Institution: University of Bradford

Unit of Assessment: B14 Civil and Construction Engineering

a. Overview

Located within the interdisciplinary base of the School of Engineering and Informatics, the Bradford Centre for Sustainable Environments (BCSE) is one of eight University focal points for strategic investment in research and knowledge transfer. The Centre was established in 2010 under the leadership of ***Lam*** to respond to the University's mission of *Making Knowledge Work* and operates at the dynamic and innovative interface between high quality research and industry. We are leading on interdisciplinary approaches that integrate technological, organizational, and societal solutions to meet contemporary environmental challenges. The Centre is home to a dedicated team of specialists and champions two main themes, **Environment** and **Infrastructure**, which are intrinsically linked by the challenges of achieving more sustainable solutions in the natural and built environments. The group recognizes the importance of sustainability for infrastructure systems and the requirement to provide technologies to address the needs of such systems to adapt to climate change, to reduce their impact upon the environment, and to address wider societal and wellbeing agendas.

The mission of BCSE is to operate across the interface between industry and top quality research. Underpinned by a strong RCUK track record, the Centre is meeting this goal with substantial support from major companies (e.g. Tata, Arcelor, Yorkshire Water). Delivery includes fundamental empirical and interdisciplinary research taken through to the end-user by informing revisions to industry standards (e.g. Eurocode 4 Committee CEN/T250/SC4), codes of practice (AISC 360-10) and design provisions (e.g. ACI318, EN1994-1-1), commercial exploitation (e.g. Acoutechs Impact Case Study), and the wider wellbeing agenda (e.g. urban tranquillity and the Canterbury post-earthquake regeneration) that also includes environmental standards development (e.g. ISO/DIS 12913-1) and European Standards (CEN EN 1793-4) on noise prediction modeling of road traffic noise. These reflect our deepening relationship with industry, in effective research collaboration and delivery of high added value products, and our relationship with the wider human and natural environments.

b. Research Strategy

The BCSE pursues research excellence that addresses challenges associated with the creation of new sustainable infrastructure and the maintenance of existing infrastructure for future generations, and is based upon multidisciplinary activity that is essential for modern engineering research. This is achieved through a balanced portfolio of fundamental and applied research supported from a broad range of funding sources secured from research councils (e.g. EPSRC), the EU (e.g. FP7), and from government bodies (e.g. DTI, Korean MoE) and industry, to deliver fundamental research applications impacting upon public health, wellbeing, and resource-innovative construction. This has been supported by investment in new academic staff, in infrastructure, and in facilities that have transformed our research capability to one emphasizing excellence within and across the two central themes of **Environment** and **Infrastructure**. These research themes address directly the 21st century challenges facing the civil engineering profession (reducing waste and developing more sustainable construction materials) and facilitate staff from a unique range of multi-disciplinary backgrounds in the development of innovative and sustainable engineering solutions.

The Centre will deploy its expertise to these broad engineering and societal challenges by focusing upon the linked themes of composite construction, smart infrastructure, and environmental impact. Two initiatives that will be used to shape this direction for BCSE are the Department of Business, Innovation and Skills (BIS) policy paper, Construction 2025 (focusing upon two of the four ambitions: a 33% reduction in the cost of built assets and 50% lower emissions from the built environment) and the EU Horizon 2020 theme of Tackling Societal Challenges (climate action, environment, resource efficiency and raw materials). To support this we aim to sustain and expand

the leading edge facilities in our laboratories and to build research capability and capacity. We have significantly achieved both aims during the census period, with extensive development of all of our key areas.

The **Environment** theme is focused upon studying the science underlying current and emerging environmental impacts, and on the ways in which these impacts can be mitigated. Key objectives are to focus on understanding of wastewater and treatment systems (including sediment and pollutant transport), urban water systems, noise in the environment, and refined experimental and numerical methods for analyzing engineering structures. The impact of environmental noise, flooding, sediment transport, water transported pollutants, and extreme waves are currently under investigation. This includes their impact upon both the natural and the built environments, ranging from rivers, estuaries and coasts to sewers and water distribution pipes. Much of the work revolves around the use of sophisticated laboratory techniques, strongly coupled with the development of new modelling and sensor technologies to allow the development of new intervention and mitigation technologies.

Our environmental research is driven by the importance of sustainability for infrastructure systems (***Oltean-Dumbrava***, ***Pheasant***, ***Watts***, ***Mohamed***) and on the requirement to provide technologies that address the needs of such systems to adapt to climate change and to reduce their impact on the environment. New technologies have been developed to better protect the environment (e.g. *ArmaSound*), to optimize infrastructure systems to enhance their sustainability (*SewerBatt*™), and to contribute to urban environment adaptations to climate change, in particular addressing water and energy issues (Oltean-Dumbrava[3]). Research has focused on the modelling of the transport and transformation of water-borne pollutants (Mohamed[1]), consolidating sediment deposits, and acoustic-based sensors for real-time characterization of hydraulic processes in open channels and pipes. Links with other academic staff in the School have enabled the development of autonomous wireless sensor networks to optimize performance of water infrastructure.

Research on soil-structure interaction (***Mohamed***) is focused on consolidation of soft soils and soil reinforcement (Mohamed[2]), and the treatment of wastewater using soil aquifers (Mohamed[3], Mohamed[4]). Research on the development of Smooth Particle Hydrodynamics models has focused on the transport of pollutants in the environment and water-generated noise. Research in the Environment theme ranges from fundamental studies of turbulence and acoustic attenuation over rough boundaries through to applied research, in partnership with UK water companies, on surface pollutant transport and infrastructure monitoring and optimization. We are members of the Pennine Water Group (PWG), which is an EPSRC-funded Platform Grant centre dedicated to research into water and wastewater. The PWG aims to advance engineering and scientific knowledge across all aspects of potable water, storm water and wastewater service provision, and management of associated assets (Oltean-Dumbrava[1,2]).

In the field of sustainable built environment and construction management, work continues in multi-criteria decision support systems to develop more robust analysis frameworks, methods and tools used in sustainability assessment and multi-disciplinary/criteria holistic approaches (***Oltean-Dumbrava***). Our research into the development of models for acoustic attenuation in the vicinity of rough dynamic boundaries and outdoor noise propagation continues with a focus on sustainable acoustic environments (Oltean-Dumbrava[4]) or 'soundscapes' (***Watts***, ***Oltean-Dumbrava***, ***Pheasant***). This research recognizes the increasing importance of protecting quiet and tranquil places (Watts[1], Pheasant[1]) as required by the Environmental Noise Directive, and has been cited in the Civil Aviation Authority's ERCD REPORT 1207 (2012) on 'Tranquillity: An overview'.

The **Infrastructure** theme focuses on developing a deeper understanding of the interaction between structures and the environment through the development of new construction techniques and low energy construction materials that have higher levels of sustainability. The group (***Lam***, ***Dai***, ***Sheehan***) has an international reputation in research on steel and composite construction and is developing new structural analyses and construction methods in order to gain a deeper and improved understanding of the behaviour of buildings and structures, to improve their safety and to develop better rehabilitation strategies. An emerging area of activity is research into steel and

composite structures that provide better structural efficiencies and hence more sustainable and economical construction solutions (Lam[1], Sheehan[1]), which links to Construction 2025. Specifically, in composite construction with precast hollow-core slabs, extensive research has been focused on semi-rigid connections. It shows that these forms of composite connections, when used in design, will lead to reductions in beam sizes, which in turn will reduce the overall cost of buildings.

A second area of composite construction that has been extensively researched (***Lam***, ***Dai***) is the behaviour of shear connectors in composite beams (Lam[2], Lam[3]). The work has underpinned design treatments in British, European, and other national standards for composite construction. Finite element models were developed and have been confirmed against the results of laboratory tests to properly represent each major facet of behaviour, and this has permitted a better understanding of the complex load transfer mechanisms and explained some initially puzzling experimental findings. Current EPSRC-funded research on the behaviour of elliptical steel hollow sections is being carried out (Lam[1]). The development of design rules will have an immediate impact upon industry by enabling designers to design using this form of structure. Research on reinforced concrete (***Ashour***, ***Lam***) addresses the performance of reinforced concrete structural elements and their structural optimization with particular emphasis on assessment and repair against ACI318 sector design provision (Ashour[2], Ashour[3]). The work, focused on the use of novel structural materials such as CFRP and GFRP bars and laminates on RC structural elements for retrofit and for extending the life of existing concrete structures, has been recognised internationally with sponsorship from the Korean Ministry of Education (Ashour[1]).

In addition to experimental studies conducted by the group, numerical analyses using finite element techniques have continued (***Lam, Ashour, Dai, Sheehan***). A developing area of research by this group is in the area of fire engineering research (Dai[1]) and on the cyclic behaviour of composite columns.

During the REF2014 period BCSE staff members attracted £3.3m external RKT funding and published a significant number (151) of peer-reviewed journal papers as well as papers in conference proceedings (144). Publication guidance directs all academic staff to focus upon publishing in high-quality journals in their speciality. Most of these journals are highly regarded and ranked A* or A by the Australia ERA Journal Ranking.

We have a strong track record of successful collaborations with (i) industrial partners (including Arcelor Mittal, the world's leading steel manufacturer; the Steel Construction Institute; Yorkshire Water, Billington Structures Ltd; Tata Steel; ASD Westok Ltd) in the UK and overseas; (ii) with Standards Committees (British Standard Institute B525/ and CEN/T250/SC4 responsible for BS5950 and Eurocode 4), and (iii) with health end-users (Royal Surrey County Hospital; Bupa).

The Centre's proven capability in environment and infrastructure innovation is seen in the continued sector-influencing nature of our work, evidenced by our involvement (***Lam***, ***Dai***) in contributions to Eurocode 4 (Lam[4], Sheehan[1]) related to shear connection rules for modern long span construction. Our innovative multi-disciplinary approach to urban design has been recently applied to the post-earthquake regeneration of Canterbury, New Zealand (Watts[1]) and which is presently being evaluated in terms of supporting environmental design within care homes managed by a major healthcare provider, Bupa (***Watts***, ***Pheasant***).

c. People

Our current team comprises a dynamic blend of senior staff, providing research leadership, and high-calibre Early Career staff working in a highly collaborative environment. The loss of 4FTE of research-active staff in a single transfer to another HEI just months before the REF2014 census date was rapidly mitigated by investment in and appointment of (i) new Early Career researchers (***Sheehan***, ***Pheasant***, ***Dai***) with two additional Early Career appointments approved and (ii) approval to appoint a Professor of Civil Engineering. These appointments are testimony to the research quality of the current group and confirm the sustainability of research in civil and

environmental engineering.

New **academic staff** members have reduced teaching and administrative duties and prepare a research development plan, supported by experienced mentors. New staff members are inducted into the University's ethics policy, with a commitment to maintaining high ethical standards in research. All staff commit to the University's *Equality and Diversity Strategy 2011-14* (which also underpins practice in recruitment and selection), complete a *Diversity in the Workplace* e-Learning module and have access to an on-going programme of staff training courses. We subscribe to the principles of the *Concordat to Support the Career Development of Researchers*. All newly appointed academics are required to seek external funding, but also receive pump-priming support to develop new research initiatives. New members of the professoriate have received University and School support for laboratory refurbishment and equipment according to their needs.

Post-Doctoral researchers: in addition to attracting research active academic staff, the nature of our research has facilitated a high number of post-doctoral research assistants (PDRA) working alongside our research active staff, more than 1.5 per academic FTE per annum in the REF period. The directly-employed PDRAs and the contribution of visiting post-doctoral researchers hosted by academic staff provides a comprehensive global view of civil engineering to our PhD students, and provides the additional maturity of thought and practice to support excellent PhD progression.

Research students: our postgraduate students benefit from studying in an interdisciplinary academic environment with access to an excellent range of well-equipped research and office facilities and sharing of best research practice. Researchers are encouraged to work together to share ideas and to generate lively discussion through seminars and workshops. We are committed to developing young researchers and working to embed the Concordat's key principles, and we shall continue to grow our PhD student numbers (the trend is seen in the number of PhD students joining the Unit in recent years).

All PhD students have a support committee, with a Principal Supervisor and 1 or 2 Associate Supervisors. All students are required to agree a Personal Development Plan with their supervisors at the beginning of their study, and there is a rigorously enforced system for recording both student progress and regular formal meetings between students and their supervisors. The University's *Statement of Principles Relating to the IPR of Student Research* ensures inclusion of students as authors wherever their research contributes to a paper. The University Graduate School provides a programme of research and transferable skills training (including employability skills). Formal MPhil-PhD transfer occurs after *c*. 12 months. Postgraduate research students receive an annual subvention of £1000 towards research expenses, to cover the costs of laboratory work, field research and conference attendance. Early Career staff progress to Principal Supervisor status through initial involvement as Associate Supervisors.

Towards the end of their first year PhD students are required to prepare and submit a Transfer Report that is read by two assessors from within the School who are not the student's supervisors. There is then a *viva voce* assessment at which a decision is made to recommend the student's transfer to full PhD registration status, or to propose additional work that is required before this recommendation can be made. For both staff and students, there is explicit information in our recruitment literature to encourage applications from minority backgrounds and from female engineers, in order to widen access into civil and environmental engineering.

d. Income, Infrastructure and Facilities

The Centre's **income** has grown significantly, attracting ~£3.2m during the census period. Income per research-active staff has increased by more than 50% per annum from ~£50k/fte per annum during the RAE2008 period to ~£88k/fte per annum over the REF2014 period, maintaining growth seen during RAE2008. The basis for the continued growth is partly due to the increase in the depth and strength of infrastructure research and partly due to the continued development in environmental research during the REF2014 period. Our research strategy will drive bidding priorities over the coming years to engage more fully with sustainable construction and

environments and low-carbon agendas (expressed in EU documentation and the Horizon 2020 framework).

The School **infrastructure** within which the Centre works includes a Technical Manager overseeing a team of 35 technicians (fully-trained to carry out activities ranging from detailed fabrication of test specimens to provision of appropriate technical support), a network of RKT Centres (in addition to the core BCSE) across which the Centre's activities often span (for example, the Advanced Materials Engineering RKTC), a full-time Procurement Officer working for the School to ensure tendering compliance and added-value services and goods, and a Business Manager (with particular strength in networked European activity).

The School support capability is complemented by a wider University infrastructure comprising financial and business development resources, and conference and workshop facilities that the Unit regularly accesses, based around the Research and Knowledge Transfer Services (RKTS) team (that supports Intellectual Property protection, business development, grant development and submission, industrial partnerships, local business engagement, amongst other activities), a number of University research facilities (e.g. an Analytical Centre) for detailed characterisation and specimen analysis, and the Re:centre, a new ERDF-funded Sustainability Enterprise Centre that provides physical space for business representatives to interact with researchers on a regular basis and to build new collaborations at the University.

There are extensive **facilities** in the School to support the depth of experimental activity required to develop the quality output and impact delivered within the research themes. The *Hydraulics Laboratory*, one of the largest in the UK, houses a number of flumes and hydraulic rigs for the study of environmental fluid mechanics and urban water drainage. In recent years the laboratory has attracted significant funding from EPSRC and from other funding bodies, including the EU, DTI, and Yorkshire Water. Members have strong links with industry and the laboratory is actively utilised for consultancy work, often in the construction of scaled, physical models of hydraulic structures.

The associated *Acoustics Laboratory* has benefitted from *c*. £250k of spend to host an extensive range of acoustic equipment to support materials characterisation (e.g. transmission loss, impedance tubes, flow resistivity, porosity and tortuosity, anechoic chamber), materials production (granulator, cyclone separator, mixers, moulds, cold extrusion), and numerical modelling. The main areas of the Centre's research supported are in the theoretical and experimental investigation of sound absorbing materials and sound propagation in lined channels. Research is also conducted on outdoor sound propagation and the design of environmental noise abatement methods.

The *Heavy Structures Laboratory* has one of the largest strong floors in the UK, and the School has recently invested *c*. £500k towards the refurbishment of this space. A main ring hydraulic system with twin pumps capable of delivering 300l/min of hydraulic power has been installed and now supports full-scale experimental studies on structures in static, dynamic, and impact loading situations. Several servo-controlled actuators and control systems were acquired together with brand new loading frames having a capacity of 5,000kN. Since the refurbishment of the heavy structures laboratory, some of the longest single span composite beams have been tested in the facility with funding from the UK and Europe.

e. Collaboration and contribution to the discipline

Collaborative research is fundamental to our work, whether involving interdisciplinary teams across the University or national/international partnerships. Increasingly we have developed internal partnerships that engage the institutional interdisciplinary potential (e.g. via the Re:Centre).

The University has recently become a member of the Centre for Low Carbon Futures (CLCF), a collaborative organisation focusing on sustainability for competitive advantage, and bringing together engineers, natural scientists and social scientists from a number of universities including Birmingham, Hull, Leeds, Sheffield and York to deliver high-impact research on the current themes

of energy systems, green growth and smart infrastructure. BCSE aligns closely with its mission.

Key drivers of BCSE are to deliver international visibility and leadership, combined with industrial and sector credibility. To this end the Centre's members collaborate with researchers from Europe, North America, and Japan, evidenced by input to EU projects, joint journal publications, and funded visits by post-doctoral researchers. Funding from EPSRC, EU, Royal Society, Royal Academy of Engineering, and industrial sources (e.g. Arcelor Mittal, the world's leading steel manufacturer) together with the Steel Construction Institute, Billington Structures Ltd, Tata Steel, ASD Westok Ltd, support research collaboration with our other international and industrial partners.

The international agenda of BCSE has been supported by staff collaborating with researchers from National University of Singapore, Nanyang Technological University, Kyoto University, TU Delft, WL Delft, University of Luxemburg, University of Stuttgart, IIT Mumbai, IIT Kharagpur, Ecole Nationale des Ponts et Chaussée (Paris), Humboldt State University, Laboratoire Central Ponts et Chaussée (Nantes), University of the Applied Arts, Vienna, Louisiana State University, Mokpo National University (South Korea), University of Gent, University of Padua, Technical University of Braunschweig, University of Hong Kong, North China Electric Power University, Institut National de Recherche Scientifique et Technique (Tunisia), Islamic University in Gaza, Tanta, Mansour Universities in Egypt, Polish Academy of Sciences (Krakow), University of Applied Arts (Vienna), Hong Kong Polytechnic University, Tsinghua University (China), and the University of Western Sydney (Australia).

Lam holds visiting professorships at both Tsinghua University (China) and Hong Kong Polytechnic University. The Centre has representation on the councils and branches of the learning societies in the UK, US and Europe that have major influence on public policy and services; these include ICE, IStructE, ECCS, and ASCE (***Mohamed***, ***Sheehan***, ***Oltean-Dumbrava***, ***Lam***). We also have representatives on the Standard Committees in the UK, Europe and the US for the development and revision of the Codes of Practice, which have major impacts upon practitioners and professional services.

Overall we contribute a variety of unique capabilities to our discipline sectors, in advanced construction materials engineering and environmental engineering, providing a lead in the UK to our communities expressed in innovative collaborative ventures (with, for example, health and wellbeing implementers), all of which has helped to attract worldwide recognition. We shall continue to build on this success, pushing our discipline boundaries, developing further fruitful interdisciplinary co-operations across engineering and health sciences, promoting resource efficiency, and wellbeing, and genuine international co-operation to mutual societal benefit.