Institution: Imperial College London

Unit of Assessment: 14 - Civil & Construction Engineering

A. Context

The research undertaken in the Department of Civil and Environmental Engineering has had substantial economic, social and environmental impact. This impact has arisen both within the industrial and professional domains traditionally associated with Civil Engineering (e.g., the construction sector, public health and the utilities) and increasingly on new interfaces we have actively developed with adjacent domains such as agriculture, healthcare, ICT, satellite systems and automotive. The principal beneficiaries and forms of impact include:

- **Industry**: Industry has benefitted through collaborative research and consultancy addressing key industrial challenges [case studies 1, 2, 3, 4], through the creation of spin out companies offering new products and services and through the licensing of new IP. Since 2008, we have attracted £13.5M in direct industrial funding, providing £5.8M in consulting services to industry.
- **Government**: Through working closely with government organisations such as Defra, DECC, DfT and TfL our work has influenced the formation of public policy at local, national and international level, especially in the areas of flood risk management and transport investment appraisal [case studies 5, 6].
- **Professional practice**: Through the translation of our research results into widely adopted codes and standards that have substantially improved professional practice in several areas, including structural steel design [case study 7] and off-shore engineering [case studies 1, 2].
- **Environment**: Research in the areas of low carbon construction, urban energy systems and transport-related air quality management have all contributed to a reduction in CO_2 emissions and local air pollution. Research in the recycling of wastewater biosolids and in extracting useful materials from other waste-streams has improved natural resource efficiency**.**
- **Health and welfare**: Research in the areas of extreme wave loading, earthquake engineering, drinking water quality and air traffic control have all contributed to a reduction in the exposure of human populations to health and safety hazards. Work in structural biomechanics has lead to improvements in the quality of healthcare.
- **Public**: In order to raise public awareness, understanding and enthusiasm for science and engineering, whenever possible we take the opportunity to actively disseminate our research through traditional and new media channels (TV, radio, web, social media) and through dedicated outreach activities including public lectures, demonstrations and Masterclasses.

B. Approach to impact

We attach great importance to maximising the impact of our research on industry, government, the profession and the wider community, in line with Imperial's overall mission: "*To develop our range of academic activities to meet the changing needs of society, industry and healthcare*".

We describe below a number of specific mechanisms that we have put in place to support our staff to generate impact from their work. However, perhaps the most fundamental component of our approach to impact is the creation and maintenance of a culture within the Department in which the importance we attach to impact is fully understood by all staff and is fully reflected in our processes of staff recruitment, development, promotion and reward. There are many dimensions to this. For example, actual or potential impact is one of the criteria considered at recruitment and the development of impact forms part of the personal development and mentoring plans for Early Career Researchers. We actively promote and celebrate leading examples of high impact research and senior academics are expected to promote the importance of impact within their research groups. In order to ensure that all staff are aware of the College-level mechanisms available to support impact, we work closely with *Imperial Innovations* (a publicly listed company specialising in technology transfer, company incubation and venture funding and providing support in all aspects of patenting and licensing process) and *Imperial College Consultants* (a wholly owned subsidiary of Imperial which handles all aspects of consultancy activity) to arrange briefings on issues such as intellectual property management, start-up formation and consulting practice and to organise drop-in sessions at which staff can discuss tentative ideas for exploitation with nominated contacts. We also meet quarterly with the College's Corporate Partnerships team to identify opportunities to apply new research results through the College's existing corporate relationship network and to explore opportunities to develop new corporate relationships based on emerging capabilities. Impact related activities are strongly incentivised by direct payment from consultancy and via a

well-developed 'rewards to inventors' scheme for the proceeds from licence agreements and staff setting up spin-outs have a significant shareholding in the business at the outset. Impact and public engagement also forms part of our annual staff appraisal process and is a criterion for academic promotion. The specific Departmental mechanisms used to create and promote impact include:

B.1 Engagement and collaboration with industry

- **Strategic partnerships:** We work with key industrial and public sector partners (e.g., Arup, BP, Laing O'Rourke, Transport for London), who, as well as partnering with us in individual grant applications to third party funders and directly supporting research of relevance to their business, play an important wider role in helping us to explore research needs, provide feedback on research visions and advice on pathways to exploitation and impact. Relevant mechanisms include workshops, away days and drop in clinics with senior industry staff.
- **Industrial consortia and networks:** In addition to collaborating with industry in specific project proposals, we also participate in 17 different industry consortia and networks, which bring together, on a long term multi-project basis, industry players to define research needs and collaboratively fund industrially relevant research and propagate results to practice. For example, our Railway and Transport Strategy Centre operates five public transport benchmarking clubs comprising more than 70 operators worldwide, we work with the Willis Research Network, the world's largest partnership between academia and the insurance industry and as a full partner of NANOCEM, a consortium which includes, and is funded by, the world's major cement producers. In the offshore energy sector, we have been invited to participate in 9 prestigious Joint Industry Projects, which enable us to rapidly transfer our fundamental research in a multi-sponsor environment.
- **Joint research centres:** The Department hosts four industrially-funded research centres: the Laing O'Rourke Centre for Systems Engineering and Innovation, the Lloyds Register Foundation Transport Risk Management Centre, the NEC Smart Water Lab and the Cisco Future Cities Centre. These provide direct channels for transmitting research results to industry.
- **Industrially funded posts**: These posts provide an ongoing point of contact between the Department and key industrial collaborators, and serve to stimulate and focus impact related activities. Since 2008, we have had seven posts funded in this way; two chairs fully-funded by industry (Laing O'Rourke and Geotechnical Consulting Group), two Chairs co-funded by RAEng and industry (SITA and BP) and three industrially-funded lectureships.

B.2 Intellectual property and commercialisation

- **Intellectual property generation and start-up companies:** The Department actively encourages its staff to protect and exploit their innovations, working in collaboration with Imperial Innovations (with which Imperial College has a pipeline agreement covering the exploitation of IP). Since 2008, our staff have registered 61 invention disclosures, filed 9 patents and founded or developed a number of start-up companies including Novacem, CELLBEAM, Embody Orthopaedic and UrbEn.
- **Consultancy**: Staff are also encouraged to capitalise on their specialised knowledge and expertise by undertaking external consultancy work through *Imperial College Consultants.* Since 2008, we have undertaken over 230 such projects. Examples include a numerical modelling study undertaken on behalf of the HSE to identify the cause of the Gerrards Cross tunnel collapse and *Nethercot* acting as expert witness for Multiplex in their £280m claim (largest to date in the UK Construction Court) over the design of the Wembley stadium roof.

B.3 Knowledge transfer

- **Exchange of personnel:** The Department encourages staff to take full advantage of the many formal mechanisms of exchange available including KTP/KTS, CASE and Industrial studentships, EPSRC Impact Acceleration awards (at least one of which has led directly to the founding of a start-up) and Marie Curie Awards. We also frequently create mechanisms of exchange within our own industrially funded projects. For example, as part of the operation of our public transport benchmarking consortia, we host an industrial secondee on a 6 monthly rolling basis (a total of 13 secondees from 8 different countries have so far taken part in this scheme) and we host, on an ongoing basis, a NEC Fellow in our Smart Water Lab.
- **PhD students and post doctoral researchers**: Over 75% of our PhD and research projects involve joint working with industry, as sponsor and/or collaborator. The vast majority of our PhD students and post-doctoral researchers are thus directly exposed to industry and in many cases

have formal industrial co-supervision arrangements. For example, in our EPSRC- and industry-supported Industrial Doctorate Centre for the Water Sector, each EngD project has an industrial sponsor and the student spends 75% of their time working with the sponsor company. Since 2008, approximately half of our 210 graduating PhD students and leaving post-doctoral researchers have gone on to work for industry, as a first destination.

- **Training and professional development:** The Department has a long tradition of providing technically focused CPD training, a feature of which is the rapid integration of research results into course content. For example, we have developed, jointly with Shell, a short course based on our innovative work on piling methods [case study 2]. In total, since 2008, we have provided such training to 457 participants, spanning the fields of geotechnics, structures and transport.
- **Innovation and translation funding:** Staff are encouraged to engage fully with the specialised innovation and translation funding mechanisms available at a national level through the TSB and EPSRC and at European level through the EIT's Knowledge Innovation Communities in Climate Change and ICT, both of which have bases in the College. TSB funding has played an important role in the commercialisation of several lines of research including the development of carbon neutral construction products and EIT funding is enabling the commercialisation of EPSRC and NERC funded research in the area of climate hazard modelling.

B.4 Policy and professional influence

- **Government and regulators**: We maintain strong relationships with relevant international, national and local government agencies, through which our research is able to influence technological and policy strategies at a senior level. Since 2008, staff have for example held senior advisory positions within the UK Parliamentary Select Committee system, DECC, Defra, DfT, GLA and TfL as well as the Office of Rail Regulation, Ofgem, Office for Nuclear Regulation and the European Council of Transport Ministers.
- **Codes of practice and standards:** The Department encourages staff to take a leading role in learned societies (e.g., RAEng, RS) professional associations (e.g., ICE, IABSE, CIBSE) and standards organisations (e.g., BSI, API, ISO) including, when appropriate, providing partial relief from other duties. These roles provide a platform through which our research can influence the development of professional practice and special insight into issues such as the evolution of technical standards and codes (which is an important route to impact for much of our work).

B.5 Public engagement and outreach

- **Public engagement:** The Department actively encourages the dissemination of its research to the general public, with the aim of increasing awareness and enthusiasm for the subject and generating public debate. In doing so, we draw on the expertise of the College's Communication and Development team and make use of multiple media channels. For example, *Polak's* work on urban traffic and air quality management was featured on BBC TV and Radio, Sky News and Channel 4, by news agencies in the US and China and by social media commentators.
- **Outreach:** We also participate fully in outreach activities such as the Imperial Festival, an annual 2 day public event featuring exhibits and demonstrations. In our outreach, we pay particular attention to framing communication to engage the young. For example, aspects of *Phillips*' work on biomechanics were presented in a Royal Institution lecture for 14-17 year olds entitled "Why Don't We Fall Over When We Stand Up?" which was also featured on Blue Peter.

C. Strategy and plans

The importance of impact is strongly embedded in the Department's culture and history. However, we recognise that many aspects of the construction sector are changing, and that to maintain our success, we must respond. In brief, the key trends we see are:

- Continuing disruptive technological innovation resulting in the further blurring of traditional disciplinary boundaries, increasing the need for multi-disciplinary collaboration.
- Accelerating globalisation of the construction industry, creating new technical challenges, new industrial players and new routes to impact.
- Greater emphasis on the efficient and sustainable whole life operation of infrastructure systems and services including maintenance and reuse, smart systems and cross-sectoral integration.
- Greater emphasis on new business models for infrastructure and service delivery, with corresponding implications for the assessment of vulnerabilities, risks and resilience.

In developing a strategy that will enable us to build on and extend the successful methods outlined in Section B, we have analysed the history of the impact generation described in our case studies

and other successful examples in order to identify key enablers and barriers. A number of key issues emerge as being of particular importance:

- Understanding current *and emerging* industrial challenges *and opportunities* [case studies 1, 2];
- Maintaining continuity of relationships notwithstanding staff turnover [case study 3];
- Ensuring that both staff and industrial collaborators are aware of the full range of engagement mechanisms and that staff understand industrial funding cycles and;
- Seeking to generate the conditions in which a virtuous *research-to-impact-to-research* cycle is created and maintained [case study 4].

This analysis has informed our future impact strategy, the key elements of which are:

- Undertake horizon scanning exercises, jointly with our strategic industrial partners and key overseas academic collaborators to identify the main technological and institutional trends affecting their business.
- Develop a new Departmental communications strategy, placing key emphasis on impact and on positioning ourselves to benefit from the changing global context.
- Create a senior Departmental post with responsibility for promoting and overseeing translation and impact, reporting to the Departmental Research Committee.
- Extend the very successful industrial club model more generally across the Department and in doing so, explore alternative business models for subscription and arrangements for access to students, researchers and facilities. We are currently piloting this approach with our new Intelligent Infrastructure and Transport Laboratory.

D. Relationship to case studies

There are many examples of significant impact in the Department. We have submitted seven case studies selected on the basis of: (i) at least one and no more than 2, from each Section and (ii) representation of the full range of mechanisms (B.1 to B.5) described in Section B, which individually and in combination, have created the impact.

In case study 1 on design approaches for offshore structure piled foundations, much of the underpinning research was generated through a JIP consortium (B.1) which developed from earlier consultancy work (B.2). Results were propagated to practice via standards bodies (B.4) and elements of the work have been presented in short courses and CPD activities (B.3).

Likewise in case study 2, on extreme wave loading of off-shore structures, the underpinning research was also based on extensive long-term collaboration with strategic industrial partners including through JIP consortia (B.1) and impacts have arisen both through the incorporation of results into international standards (B.4) and follow-up commercial consultancy (B.2).

In case study 3, on public transport benchmarking, five industry clubs (comprising some 70 public operators worldwide) were created (B.1) both to support the underpinning research and to benefit from follow-up targeted application via consultancy (B.2). These impacts have been reinforced by subsequent people-focused knowledge transfer activities (B.3).

In case study 4, on the mitigation of geotechnical risk through the development of advanced numerical tools, impact is based on the application of bespoke software via a strategic partnership (B1) and the provision of consulting services (B.2) and also through professional guidance promulgated by the ICE (B.4). In addition, a senior academic post is directly supported by the strategic partner (B.1) and high profile applications have frequently been used in outreach activities including TV programmes and public lectures (B.5).

In case study 5, on flood risk management, impact is based on the commercialisation of software tools (B.2), consultancy services to industry (B.2) and influence on public policy in the water sector at a national and international level (B.4). Results of the work include the development of a public consultation platform (based on flood risk models) that has been used in local communities, schools and with NGO (B.5).

Case study 6, on methods of appraising the wider economic impacts of transport investments, has its roots in strategic partnership (B.1) and consultancy (B.2) which in turn led to a series of collaborative projects (B.1), the outputs of which formed the basis of professional guidance promulgated by the UK Government (B.4). The work has also attracted media attention in connection with its application to the HS2 project (B.5).

In case study 7, on structural use of stainless steel, the principal impact has been on international design codes (B.4), where our research supported the development of new codes that in turn enable producers, designers and contractors to make most effective use of the material.