the latter being a combination of QR and rewards for research grant activity. The University's Researcher CPD Framework aligns support and development options against each of the domains/sub-domains of VITAE Researcher Development Framework. This support extends to doctoral students, early career researchers (ECRs) and RCS and provides University wide solutions to generic areas of research training.

The contribution of ECRs has been highly significant; several members of staff in this submission have positively availed of the nurturing and probation processes. Frequently new academic staff appointments will have benefitted from either PhD training or previously held a position as a RCS member; others with a professional background are encouraged to engage in research through PhD registration. New staff members have access to the University's Online Welcome & Orientation Programme, benefit from local induction and the SBE mentoring process (all new appointees have an induction colleague). Furthermore, SBE has the policy of reduced teaching in the first year of appointment. New staff members are encouraged to engage with an appropriate research centre, develop publication plans, to apply for associate membership of BERI and progress to core membership through publications, involvement in research grants, supervision of PhD students and wider engagement/research impact. ECRs are facilitated in this process by regular meetings with the BERI Director and appropriate centre director. Funding support allows ECR staff to develop their research through conference attendance, training and equipment needs. Support carries on throughout their academic career with the expectation that staff members increasingly generate research income and publish research findings. Enrolment on the PG Certificate in Higher Education Practice, which incorporates a module on Supporting Research Practice, is a requirement for new staff. The Doctoral Innovation Programme provides support and development requirements for staff in supervising doctoral students.

The University has a long tradition of ensuring that researchers are appropriately managed including career development needs. Implementation of the Research Concordat is addressed by several mechanisms. First, the Research Concordat Steering Group (RCSG), a sub-committee of the University's R&I Committee, chaired by the PVC (R&I), is charged with monitoring and reviewing the implementation of institutional policy related to RCS including the Research Careers Initiative. The Faculty is represented on the RCSG by Haran (Senior Research Fellow, BERI). This committee and the Research/HR Forum provide the means for RCS to raise issues appropriate to the research environment. Second, all RCS staff in SBE are members of BERI and hence are fully integrated into information flows (grants, awards, finance), attend BERI seminars and Away Days. Third, RCS take part in DAR and are eligible for the annual progression round; a number of RCS within BERI have successfully achieved promotion during the assessment period. Fourth, RCS frequently attend conferences and publish with academic staff enhancing career opportunities. The submission includes two RCS who are principal investigators on grants (Haran, McIlhatton) and several (8) who previously held research positions within the last ten years. A number of RCS employed during the assessment period have utilised their experience to obtain employment in industry/practice/public sector (Cave, Hardy, Kattakayan, Saffers, Suzanne). All RCS are actively encouraged to participate in the Careers in Research Online Survey (CROS).

It is the University's policy to provide equality of opportunity to all. The unit endorses the University's Equal Opportunity Policy and the Code of Practice on the selection of staff for REF2014 and all staff members involved in selection decisions received equality and diversity training. The University's Equality and Diversity Services is responsible for developing and promulgating policy and good practice on equality. HR implements a highly prescribed process in advertising for and recruiting new appointments. BERI operates within this institutional framework and works with a HR consultant concerning recruitment. Recruitment objectives are driven by

staffing profiles and perceived gaps in expertise, strategic decisions regarding future directions of SBE and BERI and implications arising from departures of staff. In the case of RCS appointments, recruitment reflects success in achieving externally funded research awards. Virtually all staff members in this submission are on long-term contracts providing stability upon which to plan and develop research strategies. The demographic profile of the unit is well-balanced between senior staff and those staff members who are at an earlier stage in their career and have been recruited over the past decade. This demographic balance is a positive characteristic through providing experience, leadership and management skills within the research centres in BERI and engaging recent appointees in the management and administration of projects through team working. The success of this approach is evidenced by many instances of new staff members utilising this experience and becoming principal investigator in subsequent research applications.

Over the assessment period, the submitting unit has benefitted from the stability offered by a core group of staff who were either in a leadership position in RAE2008 or, at that stage, earlier in their career now playing a key role in this submission. The natural dynamic of new staff recruits, coupled with departures or changes in staff circumstances has led to considerable refreshing of staff in this submission compared in RAE2008. New recruits include Anderson (CST), Brennan (HySAFER), Choi (FireSERT), Davison (RPP), Haran (RPP), Levendis (FireSERT), Lloyd (RPP), McCord (RPP), McIlhatton (RPP), Ming Huang (CST), Mondol (CST), Ritchie (RPP), Tretsiakova-McNally (HySAFER), van der Krabben (RPP) and Zhang (FireSERT). The recruitment pattern has embraced staff at different levels and with differing degrees of research experience. Levendis, Lloyd and van der Krabben are appointments at a professorial level. In contrast, other appointments include staff coming either from PhD programmes (Anderson, McCord, Ritchie) or previously in a research capacity (Brennan, Davison, Mondol, Zhang). Due to the pro-active recruitment policy and the employment of high quality staff, departures have not had any significant detrimental impact on research though notable departures include Elkadi (Deakin), Parsa (Salford), Peel (Dundee), Perera (Northumbria), and Webb (deceased). Overall there is less than a 60% overlap of staff in this submission and that in RAE2008, with an increased volume of submitted staff, indicating that succession planning has been effective in sustaining research activity. Policy is to utilise joint appointments on a manageable scale, the experience is that such appointments can bring considerable added value as in the case of the late James R Webb and the current holder of this chair van der Krabben. A number of staff received prestigious personal research fellowships or related awards over the assessment period: Smyth the Royal Academy of Engineering Global Research Award; Lloyd was elected as an Academician of Social Sciences; Gray was President of the Chartered Institute of Housing (2010-2011), Ali (FireSERT technologies) won the Hi-Tech category in the 25K innovation awards (Northern Ireland Science Park).

All staff members have an equal opportunity to bid for funding through the BERI recurrent budget, to apply for promotion, to actively participate in a research centre of choice and engage in the activities of BERI. Core and associate members of BERI benefit from, on a sliding-scale, reduced teaching loads to reflect time required to engage in and deliver research. Short periods of study leave can be facilitated, for longer periods of study leave (a semester) the Faculty requires the staff member to engage in a more formal process with applications to be approved by Head of School and RI Director before consideration by the Faculty's R&I Committee. The submitted unit is sensitive to those staff whose research career has been interrupted. Different layers of support are available with the appropriate research centre director working in conjunction with BERI/SBE to ensure that workload is tailored to meet the special circumstances with the facility to re-engage in research. The BERI Membership Committee is sensitive to such circumstances in facilitating mechanisms whereby the staff member is not disadvantaged in relation to research resources.

Research quality and integrity are fundamental. Standards are set by the University's Code of Professional Integrity in the Conduct of Research which is underpinned by policies and procedures relating to the ethical review of research involving human participants. The University's Research Governance keeps policies under review to ensure adherence with the Universities UK Concordat to Support Research Integrity and carries out annual reviews on compliance. All grant applications need to demonstrate adherence to research ethics and any proposed projects involving human

subjects are reviewed by the Faculty's Research Governance Filter Committee and, where necessary, referred to the University committee or externally to the Office for Research Ethics Committees NI. All areas of governance, methodology and ethics are examined; each proposal must meet University requirements before approval to proceed. Authorship policies adhere to the University's Code of Practice on publications. The normal practice is that a significant contribution to the original research should be reflected in the authorship. In the case of an output from a PhD student, the practice is for the doctoral candidate's name to appear first.

ii. Research students

Research students, full-time and part-time, are central to the vibrant culture of scholarship in BERI. The number of PhD students fluctuates annually but to provide a reflection on the scale of activity, 80 PhD students were registered during 2011-2012. The sustainability of the PhD programme in Built Environment over the REF cycle is highlighted by a total of 58.67 successful doctorates (REF4a), exceeding the number in RAE2008 (52 over a longer period). The submitted unit recruits PhD students internationally with the majority non-UK/Ireland. The countries of origin of PhDs over the assessment period has been diverse (India, Pakistan, Malaysia, UAE, Iran, Philippines, Thailand, Vietnam, Albania, Poland, Ukraine, Russia, France, Cyprus, Israel, Egypt, Tunisia, Nigeria, Ghana, Tanzania, Cameroon, US). Recruitment has benefitted from funding through DEL awards and by University Vice-Chancellor's Research Studentships (VCRS). These are awarded on a highly competitive basis for advertised topics through an annual call. In addition, the submitted unit has successfully diversified the funding base. Over the assessment period several PhD students have received scholarships through additional funding sources: DEL CAST Awards (1 with Emerson/Copeland), DEL Cross Border Energy Storage Award (2), the REI (4), the National Roads Authority Ireland (2), the Charles Parsons Energy Award/SFI/DENCR (7), the Ordnance Survey NI/Land & Property Services (1), Marie Curie fellowships 4 in total (2006-2011) through the project EST fundamentals of hydrogen safety, EPSRC CALEBRE (2) and EPSRC SUPERGEN project (3), EPSRC Faraday (1), FP7 funding (HyIndoor) (1) and from the Korean Ministry of Knowledge Economy (2). These have been complemented by external self-funded non-EU students who have significantly added to the research culture of BERI.

Integration into the research culture is facilitated by clustering PhD students in high quality offices linked to the four research centres in BERI. At a University level, research students undertake generic research training with the ability to select from a range of training credits across all three years of a full-time PhD programme including employability skills and career development (part-time PhDs are encouraged to engage in this training). The Doctoral Innovation Programme provides a comprehensive range of professional development training on transferable professional skills and research techniques. Doctoral students have the option of both Project Management Accreditation (ILM Level 5) and associate membership of the Higher Education Academy. The University also offers online Epigeum courses including research methods, project management in a research context, research ethics, presenting papers and career planning. At a Faculty level, the RGS organises induction programmes, a welcome reception and an annual conference at which students deliver paper and poster presentations, culminating in an Awards Reception and Dinner (awards for best PhD, best published paper, best poster). PhD students are encouraged to attend the seminar series organised by BERI and within the respective research centres. Engagement with Visiting Professors and Scholars: Jourdan, Tchouvelev (HySAFER), Newell, Peiser, Roulac, Sieracki (RPP, through the O'Hare Chair Visiting Scholars Programme), Minchner (CST), Allam, Charters, Chow, Vassart, and Wen (FireSERT) has benefitted PhDs in helping to validate methodologies, access data sources, widen perspectives and facilitate introductions. Formal engagement by the PhD community occurs through representation (two student representatives) on RGS Board and a representative on the Faculty's R&I Committee. External audit of the Faculty's RGS (in 2011 by KPMG) found supervisory and administrative practices to be exemplary.

d. Income, infrastructure and facilities

The submitted unit has received extensive external research funding over the assessment period with grants from EPSRC, CEC, government departments/agencies, the private sector and charities. Over £15.53M in new research grants was notified during the assessment period and total spend amounted to £13.2M (REF 4b) compared to £10.63M in RAE2008. The sustained

increase in research council activity, £3.57M over the REF cycle is of particular significance. The excess in income over expenditure highlights not only BERI's success in achieving new funding but importantly capturing an income stream to sustain the research programme going forward. Some grants were specifically won by staff solely within BERI though there are many instances of working in partnership. Typically the latter has characterised funding received under European programmes notably FP7 though not exclusively, for example the Housing and Neighbourhood Monitor funded by the Joseph Rowntree Foundation (with Manchester and Glasgow). Strategies to generate income have been to target selected calls from research councils in particular EPSRC, for new staff to address first grant schemes, to work with other universities and industry partners and to target funding directly related to the Programme for Government for NI such as the DEL Cross-border R&D grant on energy storage (£1.54M) and InvestNI Proof of Concept (7 awards). The submitted unit has sought to work closely with government departments/agencies with several funded studies impacting on policy formulation. Engagement with professional bodies such as the Royal Institution of Chartered Surveyors (RICS) has been important from a dissemination perspective notably in terms of global reach. Likewise involvement with the private sector, through the example of the REI, has been a significant aspect of BERI's strategy to generate grant income.

Major prestigious grants started over the assessment period are: **EPSRC** awards to CST concerning retrofit technologies, energy storage and advanced solar/glazing research through awards such as CALEBRE Consumer-Appealing low energy technologies for building retrofitting (£248K), BMT-CES Biofuel micro-trigeneration with cryogenic energy storage (£107K), High performance vacuum flat plate solar thermal collectors for hot water and process heat (£271K); in FireSERT awards have advanced research in the areas of flame retardance and the development of fire safe steel structures through grants such as The effects of nano and molecularly-dispersed additives on flame retardance (£319K), Behaviour of axially restrained steel columns with elliptical sections subjected to severe fire (£230K) and in HySAFER advancing hydrogen safety science through for example SUPERGEN Hydrogen and Fuel Cells Hub (£186K). **CEC FP7** awards to CST reflect the centre's focus on both energy storage and solar technologies through EINSTEIN Effective integration of seasonal thermal energy storage systems in existing buildings (£429K), MERITS More effective use of renewables including compact seasonal thermal energy storage (£233K), DECARBIT enabling advanced pre-combustion capture techniques and plants (£137K), CESAR Cost effective solar air conditioning (£210K); in RPP research awards concerning response to urban security issues through development of the evidence base and systems to inform decision making BESECURE Best practices for enhancing security policy in urban zones (£416K), HARMONISE Holistic approach to resilience and systematic actions to make large scale urban built infrastructures (£280K), COBACORE Community based comprehensive recovery (£415K); in FireSERT ENFIRO Life cycle assessment of environment compatible flame retardants (£334K), AIRCRAFTFIRE fire risks assessment and increase of passenger survivability (£288K) and in HySAFER developing numerical and experimental investigation through projects H2FC Integrating European infrastructure to support science and development of hydrogen and fuel cell technologies (£461K), HyFACTS Identification, preparation and dissemination of hydrogen safety facts to regulators and public safety (£161K), HyIndoor Pre-normative research on safe in-door use of fuel cells and hydrogen systems (£277K) and HyResponse (£270K). **Other European grants** in CST again reflect the emphasis on energy storage and energy system modelling including INTERREG IVA SPIRE Storage Platform for the Integration of Renewable Energy (£2.93M), BIOMARA Sustainable fuels for marine biomass (£230K), Northern Periphery Programme OCTES opportunities for community groups through energy storage (£105K) and SULA Sustainable Living Assistant (£125K). Awards from **Government departments/agencies** include DEL Cross Border R&D Programme Energy Storage (CST/RPP/HySAFER £1.54M), Korean Ministry of Knowledge - Development of advanced PBD method for structural fire protection using innovative insulation material (FireSERT, £140K), Northern Ireland Housing Executive House prices, rents and affordability (RPP, £295K plus £52K co-funding from Bank of Ireland for the Northern Ireland Quarterly House Price Index), InvestNI A solar accelerator design for small scale bio energy production (CST, £103K), A low cost easy to install twin vessel integrated collector storage solar water heater using phase change materials and vacuum technology (CST, £100K) and Safety valve for high pressure hydrogen storage (HySAFER, £101K), National Roads Authority (Ireland) Assessment of warm mix asphalt for road surfaces (CST, £128K). From **Charities and**

professional bodies grants include RICS awards on The future of private finance and public private partnership (RPP, £48K) and The role of the RICS and global valuation standards in influencing practice (RPP, £25K), Joseph Rowntree Foundation Housing and Neighbourhoods Monitor (RPP, £67K), Energy Savings Trust Using CAMA to model energy efficiency in housing (RPP, £20K), Royal Academy of Engineering Solar energy in the wine making industry (CST, £29K); ICLRD CROSPLAN cross-border spatial planning development and training network (RPP, £33K). **Private sources** include in excess of £500K (RPP) to support the REI. The extensive portfolio of awards has been fundamental in sustaining research activities and facilitating the generation of high quality research output not only through journal papers but also reports, contributions to books and conference presentations including keynote and invited papers.

Building upon infrastructure development over the previous RAE (2000-2007), the funding strategy of BERI for the REF cycle has been to further develop the high quality existing infrastructure base. Significant investment has taken place through resources in BERI complemented by the DEL RCIF award 2009-2011 of £1.45M. This has been the single major source of infrastructure funding to BERI during the current cycle. The largest investment has been in the development of test houses (two solid wall dwellings) which replicate circa 8 million other homes in the UK (Terrace Street). The 'Terrace Street' project is helping to address strategic priorities around fuel poverty through understanding how buildings measure up to the elements with the potential to support cross-disciplinary research in connected health. Enhanced laboratory space and equipment has facilitated the development and evaluation of new technologies (in particular biomass analysis) and investment into software and tools for data analysis, sustainability modelling and risk assessment.

Infrastructure strategy is based on complementing dedicated equipment with flexible research space to provide a high quality environment. For CST this is also apparent in the development of laboratories for advanced glazing manufacture, solar thermal and solar PV concentrator design and manufacture, biomass gasification and engine testing, combustion, emissions and ash analysis, thermal energy storage with phase change materials, electrical energy storage, heat pumps, road surface testing, materials analysis and thermal comfort. Overall, CST has specialist laboratories of 700m^2 to support the range of energy related research activities, particle imaging velocimetry (laser based) laboratory and an outdoor solar test area. A highways engineering test area incorporates laboratories for the structural testing of surface materials, aggregates and skid resistance with specialist equipment for simulated trafficking at slow and high speeds, environmental conditioning and 3d spatial analysis using stereo photogrammetry and laser.

FireSERT has state of the art facilities, unequalled in a university setting. These include a 600m^2 burn hall which houses a range of calorimeters including a ten-megawatt facility for full-scale research. Large-scale combination wall and floor furnaces with intermediate/small scale furnaces facilitate experimental research and product development. A Computational Fluid Dynamics (CFD) fire modelling suite complements the experimental facilities. A 250m^2 fire dynamics laboratory provides the link between small, intermediate and large scale work. This laboratory, equipped with two cone calorimeters, can accommodate burning in reduced oxygen atmosphere. A water mist fire suppression system represents further significant investment in the infrastructure base and the human behaviour laboratory is used to simulate responses to fire situations and evacuation.

In HySAFER, the focus is on contemporary tools such as CFD and the computational power to sustain research: hardware includes 3 DELL servers R815 (4 CPUs x 12 cores each), DELL server R910 (4 CPU x 8 cores x 2 threads), 2 DELL servers (PowerEdge C6145, 8 CPU x 16 cores), Ansys 14 CFD package (25 tasks, up to 76 parallel CPU calculations), FieldView, in-house CINDY software for calculation of hydrogen vented deflagration dynamics with inertial vent covers. A particular innovation since 2012 has been HySAFER's ability to access European infrastructure for hydrogen and fuel cell research through the H2FC infrastructure project. The acquisition of 4 new computing servers in 2011 through RCIF has facilitated expansion of the network infrastructure.

RPP's infrastructure has likewise benefitted from investment through DEL RCIF. GIS facilities have been significantly upgraded supporting the requirements of FP7 grants (BESECURE, COBACORE) including a GIS based open source server, ArcServer, a full suite of ArcGIS Desktop

with extensions Spatial Analyst, 3D Analyst and Geostatistical Analyst. Staff in the Centre also have access to Solver for portfolio analysis, E-views for statistical and econometric analysis, neural networks and spatial analysis (Spatialest and Piianalytics) facilitated through cooperation with Geopii (a University spin-out company) and transportation modelling (Paramics) and propriety databases through the University's subscription to Datastream, Co-star Focus, IPD, the Infrastructure Journal database and staff collaboration with Real Capital Analytics.

The growing infrastructure base underpins the University's support for research in the built environment, as a strategic priority area for investment, including technical staff to service the extensive laboratory provision and provide support for PhD students. Infrastructure provision for research students is an integral part of this investment. Research students are located in clusters, in close proximity to research laboratories, in high quality dedicated accommodation with individual workstations, IT and office facilities. All full-time PhDs have high spec computing either a new fixed PC or high powered laptop on commencement of their study. Co-locating PhD students adjacent to their supervisors and technical support provides the desired working environment for the student research experience including access to high quality library and information systems.

e. Collaboration and contribution to the discipline or research base

Interdisciplinary research, in providing a mechanism to enhance the discipline, is central to BERI's strategy as evidenced by collaboration with partners in academia, industry and the professions including internally within the University and more frequently with external partners. Examples of the former include the Computer Science RI on total energy management (TEMPO), the Environmental Sciences RI on marine spatial planning, the Engineering RI on environmentally friendly solvent systems (KTP), RI Social Science on urban security and the RI Art & Design on design, regeneration and urban security (BESECURE FP7 project). Arrangements to support interdisciplinary work internally arise from close collaboration between RIs, their respective directors and in particular through individual associations between staff sharing common research interests. The BERI recurrent budget and Innovation Awards have been used as a means of encouraging the development of such interdisciplinary work.

Funding is used to proactively encourage external partnerships (CEC FP7 and other projects), often crossing disciplinary boundaries, activities which are fundamental in enhancing the future sustainability of research both in BERI and internationally with our partners. Examples over the REF cycle abound crossing all research centres in BERI. **Industrial partners** (not mentioned elsewhere in REF5) include in the UK/Ireland: Alstom, AmRay, Building Research Establishment, Steel Construction Institute, Westok, Doonson Babcock, Emerson/Copeland, Essexford Joinery, Future Analytics Consulting, Glaseal, Glen Dimplex, Investment Property Databank, Shell, Unilever; examples outside UK/Ireland include Arcellor Mittal (Luxembourg), BMW Forschung und Technik GmbH (Germany), Commisariat a l'Energie Atomique (France), CTICM (France), Daimler AG (Germany), Det Norske Veritas AS (Norway), ENEL (Italy), Fraunhofer (Germany), Selex-Finmecanica (Italy), FM Global (USA), FOI (Sweden), General Motors (USA), ITTI (Poland), IRIS Vernici (Italy), L'Air Liquide (France), Norsk Hydro ASA (Norway), PlugPower BV (Netherlands), Siemans (Germany), Statoil (Norway), Tecnalia (Spain), Total (France), Volvo (Sweden), VTT (Finland). **Academic partners** (not mentioned elsewhere in REF5) in UK/Ireland include the universities of Aberdeen, Aston, Bath, Birmingham, Bolton, Central Lancashire, Edinburgh, Glasgow, Greenwich, Heriot Watt, Imperial College, Kingston, Leeds, Loughborough, Manchester, Newcastle, NUI Maynooth, Nottingham, Oxford, Queen's Belfast, Sheffield, St Andrews, University College Dublin, Warwick, University College London, West of England; examples outside of the UK/Ireland include Alessandria (Italy), Alicante, Lledia, Universidad Politecnica de Madrid (Spain), Calgary, Concordia, McGill, Queen's University (Canada), Denmark Technical University, Liege (Belgium), Lille, Corsica (France), Maryland, Washington State (USA), NTNU (Norway), Patras (Greece), Shanghai Jiao-Tong (China), Tokyo University of Science (Japan), Warsaw University of Technology (Poland), Western Sydney (Australia), Weimar, Wuppertal (Germany), Yonsei (Korea).

Networks and industrial collaborations have enriched the research environment and contribute to the discipline through sharing of ideas and joint strategies, accessing experimental data and other complementarities. Participation has facilitated staff development by involvement in cutting-edge research issues at an international stage. For example, CST is a founding member of SIRAC

(Sustainable Innovation in Refrigeration and Air Conditioning), a member of POREEN (Partnering Opportunities between Europe and China in the Renewable Energies and Environmental Industries), and through the UK India Education & Research Initiative has collaborated with the Tata Energy and Resource Institute (India) in developing an anaerobic digester to use solar energy to generate gas from domestic organic waste. Likewise, FireSERT's collaboration with the International Centre for Numerical Methods in Engineering (Spain) in combustion, fire suppression models and the development of open source software code (KRATOS CFD) for industry users, with the Japan Aerospace Exploration Agency in developing intrinsically safe polymeric fuels and a Royal Society International Exchange with the University of Science and Technology, China. The Korean Evaluation Institute of Industrial Technology and the Korean Institute of Construction Materials have established long-term agreements with FireSERT; HySAFER is a founding member of the International Association for Hydrogen Safety and RPP's leading role with TNO (NL) in FP7 projects, BESECURE and COBACORE, has created networks involving organisations such as the Stephen Lawrence Charitable Trust in the former and the International Red Cross in the latter. Through active involvement, these networks and collaborations have been essential in facilitating staff in BERI to advance knowledge and enhance the discipline areas over the REF cycle.

BERI has contributed extensively to the sustainability of the discipline through active engagement in professional bodies and international organisations, conference keynote addresses, journal editorships, membership of editorial boards and participation in international networks. Adair is Deputy Editor Journal of Property Research, Ali Editor in Chief Journal of Structural Fire Engineering, Boyce Guest Editor (2012) Fire and Materials, Davis Associate Editor Journal of Financial Management of Property and Construction, Delichatsios Associate Editor Journal of Fire Safety Science and Technology, Hewitt Editor in Chief International Journal of Ambient Energy, McGreal Editor Journal of European Real Estate Research, Nadjai Deputy Editor of the Journal of Structural Fire Engineering. Most staff members in the submission are on editorial boards or review for leading journals. Adair is an expert assessment panel member RICS Education Trust, Berry is Executive Director of the European Real Estate Society (ERES), Boyce Chair of Symposium Committee Human Behaviour in Fire, Delichatsios member of DCLG Expert Panel for Fire & Resilience Directorate, McGreal a Board Member of ERES, Nadjai member of EPSRC Peer Review College. Over the REF cycle several staff have contributed to the discipline, holding visiting professorial or fellowships internationally: Adair Universiti Tun Hussein Onn Malaysia, Delichatsios Tokyo University of Science, Chinese Academy of Sciences and the University of Newcastle (Australia), Hine Charles Sturt University (Australia), Lloyd University of Malaya, McCluskey University of Technology Malaysia, McGreal University of South Australia, Molkov Karlsruhe Institute of Technology, Smyth Griffith University, Yohanis State Oklahoma University.

In contributing to the research community, BERI hosted several international conferences during the assessment period. In February 2010 an international workshop Developments, Strategies and Solutions for Fire Safety Issues and November 2112 Innovative Construction Design for Fire Safety Engineering (FireSERT); in February 2011 International Conference for Sustainable Energy Storage (CST/RPP/HySAFER) attracted 170 delegates from UK, Europe, US, China, Japan and Korea. HySAFER organised the advanced research workshop series Progress in Hydrogen Safety, the biennial International Conference on Hydrogen Safety and the triennial International Seminar on Fire and Explosion Hazards. RPP hosted the Commonwealth Association of Surveying and Land Economy conference August 2008, was co-sponsor of the Isle of Skye Real Estate Symposium August 2010, held the Planning, Law and Property Rights conference in February 2012, The Conference of the Isles on transitions in housing October 2012, was co-host (with National Real Estate Development Council) of 7th National Seminar Emerging Frontiers for Spatial Planning in Delhi, April 2013 and was the academic partner for RICS COBRA2013 in New Dehli. Through such activities the unit has provided leadership across and has positively contributed to the sustainability of the discipline. By example, Ulster's leading role in real estate research networks (ERES) has contributed to advancement at a European level. Benefits of such engagement have flowed to PhD students through conference bursaries from the American Real Estate Society in 2008 (Singhal), 2010 (McCord, McIlhatton) and 2011 (Brown, Hinch, Odeleye) most of whom subsequently have achieved academic or research positions at Ulster or overseas.