Institution:	**Loughborough University**
Unit of Assessment:	**B14 Civil and Construction Engineering**

a. Overview

This submission reports on the research achievements and future research strategy of the 33 staff in the Civil and Construction Engineering Unit within the School of Civil and Building Engineering at Loughborough University (LU). We are one of the UK's largest self-contained multidisciplinary civil engineering and built environment Schools, and are returning staff in two equally-sized REF Units of Assessment (UoA) B14 and C16. Our UoA, B14, is a world leading centre for transdisciplinary research in **Civil Infrastructure Engineering**, **Transport** and **Water and Waste Management**. This position has been secured through responsive and engaged delivery of high quality application-focused research that is conducted within a world-class research environment by staff who are committed to the highest standards of research excellence. Compared to our RAE2008 submission the number of staff returned in the Unit has increased by 16% and the volume, quality, significance and impact of our research has been enhanced by: the targeted recruitment of staff with international standing and/or exceptional research promise; our commitment to supporting the Continued Professional Development (CPD) of all staff (Section c); and a £607k capital investment programme, which have collectively enabled us to attract research income worth £7.67m and further enhance our international reputation. Many of our research outputs have been created for, and in partnership with, industrial collaborators and this has ensured demonstrable impacts on policy and practice worldwide (Section b and REF3a/b). Our agile yet coordinated approach to exploiting emerging funding opportunities and driving new research agendas, combined with our established research pedigree and proven expertise in knowledge exchange, has enabled us to refresh and intensify our research activity.

b. Research strategy

The strategy in our RAE2008 return identified four priority research areas, all of which address sustainable practices. These were: reducing transport emissions; examining the impact of climate change on infrastructure performance; mitigating hazardous residues in waste water systems; and developing policies and practices that support international development goals to increase access to safe water and sanitation in low-income countries. During the current REF period we have delivered the strategy defined in RAE2008 by extending our research in the four priority areas through staff working across two themes: **(1) Infrastructure and Transport** (comprising ***Civil Infrastructure Engineering*** and ***Transport*** sub-themes, Staff Group A) and **(2) Water and Waste Management** (Staff Group B). These themes structure our research activity, allow us to drive new agendas, prioritise resources and develop the specialisms of new staff. Each theme/sub-theme is led by a senior academic who coordinates activities in line with staff expertise and emergent funding opportunities and promotes transdisciplinary research within and beyond the Unit to ensure the continuous delivery of high-quality industry-relevant and exploitable research.

The success and significance of the Unit's research have recently resulted in LU adopting *'Changing Environments and Infrastructure'*, which encompasses all of the research activity in this Unit, as one of its six institutional strategic research challenge areas, and Dixon has been selected to be the challenge leader. This will ensure that resources (e.g. capital investments and PhD studentships) will be prioritised to our themes. The five year strategic plan is to extend our global reputation for world leading research in **Infrastructure and Transport** and **Water and Waste Management.** We will use our exceptional research environment to attract, retain and develop world-leading researchers who can devise and deliver multifaceted transdisciplinary research projects. These will be developed through collaborative partnerships that deliver practical solutions to social, industrial, and environmental challenges locally, nationally and globally.

In support of our continuing strategic focus on sustainable practices, the School's two UoAs (B14 and C16) are jointly creating a new centre to unify our research. The *Loughborough Centre for a Sustainable Built Environment (LCSBE)* will overarch our research themes, representing a unique collaboration between researchers, leading design and construction organisations, professional and regulatory bodies, infrastructure operators and construction clients. Building on our multiple networks (Section e) and the opportunities afforded by LU's new London campus, LCSBE will act as a single centre of excellence for research projects, industry-based doctorates, consultancy and

research-informed training in all aspects of sustainable construction and infrastructure. Part-funded by industry, LCSBE will provide a vehicle for ensuring the downstream impact of our work, and for supporting fresh, user-informed upstream research activity via a more diverse range of funding opportunities. Specific activities, achievements and strategic plans are detailed in each theme**.**

(1) Infrastructure and Transport In this theme we have completed 99 externally funded projects since 2008 with a project spend of £4.49m and graduated 25 doctoral students.

Sub-theme: Civil Infrastructure Engineering *(Dixon - Academic lead, Chandler, El-Hamalawi, El-Rimawi, Fleming, Fowmes, Frost, Goodier, Lombardo, Palmeri, Robins, Wackrow).* Our research develops improved methods for modelling, analysing, designing and monitoring structural and geotechnical systems using computational and experimental approaches. We continue to address our four main RAE2008 areas: Stability of slopes (*Dixon, El-Hamalawi, Fleming, Frost*); reliability of soil-geosynthetic systems (*Dixon and Fowmes*); enhanced sport infrastructure (*Fleming and Frost*); and digital photogrammetry and monitoring (*Chandler and Wackrow*). Research excellence has been maintained and strengthened through the recruitment of new lecturers in engineering geology (*Fowmes*), geomatics (*Wackrow*) and structural systems (*Goodier, Lombardo, Palmeri*). Our EPSRC Adaptation and Resilience in a Changing Climate FUTURENET project (*Dixon, Ryley, Frost, Fleming*), with seven university and stakeholder collaborators, developed a methodology for quantifying transport infrastructure resilience in a changing climate. *Dixon* also leads the (initially EPSRC funded) Climate Impact Forecasting for Slopes (CLIFFS) network of academics and stake-holders, a key output of which is the EPSRC iSMART project awarded to five university partners and the British Geological Survey on infrastructure earthwork performance in response to climate change. Our work also includes development of modelling strategies for desiccation cracks (*El-Hamalawi, Dixon*) and the EPSRC multi-grant Slope ALARMS study of acoustic emissions generated by slope failures (see REF 3b, *Dixon*).

Research on the structural performance of waste containment systems continues to advance international understandings of waste/containment system interaction and is used to define UK design practice (*Dixon, Fowmes*). Our research has also: delivered optimised leak detection and location in plastic water supply pipes (*Dixon*); assessed the sustainability of geosynthetic based geotechnical solutions (*Dixon, Frost, Fowmes*); investigated the influence of site practices on lime stabilisation (*Dixon, Fleming*); examined novel methods for assessing and protecting steel reinforcement from corrosion (*Goodier,* Austin of C16); delivered improved models of timber structures in fire (*El-Rimawi*); enhanced the design of precast structural systems (*Palmeri*); assessed ground-borne vibrations from railways (*Frost, El-Hamalawi, Fleming*); and provided wear prediction for grouted connections used for off-shore wind turbine installations (*El-Hamalawi, Palmeri*). We are also participating in the five-year £7.5m collaborative "Institute for Sports Research" with NTU Singapore (*Fleming*) and have developed a life cycle assessment and carbon evaluation software tool with transport colleagues (*Ison, El-Hamalawi, Frost*).

The appointment of three new academics with expertise in structures and materials has broadened and invigorated our research capabilities and provided valuable expertise in off-site modular construction and more sustainable concretes (*Goodier*), structural dynamics (wind and earthquake) engineering (*Palmeri*) and computational mechanics for composite materials and structures (*Lombardo*). These appointments have generated new research (exemplified by *Goodier's* work on reducing urban CO_2 emissions through the EPSRC-funded CLUES project and *Palmeri's* work on nano-reinforced rubber for vibration-proof structures) and initiated multi-disciplinary collaborations within and beyond the Unit (i.e. *Chandler* and *Palmeri's* use of digital cameras for structural health monitoring and *Goodier's* collaboration with Gibb (UoA C16) applying offsite approaches in Civil Engineering). Our 5-year strategy is to: better understand interactions between earthworks, vegetation and climate change, and produce guidance for the safety and resilience of geotechnical transport infrastructure; develop improved modelling capabilities and computational techniques for assessing the performance of new and existing structures under severe loading conditions (i.e. blast, earthquakes and fire); enhance the accuracy of structural and geotechnical monitoring using digital cameras; improve the design, construction, maintenance and play performance of sport-related infrastructure; and enhance the sustainability of construction and maintenance processes.

Sub-theme: Transport *(Bristow - Academic lead, Budd, Enoch, Ison, Pitfield, Quddus and Ryley)***.** Since RAE2008 we have enhanced our reputation for conducting fundamental, innovative and

policy-relevant research in the areas of transport safety, technology and environmental sustainability. Our commitment to delivering research that helps to reduce carbon emissions, reduce deleterious environmental externalities, and improve the environmental sustainability of different transport modes is exemplified by our EPSRC funded projects on: aviation (*Bristow, Budd, Ison, Pitfield, Ryley*), demand responsive transport (*Enoch, Ison, Ryley, Quddus*), intelligent transport systems (*Quddus*) and carbon mitigation (*Bristow*), and EU/UK Government funded work on travel plans (*Enoch, Ison*),. The principal outcomes of the 2008 RAE strategy include: developing research on quiet areas and restorative space (*Bristow*); advancing the EPSRC noise futures network (*Bristow*); funded research on travel behaviour, transport policy and the environmental impacts of surface and air transport (*Bristow, Budd, Enoch, Ison, Ryley*); new avenues of transdisciplinary research in transport safety, risk analysis, and EPSRC funded accident modelling for both surface (*Ison, Quddus*) and air transport (*Budd, Pitfield*). This research has collectively changed transport policy and practice worldwide and has directly led to the construction of safer transport infrastructure (see REF3a and 3b) and made valuable empirical contributions to knowledge through our collaborative research with organisations including BAA, the Commission for Integrated Transport, DEFRA, Department for Transport, UK local authorities, Eurocontrol, the Health and Safety Executive and the Highways Agency.

Our strategy is to expand our research capacity and capability to remain a world leading centre for transdisciplinary research on transport safety and the environmental implications of surface and air transport at local, national and international scales. Our comprehensive and forward-thinking staffing strategy and research will facilitate continued innovation in two key areas: *transport safety* and *transport in a changing climate*. The safety of surface and air transportation will be enhanced by research that devises new algorithms and models to predict accident frequency and severity, details interventions to minimise risk exposure, develops new technologies and autonomous vehicle systems and delivers policy recommendations that can be empirically applied worldwide by practitioners (*Budd, Ison, Pitfield, Quddus*). Our research will promote the creation of resilient and environmentally efficient surface and air transport to safeguard critical systems, infrastructures and users from new and evolving threats including climate change, infectious disease, peak oil, accidental crashes and transition to a lower carbon economy. This will be achieved via the identification and critical evaluation of strategic combinations of technological, methodological, regulatory and behavioural interventions at all scales (*Bristow, Budd, Enoch, Ison, Ryley*).

We will strengthen our collaborations with industry and regulatory partners in the UK and overseas (Section e) by creating new research ventures with professional practice. These will include the proposed pan-institutional Aviation Research Consortium (*Budd*), research into collision free surface transport (*Quddus*) and urban transport resilience (*Bristow, Ison, Ryley*). We will develop our research capacity and expertise through the targeted acquisition and mentoring of new staff with skills and expertise that align with our strategy, and through investment in new equipment (Section d). The appointment of early career lecturer *Budd* in January 2009, who specialises in the socio-environmental and operational challenges of civil aviation, confirms our commitment to remaining a world leading centre for air transport research.

(2) Water and Waste Management *(Wheatley - Academic lead, Cotton, Fisher, Kayaga, Reed R, Reed B, Odhiambo, Pattison, Sander, Sansom, Shiono, Smith, Smout, Sohail).* In this theme we have completed 66 externally funded projects since 2008 with a project spend of £3.18m, and graduated 31 doctoral students. Our research covers water supply, waste management, sanitation and flooding. In RAE2008 our strategy was to respond to international development goals to increase water and sanitation provision and this continues to be a key part of our work. We also planned to strengthen our work into biofuels from waste, improve the life cycle sustainability of biodiesel, better understand the impact of hazardous residues in waste water, promote recycling and the re-use of materials and to extend studies of flooding and erosion in adverse climates. All these areas have been advanced during this REF period. Our international research quality is evidenced through our involvement, by invitation, in the $20M Gates foundation international project into future toilet technologies for 10 million people (*Sohail, Wheatley*) and our work on the European Union (EU) funded 'city of the future' project into sustainable urban water management (*Smout, Cotton, Kayaga, Sansom, Smith*). Complementary research includes work on rain water harvesting and leak detection (*Wheatley, Smout, Dixon*), menstrual hygiene (*Fisher*) and water/sanitation issues for vulnerable groups (*Reed B, Fisher, Sohail*) and during humanitarian

emergencies (*Reed R* with Bosher of UoA C16). The role of the private sector (*Sohail*), improving access to water for consumers in water poverty (*Kayaga, Sansom, Sohail, Cotton*) (REF 3b), combatting corruption (*Sohail*), using social marketing to improve sanitation (*Cotton, Sohail, Kayaga*), and addressing the organizational performance of utilities in low income countries (*Sansom, Kayaga, Sohail, Odhiambo*, *Fisher*) are other areas of activity funded by research institutes and bilateral donor agencies including DFID, the British Government aid programme, UNICEF, WHO, the World Bank, WaterAid and Médecins sans Frontières, among others. Energy recovery from organic waste is a major part of our research. We have formed a network of three universities and six companies (Unilever, Nestle, Costain, MWH, Air Products and Aquabio) to advance the use of biorefinery concepts to recover useful materials and reduce carbon emissions (*Wheatley*). We are also progressing an EPSRC project (*Wheatley, Quddus*, Osmani C16) with three universities to make integrated renewable energies (biotreatment, wind, solar and pyrolysis) and waste treatment more efficient for off grid communities.

Shiono and *Chandler's* research using photogrammetry has been extended to develop methods for estimating flood water levels in rivers (EPSRC) into the influence of riparian vegetation on river floods, funded by The Prime Minister's Initiative 2 (with Japan, EPSRC and National Natural Scientific Foundation of China). *El-Hamalawi* and *Wheatley* have developed an advanced knowledge system to predict flooding and identify remedial measures in Libya, while *El-Hamalawi* has developed a surveillance control and data acquisition system for monitoring river water quality and flow to assist flooding prediction (EPSRC with Myriad Vision and Severn Trent Water). Numerical modelling is further enhancing catchment management and knowledge of the impact of urban water and soil use on mineral cycles (*Sander, Chandler, Wheatley*). *Sander, Chandler* and *Wheatley's* international multidisciplinary NERC project is developing distribution models of soil erosion and predicting sediment and contaminant fluxes from agricultural land to surface water. Our work on flood solutions has been strengthened by appointment of new staff member Pattison.

In the next 5 years we will develop our research to support global efforts to meet international sustainable development goals to increase the availability of safe water and sanitation. Extending 're-inventing the toilet' research will be achieved using our interdisciplinary based approach to challenge existing engineering interventions to produce more sustainable solutions that improve availability of sanitation and clean water to excluded groups while minimising waste. EU funding will allow us to continue research integrating communal water recycling and waste treatment with material recovery. In flooding and sediment transport we will quantify environmental and public health risks from flooding and storm water runoff from highways, urban areas and farms. We will examine the impact of urbanization on soil use and water and carbon cycles, and develop predictive models of virus transport from farmland under varying climatic and land management conditions. LU's transdisciplinary team (led by *Wheatley*) aim to recover scarce minerals from waste using advances in materials and molecular sciences.

c. People:

Our Unit recognises that the aggregation of leading researchers in a world-class research environment is a prerequisite for the effective delivery of world-leading research. Our staffing strategy focuses on the recruitment of staff with international reputations and/or exceptional research promise and the creation of an environment that supports and encourages their intellectual growth. We align our capital investment in research facilities to provide staff with the infrastructure they need to take their research to the highest possible level. In the REF period we have recruited staff with the requisite skills and expertise to enhance key strategic growth areas in our portfolio and matched new appointments with capital investment in research facilities.

i. Staffing strategy and staff development

Since 2008, 9 lecturers (*Budd, Fisher, Fowmes, Goodier, Lombardo, Palmeri, Pattison, Reed B, Wackrow*) have been recruited and *Sansom* changed from 0.5 to 1 FTE to strengthen research capacity and capabilities across the Unit's two core research themes. This represents a 16% increase in personnel. Five of these new staff either replaced those who left the Unit through retirement (3No.) or to take up leadership positions elsewhere (Harvey to UNICEF as Senior Water and Sanitation Advisor and Nijru to the Asian Development Bank as a Water and Sanitation Advisor). *El-Rimawi* and *Odhiambo* who were not returned in RAE2008 are now included. In

transport, strategic succession planning ensured that *Budd* (who joined our transport theme as an RA in 2008) was able to progress to the role of lecturer in 2009 following a retirement. In Infrastructure, *Goodier, Lombardo, Palmeri* and *Wackrow* replaced staff who retired while *Fowmes* represents an additional position. In Water and Waste, *Pattison* replaces a retirement while *Fisher* and *Reed B* were previously RAs in the Unit. The Unit's net expansion and the appointment of staff with specific skill sets have allowed us to better align the Unit's expertise with our priority research themes. All staff hold open-ended contracts.

Our staff complement combines younger colleagues who bring fresh perspectives to our research programmes with experienced staff. The median age of staff returned is 51. The five anticipated retirements in the next five years will enable us to even better align staff expertise with our research themes and so deliver our strategy. New members of staff are provided with a fully-funded research studentship and capital funds of £15k. Additional funds are made available for travel, conferences and networking. We have robust policies for supporting the development of all staff, and a specific staff development system for probationary (early career) staff. This restricts probationers' teaching and administration duties significantly for three years (to 33, 50 and 66% of load in the 1st, 2nd and 3rd years respectively) during which time they are actively mentored by a senior academic who helps develop their research. Research performance is a priority and all academic staff submit an annual Personal Research Plan that facilitates discussions of development needs, which are then addressed through our staff development programme (accredited by the Institute of Leadership and Management). This process embeds research in performance monitoring and reward systems which are overseen by the University's Research Performance Monitoring Committee. The Research Office provides bespoke one-to-one support to staff writing grant proposals. In 2011/12 Research Staff and early career Lecturers were encouraged to apply to the Developing Future Research Leaders programme, an EPSRC funded-initiative, that enabled staff to receive a leadership development grant, dedicated coaching, action learning and 360° feedback. LU's dedicated LEADER programme supports exceptional mid-career academics through initiatives and development projects that afford participants a fuller understanding of LU's strategic planning processes and operating structure.

The effectiveness of our staff development strategy and the Unit's recruitment policy is demonstrated by the success of our staff in being promoted and/or awarded prestigious external positions. Since RAE2008, *Chandler* and *Quddus* were awarded personal chairs after stringent external verification of their research profile and *Budd, Goodier, Kayaga, Palmeri* and *Ryley* were promoted to senior lecturer. *El-Hamalawi, Fleming, Sander* and *Shiono* have undertaken extended secondment and sabbatical periods at ETH, Balarat, Grenoble and the Nagoya Institute of Technology respectively. We actively encourage staff to take up visiting positions at prestigious international institutions and Unit staff have held visiting professorships at the Universities of Illinois and George Mason, Virginia (*Pitfield*), Sydney (*Ison*) and Ecole Polytechnique Fédérale de Lausanne (*Sander*). The international networks that accrue from such activities benefit all staff via our extensive academic visitor and research seminar programme (see Section e).

In 2010, LU implemented a plan to support the career development of researchers in line with the Concordat, receiving the EC's HR Excellence in Research Award. The plan (updated in 2012) includes commitment to a University-wide research staff mentoring scheme, a revised Code of Practice for the employment of researchers, and establishment of the LU Research Staff Association. LU seeks to achieve equality for all, including mandatory recruitment and selection training, and is committed to Athena SWAN. It is a Bronze award holder and the School will apply for Silver in April 2014. In support of this, our School is engaged in an EU FP7 action research programme to establish and implement good practice in providing equal opportunities for female staff. Consistent with the high standards of LU, the Unit places upmost importance on integrity and ethics. All research, from undergraduate projects to externally-funded programmes, is subject to stringent ethics procedures and approvals from LU's Ethics Committee. LU also has a Research Misconduct and Whistle-Blowing Policy and Procedure that allows staff to report issues without fear of recrimination, ensuring a culture of research integrity is promoted and maintained.

ii. Research students

Our academic staffing strategy is closely coupled with growth in our post graduate research cohort and related training programmes and all returned staff contribute to our doctoral training

programmes, delivering mentoring and supervision and a cohort-based experience. The co-location of over 198 full-time doctoral students, and 34 research associates in the School's 1000m^2 award-winning Research Hub provides a vibrant research environment that facilitates innovative research practice and collaborative knowledge exchange within and across conventional disciplinary boundaries in Units B14 and C16. Each student has two academic supervisors and a director of research programme; many students also have an industrial mentor. Progress is monitored through regular supervisory meetings and a robust academic progress review conducted at the end of each year by an independent examiner. Overall quality is assured by quarterly progress review boards chaired by the Associate Dean Research (ADR).

All students are provided with a laptop, access to our laboratory facilities, technician support and funds for travel and conference attendance. The LU Graduate School provides transferable and employability training to meet the requirements of the researcher development framework. This includes face-to-face workshops, an annual research conference including poster competition and the 'Café Academique' forum where PhD students can debate ideas from all areas of research. Our Research Hub facilitates peer-to-peer learning between students from diverse academic backgrounds and students benefit from the School's extensive seminar programme (23 visiting speakers since 2010), quarterly doctoral seminar programme and annual research away days.

The School's two EPSRC-funded Centres of Doctoral Training (CDT) ensure a critical mass of students. The Centre for Innovative and Collaborative Construction Engineering (CICE), established in April 1999, has supported over 140 innovative Engineering Doctorate (EngD) research projects in partnership with 83 different sponsoring companies across the sector. The London-Loughborough Centre for Doctoral Research in Energy Demand is a partnership between UCL and LU, has supported 20 PhD projects at LU, and recently been extended for a further eight years. The Unit has been awarded 40 studentships since 2008 comprising 7 prestigious Centenary/EPSRC/NERC Doctoral Training Account awards, 2 notable international scholarships and, importantly, 31 EPSRC students funded through research grants or our CICE CDT.

The CDTs set the template for our future PhD training ambitions. University studentships will be aligned with LUs six research challenges, which include infrastructure (Section b). At Unit level, students will be clustered around our three research theme/sub-themes, with many straddling more than one. This will create the critical mass of underpinning endeavour needed to drive the Unit's future ambitions. It will also align PhD students with our major research projects and resources, expose them to world-class research programmes, and provide the gateway to experiencing interdisciplinary, multi-institution work in leading UK and overseas institutions. The aim is to stimulate our students, broaden their horizons, and deepen their knowledge in order to mould the built environment research leaders of tomorrow.

d. Income, infrastructure and facilities

Research Funding: Our external funding has been won through open competition from the research councils (£3.86m), the European Union (£1.06m), industry (£0.89m), charities (£0.25m) and other UK and overseas funding agencies (£1.61m). Total spend over the REF period is £7.67m, excluding the CICE CDT. Particularly significant funded areas and grants include:

- **Renewal of the EPSRC CICE EngD research centre,** £5.83m (*Ison*) was awarded for 50 students between 2009 and 2018 as the third tranche of funding for this flagship EPSRC industrial doctorate centre. Many of our alumni occupy senior positions in industry-based research and development roles, as well as academe. The CICE acts as an interlocutor between industry practice and our research and a powerful conduit for impact.
- **Infrastructure Engineering and Transport** spend in the REF period was £4.49m. Exemplar funded areas and projects include: Low carbon transport, 5 projects, £261k, EPSRC, CiFT and Transport iNet (*Bristow, Budd*); new systems and technologies for transport automation, access and safety, 9 projects, £542k, EPSRC, DoT (*Quddus*); Environmentally friendly surface and air transport, 13 projects £1.62m, EPSRC, DEFRA (*Bristow, Budd, Enoch, Ison, Quddus, Ryley*); Future Resilient Transport Networks, £473k, EPSRC (*Dixon, Fleming, Frost, Ryley*); and slope stability in a changing climate and early warning systems, 7 projects £386k, EPSRC (*Dixon*).
- **Water and Waste Management** spend in the REF period was £3.18m. Exemplar funded areas

and projects include: Re-inventing the Toilet, Gates Foundation, £947k (*Sohail, Wheatley*); an EU portfolio of 8 projects totalling £1.16m (*Smout, Cotton, Kayaga, Sansom, Smith*) on sustainable management of water for the city of the future, including SWITCH, SPLASH, BESSE; optimisation of leak detection and location in plastic pipes with Severn Trent water (STW) £329k (*Dixon*); two water filtration projects £300k, DEFRA/STW (*Wheatley*); four renewable energies projects, £253k EPSRC (*Wheatley*); two flood flow measurement projects, £581k EPSRC (*Shiono, Chandler, Wackrow*); and a soil erosion and chemical transport project, £289k NERC (*Sander, Chandler, Wheatley*).

Funding Strategies: The Unit's grant income strategy is founded upon the recruitment of, and investment in, high performing staff, coupled to our emphasis on collaborative and interdisciplinary working. We build unique capabilities which align with funding programmes by mobilising interdisciplinary teams around the needs of funding calls. Invariably these also demand inputs from colleagues from other disciplines; the LU research challenges facilitate this. Demand-managed calls are led by the LU Research Office, which coalesces multiple Units where appropriate. Our theme/sub-theme leaders (*Dixon*, *Bristow* and *Wheatley*) sit on the School Research Committee. This is chaired by the ADR, who sits on the University Research Committee, thus aligning the Unit's activities with LUs research strategy and promoting collaboration with other Schools.

The School has a full-time Research Manager who oversees and supports all funding applications through to submission and plays a vital role in identifying and channelling key information to academics about funding opportunities. A percentage of project overheads is distributed to the investigators to pump-prime future research. Over the next five years funds to stimulate new research will also be provided by the new LCSBE (Section b). This agile yet coordinated approach to exploiting emerging funding opportunities and driving new research agendas will enable us to refresh and intensify our research activity in line with our stakeholders' and funders' needs.

Infrastructure and Facilities: Research in UoA B14 benefits from the concurrent and interrelated investment in UoA C16, and this produces world-class facilities that benefit both Units. We have continued to invest in our infrastructure and facilities to align with our theme priorities and staff requirements. Our Research Hub is a world-class environment with high-quality open-plan space, providing a flexible working environment for research staff and students. This is supplemented by our ICT systems (supported by two dedicated School IT staff) and the adjacent recently refurbished university library, which includes dedicated space to support researcher interaction. Our laboratories' 3000m^2 of specialist research space is supported by a team of 14 technical staff. Since RAE2008, we have refurbished and improved UoA B14's laboratories through a total investment of £607k including: a £159k upgrade of our specialist biological and chemical containment facility (licenced zone 2); £199k for lab space refurbishment and critical equipment upgrade/replacement; and support for four of our early career researchers (*Fowmes, Lombardo, Pattison, Wackrow*) awarded a total of £85k through the EPSRC small equipment initiative and School support. Support also includes the University's recognition of the strategic importance of Civil Infrastructure Engineering that led to Capital Investment Funds being allocated to enhance our lab and field capabilities: *Palmeri* secured funds to build a new and more flexible rig to test full-scale structural elements (£80k) and *Dixon, El-Hamalawi, Fleming* and *Frost* acquired a suite of instruments to build field observatories for infrastructure health monitoring (£51k). A new Structural dynamics lab has also been established (including two twin long-stroke low-frequency bench shake tables) to support the investigations of new staff *Palmeri* and *Lombardo* (£33k). These Unit-specific investments are complemented by further UoA C16 lab enhancements totalling £773k. *El-Hamalawi* and *Sander* also have access to LU's new High Performance Computing (HPC) facility, which was funded through two EPSRC grants totalling £1.24m, enabling one of the UK's fastest high performance clusters to be commissioned. Our sports pitch research (*Fleming*) uses the laboratory facilities of LU Institute for Sports Research (£70k investment in UoA B14), which includes an indoor biomechanical facility with 3-D motion capture and high speed filming, materials characterisation and outdoor pitch test facilities. In transport, staff have been supported in the acquisition of an automatic dependent surveillance-broadcast radar decoder (*Budd*) and instrumented vehicles (*Bristow and Quddus*).

e. Collaboration or contribution to the discipline or research base

We pride ourselves on our interdisciplinary approach to addressing real-world problems in the built

environment through academically rigorous research. To this end we collaborate extensively with colleagues from a range of disciplines, both within and outside LU, drawing upon our extensive networks of research partners developed through our membership and leadership of national and international fora. By co-producing knowledge with our partners we create impact pathways for our research and shape industry agendas rather than merely responding to them.

Research collaborations: All members of the Unit engage in active on-going productive collaboration with academic and industrial partners both nationally and internationally. Many also engage local and national print and broadcasting media as a pathway to impact. This ensures our research continues to make key theoretical and empirical contributions to knowledge while delivering maximum societal impact and practical utility. The Unit currently has 47 significant collaborative research engagements with Universities and research institutions in 24 countries worldwide and numerous domestic links. During the REF period, the School has hosted 94 residential academic visitors from 18 different countries. The individual and collective international reputations and esteem held by our staff is evidenced by the number and diversity of honours, awards, industry collaborations, prizes, nominations, editorial board memberships and international speaking invitations they have received. Collaborations in **Infrastructure Engineering** include: *Palmeri* - University of Patras, University of Messina; *Lombardo* - Czech Technical University; *Fleming* – Ballarat University and with 360 worldwide academic and industry members of his SportSURF network; *Dixon* – with academic and industry membership of CLIFFS network, Universities of British Columbia and Queen's (Canada), CNR-IRPI (Italy), Network Rail, CH2M; *El-Hamalawi* – ETH; and *Fowmes* – FCC Environment. In **Transport** these include: *Bristow* - Hong Kong Polytechnic University, URS Infrastructure & Environment UK and the Hardstaff Group; *Budd* – Universities of Denver and Hamburg, Sustainable Aviation; *Enoch* – partners in Denmark and Hungary; *Quddus* - Universities of Minnesota, Purdue, Wayne State, Mississippi State, Harbin Engineering, and Rutgers; and *Ison* - University of Sydney Business School. In **Water and Waste Management**, key collaborations include: *Sander* - Ecole Polytechnique Federale de Lausanne, Cornell University; *Patterson* - University of North British Columbia; *Chandler and Wackrow* - Universities of Lausanne and Leon; *Sohail* - WHO and UNICEF, Birzeit University; *Cotton, Smout, Reed B, Kayaga, Fisher* - NGOs in water and sanitation, WaterAid, Tearfund, SNV (Netherlands), Universities of BUET and DUET in Bangladesh; *Shiono* - Kansai, Kyoto, Kyushu, Hiroshima, Tokushima and Ehime Universities; and *Wheatley* – Delft, EWAG, Stanford.

Interdisciplinary research: UoA B14 and C16 co-located staff represent every major discipline associated with the built environment. We adopt a problem-driven approach, mobilising our expertise to respond to intellectual challenges rather than being constrained within rigidly demarcated disciplinary silos. Necessarily, this approach extends into our cross-school collaborations, themselves supported by LU's six research challenges through which interdisciplinary groups are formed to address key questions and respond to funding calls. Exemplars include: *Sander, Chandler* - NERC project on multidimensional soil erosion and chemical transport experiments and mathematical modelling; *Dixon, Ryley, Frost, Fleming* – EPSRC project FUTURENET with social (Nottingham University) and climate scientists (Birmingham University); *Sansom* - ESRC funded research on sanitation governance with International Development Department, Birmingham University, London School of Hygiene and Tropical Medicine and Centre for International Education, Sussex University; *Budd* - human health implications of air transport with Geography at LU and sustainable aviation with Business School at De Montfort University and Dept. of Government, University of Essex; *Sohail* - with partners of EU TEMPUS project to reform environmental studies in Palestine, and Re-invent the Toilet with LU Design School and Chemistry School; *Dixon* – leak location project for STW with electronics and signal processing at LU; *Fleming* - sports surface research involving LU materials and the sciences of human movement and health (Exeter University).

Influence on international research and strategy: Staff are active members of national and global funding committees and professional institutions. *Bristow* was invited to co-chair Team 9 (Policy and Economics) of the International Commission on the Biological Effects of Noise and served as a Board Member of the Low Carbon Vehicle Partnership. *Ison and Quddus* are committee members of the international Transportation Research Board (TRB). *Cotton* is a member of the Global Core Advisory Group convened by World Bank, UNICEF and WHO reporting to the UN Secretary General, and an accredited UK government representative supporting the

African Union Heads of State Meeting (water and sanitation) 2008, an elected member of the Global Management Steering Group for the Water Supply & Sanitation Collaborative Council (Geneva) and was commissioned by the European Council to lead the Europe-wide Task Group to prepare the 'Africa-EU Sanitation Statement' on behalf of the EU member states and the African Ministers' Council on Water, subsequently leading to providing evidence to the House of Lords EU Committee in their session on 11th July 2013. *Fisher* supported UNICEF's Menstrual Hygiene Management Conference as an expert and is a member of the International Advisory Committee, Environment and Population Research Centre, Bangladesh; *Reed B* is a peer reviewer for Oxfam, Red Cross and WASTE; *Fowmes* is a member of two Environment Agency advisory groups on waste management; *Chandler* chaired ISPRS V/6, an international working group to promote and coordinate activities on spatial measurement of natural objects at close range; *Sohail* is a lead consultant for UNICEF, the African Water Facility, African Development Bank and is sector expert contributing to the WHO/DFID Vision 2030 with *Reed R*; *Dixon* is Task Manager for the International Geosynthetics Society (IGS) technical committees; *Wackrow* is a member of the Geospatial Engineering Practices Committee; and *Fleming* and *Frost* produced a UK best practice guide on foundation testing for the Highways Agency.

Academic leadership: *Sander* is Editor of Water Resources Research and *Ison* is Editor of the Journal of Research in Transportation Business and Management, Associate Editor of the Journal of Transportation Planning and Technology, and Book Series Editor Transport and Sustainability. *Chandler* is coordinator of the International Editorial Board of the Photogrammetric Record and *Quddus* is an Associate Editor of Transportation Research Part C: Emerging Technologies, and the Journal of Intelligent Transportation Systems. *Sohail* was Guest Editor for the themed edition on 'Water Sensitive Urban Design' in Municipal Engineer and *Budd* co-edited two special issues of Research in Transportation Business & Management. Four staff are members of journal editorial boards. Six staff have been chair of international conference organising committees including: *Dixon* as Technical Committee Chair, 4th European Geosynthetics Conference; *Fleming* as Chair of two international conferences on sports surfaces; *Goodier* led SBE2013 (International Conference on Sustainable Built Environment), National University of Civil Engineering, Vietnam; and *Ison's* activities include being Chair and topic area manager in Transport Planning and Policy for the World Conference on Transport Research Society, Chair of the Green Transport Conference, and joint organiser of SIG10 Workshop on Emerging Urban Transport Policies towards sustainability. Ten staff are reviewers and members of the EPSRC peer review college.

Academic input to professional bodies includes: *Bristow* - member of the Research Coordination Committee of the Institute of Acoustics; *Dixon* – Council member, IGS; *El-Hamalawi* - industry advisory groups: International Association of the Engineering Modelling, Analysis and Simulation Community, Geotechnical International Committee and Construction Industry Research and Information Association Geotechnical Committee; *Fleming* – member of committees - Institute of Groundsmanship 2012 fund, two TRB technical committees, and BSI PRI/57 testing of sport surfaces contributing to revisions and new standards; *Fowmes* - Vice chair of the IGS UK; *Ison* - Member of the Airport Terminals and Ground Access, Technical Activities Council Committee, Aviation Group, TRB, and Member of the Committee on Transportation and Sustainability, TRB; *Pitfield* – member of the Technical Advisory Panel on Accidental Aircraft Crash Risk Assessment, UK Office of Nuclear Regulation; *Reed B* - Chartered Institution of Water and Environmental Management: Member of Sustainability Panel; *Sander* - American Geophysical Union; *Smout* - Chair of the Board of Trustees of RedR UK.

External recognition: This includes: *Sohail* and *Wheatley* awarded the American Society of Civil Engineers Gates Foundation prize for re-inventing the toilet; *Ison* received the Rees Jeffreys Award in 2008 and 2009 (with *Frost*) for the best paper on highway engineering published in Municipal Engineer or Transport by the Institution of Civil Engineers. *Pitfield* was awarded the 2008 Moss Madden Memorial Medal for the best regional science paper. *Enoch's* TravelPlanPlus project won the European Platform on Mobility Management Award for Best Policy Transfer Project in 2012. *Fisher* received the 2008 ICE Safety in Construction medal for her paper in Municipal Engineer on women in water supply, sanitation and hygiene programmes. *Dixon*'s work on Slope ALARMS achieved The Engineer Magazine Technology and Innovation Award 2011 for Civil Engineering and a 2010 Loughborough University Enterprise Award. Unit staff have been external examiners for 79 PhDs in the REF period.