Institution: University of Greenwich

Unit of Assessment: (UoA 15) – General Engineering

a. Overview

The University of Greenwich is a strongly research-informed institution. The University Strategic Plan (http://www.gre.ac.uk/governance/vc/strategic-plan-2012-2017) aims to build on its success in creating this research-informed environment to increase the quality, volume, and intensity of research activity. Key themes of the current and future strategies are:

- To ensure that the University has a critical mass of excellent researchers through the appointment and retention of high-quality staff;
- To develop at least 20 research groups with an international reputation for excellence as measured by the significance, originality, rigour and impact of their work;
- To develop a vibrant community of high-quality postgraduate research students;
- To increase the national and international impact of its research.

The research agenda within the University is led by the Deputy Vice Chancellor for Research and Enterprise who chairs the University Research and Enterprise Committee (R&EC). Directors of Research and Enterprise for the constituent Schools and Institutes of the University are members of the R&EC. Each School and Institute is accountable to the R&EC through an annual report and strategic plan. Each Faculty operates a Research Degrees Committee which oversees Postgraduate Research programmes in the Faculty and reports to the University R&EC. The University's research work is also guided by a Research Ethics Committee, chaired by a Dean of School.

Under this UoA, the University is returning a multi-disciplinary team of engineers, physicists, mathematicians and computer scientists from the School of Engineering (SoE) and the School of Computing and Mathematical Sciences (SoCMS). The team is drawn from three research groups:

- **Centre for Numerical Modelling and Process Analysis (CNMPA**) (http://cnmpa.gre.ac.uk/), is a cross-school centre, based in both the SoE and SoCMS, and established in 1983. The CNMPA has research interests in developing computer models for multi-physics/multi-scale predictions, numerical optimisation, failure analysis, reliability and maintenance of engineering structures and process systems. Due to the highly inter-disciplinary nature of its work, the CNMPA is returning six ARs to this UoA, (**Berry**, **Deere**, **Deng**, **Wang, Xie** and **Zigan**) as well as nine to UoA 12 and seven to UoA 13.

- **Sustainability in Civil Engineering Research Group (SCERG)** (http://www2.gre.ac.uk/about/schools/engineering/research/groups/scerg), based in the SoE. The SCERG was established in 2009 by, and continues to be led by Prof Morteza (Amir) **Alani**. The SCERG undertakes research in the associated areas of applications of non-destructive methods in civil engineering and structures in general (and in particular bridge and tunnel monitoring and assessment, reliability and health monitoring of structures), environmental engineering (sustainable drainage systems and flood control), geotechnics (numerical modelling of soil and materials) and concrete technology (focussed on fibre reinforced concrete and ground supported slabs and also underground concrete sewer pipes). The SCERG is returning six ARs to this UoA (**Aboutabebi**, **Alani**, **Chen**, **Dussaillant, Faramarzi** and **Tee**).

- **Centre for Innovative Product Development and Manufacturing (CIPDM)** (http://www.gre.ac.uk/cipd), based in the SoE. The CIPDM was established in 2006 by, and continues to be led by, Prof James **Gao**. The CIPDM undertakes research in the areas of new product development, collaboration and knowledge management in the supply chain, and product lifecycle management. The Centre focusses in particular on new enabling technologies, methods and processes. The CIPDM is returning two ARs to this UoA (**Gao** and **Melis**).

The location of the SoCMS in close proximity to Canary Wharf facilitates strong research collaboration with the global businesses based there. The location of the SoE on the Medway Campus facilitates close collaboration with colleagues from the University of Kent and Canterbury Christchurch University, with whom Greenwich shares the campus to collectively provide a world-leading learning and research environment.

As a result of the highly multidisciplinary nature of the research across the two Schools, the research does not fit neatly into the REF UoA framework, and so we are returning ARs to UoAs 12, 13 and 15.

b. Research strategy

i. Implementation of Strategy Since RAE 2008

The strategic aim of this UoA since 2008 is closely aligned with the research growth strategy of the University. Specific points which reflect this are as follows:

- Whilst the number of ARs being returned to this UoA has fallen slightly since RAE 2008, (14 vs 14.6) this is attributed to the fact that the University is making its first return to UoA 13 in REF 2014, and we have also chosen to return nine ARs to UoA 12, compared to 5.5 in RAE 2008. Thus, the total number of ARs being returned across UoAs 12, 13 and 15 has risen from 20.1 in the equivalent UoAs in RAE 2008 to 35 in REF 2014.
- With respect to refereed publications, the CNMPA (including the ARs returned to other UoAs) has published 542 such papers during the REF 2014 assessment period, compared to 498 for RAE 2008, with the respective figures for the SCERG being 157 and 65, and for the CIPDM being 51 and 100.
- Over the REF 2014 assessment period, the SCERG achieved four PhD completions and generated £953k in external research grants, with both figures growing from zero (over the RAE 2008 assessment period).
- In the case of the CIPDM, seven PhD completions were achieved over the REF 2014 period, rising from zero in REF 2008. Grants awarded rose from zero over the REF 2008 assessment period to the current figure of £937k.

With regard to the future strategies set out in the RAE 2008, in the main, the key points have been achieved or exceeded, with the following group specific examples (note that SCERG was not established until 2009):

CNMPA. The EXODUS suite of evacuation and pedestrian dynamics simulation tools has been significantly enhanced, as planned. The capabilities QPM toolkit have been extended.

CIPDM. Research initiatives in design methodologies and innovation management have been established, and new links with business and industry developed (BAe Systems and Cummins).

All research outputs from the UoA which are accepted externally are deposited in the Greenwich Academic Literature Archive (http://gala.gre.ac.uk), an open repository. An internal peer review system for publications is available within both Schools, and this is coupled with a mentoring system whereby members of staff with identified research development needs are 'buddied' with more experienced colleagues working in the same or related fields. In addition, the University operates a series of paper writing workshops through the year (http://www.gre.ac.uk/research/training).

Researchers in the UoA have access to the services of Greenwich Research and Enterprise (GRE) the research office of the University. GREs main function is to support the efforts of researchers to gain external funding for their research (typically approximately five times the funding available from RAE across the University). GRE staff include Business Development Managers (BDMs) who work closely with researchers in the UoA to identify funding opportunities and create proposals to successfully access them. Both the SoE and SoCMS have dedicated BDMs, so they are physically

adjacent to researchers in the relevant UoAs. GRE runs a comprehensive series of developmental workshops targeted at meeting the needs of researchers seeking funding, (http://www.gre.ac.uk/research/training) and also administers an internal peer review college for funding bids. In addition to assisting researchers gain funding, GRE also provides a wide range of workshops as part of the University research staff development programme. These include: project management, planning and managing budgets, research survey design, media training, establishing networks/collaborations and specialist IT training.

ii. Forward Strategy and Vision

The overarching forward strategy and vision for the UoA is to grow the research endeavour, both by increasing the size of the three existing research groups, and by developing other research groups to the point at which they can be returned to this UoA.

This is supportive of, and consistent with, the current University Strategic Plan (http://www.gre.ac.uk/governance/vc/strategic-plan-2012-2017), which aims to increase the proportion of academic staff who are research active from 40% to 75% by 2017, whilst at the same time, increasing external research funding by 62% and increasing the number of postgraduate research students across the University from 350 to 500.

We expect this growth to be achieved through:

- Further developing our understanding of human behaviour associated with wayfinding, and the decision making process associated with using lifts or stairs for evacuation, better characterise and quantify the evacuation performance of people with disabilities, understand the impact of social culture on evacuation behaviour, explore the concept of multi-scale evacuation modelling to represent evacuation in large urban scales for disaster management planning. These techniques will be embedded into our EXODUS software to better represent human behaviour and widen the scope of its application.
- Further developing the capabilities of our CFD fire modelling to include; improved representation of the generation and propagation of fire smoke, improved representation of the generation of toxic products of combustion such as HCN and improving the computational efficiency of CFD fire modelling through the use of the hybrid discretisation concept and GPUs.
- Further development of our multi-physics and multi-objective optimisation capabilities for materials and manufacturing processes. To embed these capabilities into our software tools such as PHYSICA, SPHINX, ROMARA and POWERLIFE.
- Combining the latest advances in Internet-of-Things and cloud computing with our modelling tools for real time prognostics and health management of engineering products in the field.
- Continuing to enhance the science behind measurement and control of powder flow properties, particle attrition, caking and two-phase flow in industrial systems, as well as modelling and design techniques to enhance process efficiency, yield and quality.
- Increasing the particulate systems research we have started to pursue in high value manufacturing (eg aerospace) advanced materials (carbon nanotube composites) and emerging energy sources (eg biomass).
- Continuing to enhance the two existing in-house numerical models for the assessment of concrete sewer pipes by further validating the models against field data as well as extended laboratory based experimental work. This work will be extended to cast iron pipes.
- Continuing the development work in the fibre reinforced concrete structures and in collaboration with industry (Permaban and Peikko). Extend this to investigate the loading mechanism and load transfer at concrete slab joints (dowel joints).
- Further collaborate with Carbon8 (http://www.c8s.co.uk) on the development of an enhanced high value aggregate using recycled waste materials.
- On-going work on the EU COST ACTION TU-1208 project in applications of non-destructive testing methods (including ground penetrating radar) in civil engineering and in particular bridge and tunnel assessment and maintenance.
- Extending existing work on thermal energy extraction from geothermal sources by focusing on

the development of a numerical model for hot dry rock reservoir analysis.
- Further research in structural reliability analysis and optimisation of maintenance strategies will continue, with the aim to develop a set of predictive deterioration models and effective adaptation methods to changing operation environments. This will be achieved by applying reliability analysis and life cycle cost analysis techniques.
- Further development of our understanding of flooding and its impact on river morphology and ecology within the context of extreme flood-sediment-vegetation dynamics.
- Continuing to develop new methods to improve product development processes and enable effective information sharing within the global supply chain, making use of engineering knowledge including customer requirements, costing, design, project planning, manufacturing capability, maintenance and service;
- Continuing to development new digital manufacturing technologies within dynamic manufacturing processes and operations, and achieve lean, sustainable and six sigma product design and manufacturing.
- Continuing to improve the integration of advanced tools and systems in manufacturing including CAD/CAM/CAE, product lifecycle management, manufacturing execution systems, enterprise resource planning, design for manufacturing, failure mode and effect analysis, reverse engineering and rapid prototyping.
- Continued collaboration on UK Government and overseas Government (e.g. EU, DoD, etc) funded projects with leading research organisations.

c. People, including:

i. Staffing strategy and staff development

The University has committed to the goals established by the Concordat to Support the Career Development of Researchers developed by Vitae. To this end it is a signatory of the Concordat and has created a comprehensive Researcher Development Framework. Plans are in place for full implementation, including comprehensive research training programmes, from September 2013.

Furthermore, the University has extended this work and successfully gained the HR Excellence in Research award of the European Commission. This involved making substantial progress towards addressing and embedding the principles of the Concordat – and this is demonstrated through a comprehensive gap analysis and action plan (http://gre.ac.uk/hr/concordat).

The University has a dedicated equality and diversity champion who has taken a leading role in the initiatives described above. All UoAs are required to observe the University Equality Framework (http://www2.gre.ac.uk/about/policy/equality). Line managers are trained in current practice and are responsible for ensuring compliance and being pro-active in identifying areas of issue. For the REF, the University has established a comprehensive network of equality and diversity champions across all UoAs.

Within the UoA and within both Schools, consistent with the University strategy, the hiring policy is to hire only academic staff who can contribute to the research endeavour of the University, and to support existing staff to develop and expand their research work. Inevitably, since 2008, some colleagues have moved to posts outside the University (for example Prof NN Ekere and Dr KC Huang). However, where this has occurred, we have sought to replace them with new hires of equivalent experience, for example Prof M **Alani**, Dr A **Faramarzi**, Dr W **Melis** and Dr S **Zegan**. Several hiring initiatives have been undertaken over the past five years – including the introduction of new-blood research-active staff, research professor schemes, and high-profile PhD student scholarship schemes. The small number of existing staff who do not hold a PhD are encouraged to work towards such a qualification and a defined support scheme exists to provide both time and financial support to enable them to do this. Potential leaders for research groups and departments are identified at an early stage and are encouraged to undertake several of the leadership development programmes offered by the HR Learning and Development team and the Leadership Foundation for HE.

A consistent balanced academic workload model is operated across the University which provides each academic with dedicated time for research - with goals and appropriate support agreed through the University-wide staff appraisal process. The University also operates a sabbatical programme which allows staff members to take periods of time to concentrate on particular research projects, or to develop their research experience by working at other institutions (http://www2.gre.ac.uk/about/policy).

Strong communication between academics both within and across UoAs is viewed as crucially important to developing a vibrant research environment. Both Schools therefore run a programme of internal seminars and conference days, which are open not just to members of the UoA but also to colleagues from the wider University community. Postgraduate research students from relevant groups are strongly encouraged to attend these as part of their personal development programme.

Early career researchers (ECR) are identified on joining the University and provided with support via a comprehensive ECR network. The network supports the career development and management of ECR staff and contract researchers within the University. It was set up in 2009 as a direct response to the aspirations of the Concordat and in accord with the previous Roberts Report and funding stream. In order to allow a maximum number of appropriate staff to benefit from internal training and opportunities, criteria for ECR classification at Greenwich are inclusive. In addition to access to specific training and mentoring initiatives, the network facilitates communication and networking between ECRs across the University creating a strong and cohesive support community. The network runs an annual competition to identify ECRs with particularly high potential and the winners are given high-profile early career research excellence awards which include financial support for their research. Six early career researchers are being returned within this UoA; a number of other are being supported to develop their portfolios for return to the next REF exercise.

The research group directors manage the groups, providing a coherent approach to staff development within the groups and infrastructure investments to support the research strategy detailed above. Each group is a cost centre with directors having overall responsibility for managing research income/expenditure and investment of RAE, RCIF and external funds.

Each group has developed specialist MSc programmes (MSc Applicable Mathematics for CNMPA, MSc Civil Engineering for the SCERG and MSc by Research in Product Development and Manufacturing for the CIPDM) and the ARs being returned contribute significantly to the delivery of these programmes.

The main achievement of this UoA team is its ability to maintain a strong, rich and multidisciplinary research environment including a network of links with business, industry and academic laboratories worldwide. In a highly competitive research environment, they attract UK government, EU, Industry and International funds, from SMEs to multi-nationals without sacrificing their main goal of research quality.

ii. Research students

The University aims to increase the number of postgraduate research students by 40% over the next five years. There is an active programme to recruit high-quality students internationally, supported by a high-profile competitive Vice Chancellor's PhD scholarship scheme which provides generous stipends.

Greenwich provides comprehensive training of PhD students in an interdisciplinary environment. This is driven by a culture of shared resources, expertise, and facilities. Student progress is regularly and formally monitored by the Faculty Research Degrees Committee. Each student is expected to present their work – and have it subject to peer review and feedback - either at a Faculty research seminar or a postgraduate research day. This provides the opportunity for them to test their emerging work on a critical but supportive audience. Students are supported in their needs by both generic training provided at University level, and also specific training provided

within the UoA, such as specialist programming skills and training in the use of specific laboratory equipment.

Within the UoA, PhD students typically attend the appropriate MSc modules or other appropriate short courses as part of their initial studies. Presentation of their work in internal seminars and conferences hones their presentation skills in front of peers and supervisors, prior to their making external presentations. A regular programme of invited external speakers enhances awareness of relevant research beyond the university. All PhD students have access to state-of-the-art computational and laboratory facilities supported by RCIF and industry funds.

As is common across the sector, each student has a supervisory team with at least two supervisors – one of whom is fully accountable for progress and training of the student. Supervisors are required to have undergone a specified training programme within the University and have specific experience in research student supervision before becoming lead supervisor.

Within the UoA, we project continued increases in PhD student recruitment, with particular emphasis on international collaborations. The university has recently strengthened its entry criteria for doctoral programmes and this is expected to result in an increase in the quality of publications being produced by PhD students and their supervisors.

d. Income, infrastructure and facilities

The research of the UoA is supported through both external income streams (research councils, EU, government agencies, business, industry, consultancy, and licensing of software) and internal investments. Annually, the University allocates RAE income to established research groups by both formulaic and competitive internal bidding processes. The groups utilise RAE funding to underpin their main basic research activities and supplement research grant and enterprise income. This funding is used to: support active researchers with travel and equipment, provide funding for RA's and provide bursaries for PhD students. RCIF funding is apportioned to research groups to provide state-of-the-art research infrastructure. Within the Schools there are also Directors of Research and Enterprise who sit on the School Executive Committee, bringing the research and enterprise agenda to the highest levels of School governance.

In addition to academic staff on teaching and research contracts, revenue enables the UoA to engage five research fellows, thereby enhancing the capacity of the research groups.

Research infrastructure is continuously being renewed and enhanced. All research staff/students have their desk-top computers upgraded as part of a rolling programme.

The School-based computer networks are continuously upgraded by the addition of equipment e.g.: in SoCMS the 6 Tb SAN storage has been upgraded to 10TB this year, off-site backup/replication for maximum resilience of storage area, 1GB network back-bone has been upgraded this year to 10GB, 1GB switches and dedicated research servers. Other facilities include a dedicated server room space in Dreadnought Library which has been enhanced to cater for HPC servers, two distributed memory high performance clusters, a 40 processor system and a high performance shared memory 64 processor Linux cluster, implementation of virtual desktop environment and virtualisation of servers enabling research groups the ability to demonstrate software to clients and development of their specialised software. These provisions have been made available via RCIF expenditures of £1.5million since Jan 2008. Additionally, a small grid cluster has been purchased to support parallel and distributed computing research in the Greenwich campus. A ubiquitous computing software-hardware lab has been built and equipped at Greenwich using University and RCIF funds. Additionally, £160k has been spent on specialist software to support research activities within the groups.

Within the SoE, the SCERG has developed two significant test facilities, funded by RAE, RCIF, SRIF and consultancy income. The first is a 79m^3 environmental test chamber with the facility to aggressively cycle temperature and humidity, as well as spraying sea water. The second is a

concrete slab structural test facility, capable of accommodating slabs up to 84m^2. In addition, we have acquired a range of cutting-edge test equipment to support the condition monitoring of structures, including 200MHz to 2 GHz ground penetrating radar and a Leica 3D laser scanner. The total investment in these facilities has been £305k.

Advanced digital manufacturing technologies including CAD, CAM, ERP and CAE systems are heavily utilised for research. In particular, during the REF2014 assessment period, we have established the Renishaw Productivity Centre consisting of advanced computer numerical control machines (4-axis lathe and 5-axis machining centres), advanced rapid prototyping facilities with intelligent manufacturing control and simulation systems. The Centre is a joint venture between the University, Renishaw and Delphi Diesel Systems.

The Drill Hall Library at Medway and the Dreadnought Library at Greenwich are each open for more than 100 hours per week for the majority of the year and offer access to over 600,000 volumes, as well as 1,000 PCs, laptop drop-in zones, printers and photocopying.

e. Collaboration or contribution to the discipline or research base

Collectively, the groups engage with many leading Universities across the world (eg. US, Australia, Singapore, China, France, Ukraine), as evidenced by the co-authors of many publication outputs (see http://gala.gre.ac.uk). We have also have significant involvement in initiatives such as Marie Curie (e.g. Pb-Free project which supported close collaboration with City University, Hong Kong) and the Prime Ministers International Research Collaboration Initiative which supports staff exchange visits between the CNMPA and Kyoto University, Japan. We also engage with the wider community through our visiting professorships which include Professor Peter Mason (Royal Academy of Engineering Visiting Professor at Surrey University) and Professor Nihal Sinnadurai (President IEEE UK &RI Reliability and CMPT Societies). Prof **Alani** also holds the position of visiting professor at the Dnepropetrovsk Civil Engineering and Architecture Academy in the Ukraine.

Prof **Alani** is a member of the EU COST Action TU-1208 management committee (examining applications of ground penetrating radar in civil engineering) and also a member of the EuroGPR forum.