

IOAF WG5: Infrastructure interdependencies Summary of current research, 2017

UK collaboration for research in infrastructure and cities (UKCRIC)

<http://www.ukcric.com/>

£138m investment to help ensure national and local infrastructure (such as transport, water, waste, energy and ICT systems) is fit for purpose to support societal development in a changing world.

- Investment in capital equipment and facilities that underpin transformative research
- A national 'observatory' and living laboratories to test current and proposed urban infrastructure systems
- A multi-level modelling and simulation environment to allow 'what if' experiments to be carried out
- A coordination node to integrate activities and industry collaboration

UKCRIC will provide leadership and support for the development and growth of a coordinated and coherent, world class, UK-based national infrastructure research community, spanning at least 14 universities. It will engage government, city and commercial policy makers, investors, citizens and academia in a joint venture that drives innovation and value creation in the exploitation of services provided by national infrastructure. Through central coordination, providing a focal point for knowledge transfer, UKCRIC will support a step-change in the nation's approach to infrastructure investment.

Infrastructure business models (2013–2017)

Infrastructure Business models, valuation and Innovation for local delivery (iBUILD)

Richard Dawson (Newcastle University):

<http://research.ncl.ac.uk/ibuild/researchprogramme/>

iBuild has been exploring the business of interdependence, how we think about infrastructure value, and issues of scale in local delivery (reconciling local to regional to national strategic needs). These methods are being tested on integrative case studies that are co-created with stakeholders, to provide demonstrations of new methods that are intended to provide a step-change in the business of infrastructure delivery in the UK. Funding for iBuild has provided the opportunity to work flexibly with partners in industry, local and national government to address this research challenge of national and international importance.

International Centre for Infrastructure Futures (ICIF)

Brian Collins (UCL): www.icif.ac.uk

Research targeted at catalysing a broader national debate about the future of the UK's infrastructure, and how it might contribute towards a more sustainable economically vibrant and fair

society – new business models at the national to international level; and exploring interdependencies in infrastructure provision. Also included working with iBuild and IUK on the use of performance indicators for infrastructure (report available on both iBuild and ICIF websites)

Infrastructure transitions research consortium (ITRC, 2011–2020)

Jim Hall (University of Oxford): www.itrc.org.uk

Delivered research, models and decision support tools to enable analysis and planning of national infrastructure systems: energy, transport, digital communications, flood protection, water and waste. This research led to a new generation of infrastructure system simulation models and tools to inform the analysis, planning and design of national infrastructure. They have worked with partners in government and industry to examine energy, transport, water, waste and information and communication technologies systems at the national scale (performance, risks and interdependencies, testing strategies for long-term investment and testing ability to withstand extreme weather shock events to inform planning)

Multi-scale Infrastructure Systems Transition Analytics (MISTRAL 2016-2020)

Following up research and outputs from ITRC the aim of MISTRAL is to develop and demonstrate a highly integrated analytics capability to inform strategic infrastructure decision making across scales, from local to global (infrastructure systems are interconnected across scales and prolific technological innovations are occurring now that will exploit or potential threaten that interconnectiveness). Intention is to provide the evidence needed to plan, invest and design modern, sustainable and resilient infrastructure services.

EPSRC Engineering Grand Challenges (2015–2020)

Multi-disciplinary research consortia that can further advance the following Engineering Grand Challenge areas:

Challenge 1: Sustainable engineering solutions to provide water for all

Tailored Water Solutions for Positive Impact (TWENTY 65)

Joby Boxall (University of Sheffield):

<http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010124/1>

The aim is to develop solutions to make the UK's aging water infrastructure more resilient to future needs including climate change, population increase and interdependencies with other infrastructures (food and energy). The proposal is to use 'tailored solutions' (within a systems view) to address these challenges by combining measures to suit specific circumstances and constraints to achieve flexible and adaptive water systems; working synergistically for existing and new infrastructure to achieve transformative impacts.

Challenge 2: Future Cities: engineering approaches that restore the balance between engineered and natural systems

Managing Air for Green Inner Cities

Paul Linden (University of Cambridge):

<http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010221/1>

Focuses on the management of air in cities, aiming to reduce pollution and heat island effect, and to enhance air quality within cities – coupling with natural systems and does not depend solely on mechanical systems. This project will develop a facility consisting of an integrated suite of models and an associated management and decision support system that together allow the city design and its operation to manage the air so that it becomes its own HVAC system, with clean, cool air providing low-energy solutions for health and comfort. This will be achieved by using natural ventilation in buildings to reduce demand for energy and ensuring air pollutants are diluted below levels that cause adverse health effects, coupled with increased albedo to reduce the heat island effect plus green (parks) and blue (water) spaces to provide both cooling and filtration of pollutants. The intention is to include modules for the built environment, public spaces and transportation, and provide estimates of the life-cycle costs and benefits of the various scenarios at the individual building, city block and borough scales. Eventually, it is envisaged that this will also include social and health effects.

Balancing the impact of City Infrastructure Engineering on Natural systems using Robots

Phil Purnell (University of Leeds):

<http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010523/1>

Pioneering scientific research (and research methods) into: autonomous systems for minimally invasive infrastructure sensing, diagnosis and repair; development of advanced robots for deployment in complex live city environments; and the socio-technical intricacy of the robot - human - natural systems interfaces. We will develop pioneering robot designs, technical implementations and socio-economic impact cases linked to specific application requirements, starting with three case-study systems:

- o "Perch and Repair" remote maintenance and modernisation of lighting columns to promote their use as multifunctional platforms for city communication nodes;
- o "Perceive and Patch" Swarms of flying vehicles for autonomous inspection, diagnostics, repair and prevention of highway defects (e.g. potholes);
- o "Fire and forget" hybrid robots designed to operate indefinitely within live utility pipes performing inspection, repair, metering and reporting tasks.

Challenge 3: Engineering across length scales, from atoms to applications

Synthesizing 3D metamaterials for RF, microwave and THz applications (SYMETA)

Yiannis Vardaxoglou (Loughborough University):

<http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010493/1>

To deliver a palette of novel, multi-functional 3D metamaterials (synthetic composite materials with structure that exhibit properties not usually found in natural materials) using emerging additive manufacturing (AM), with the potential to support a single 'design-build' process. Our goal, to

compile a palette of meta-atoms (the basic building blocks of metamaterials) and then to organise these inclusions systematically to give the desired bulk properties, opens up a plethora of new structures. This will not only improve existing applications but inspire new applications by breaking down barriers to innovation. A more rationale and sustainable use of materials will reduce waste, timescales and the cost of the manufacturing processes involved.

Engineering van der Waals heterostructures: from atomic level layer-by-layer assembly to printable innovative devices

Konstantin Novoselov (University of Manchester)

<http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010345/1>

To develop new composite materials which can be assembled and printed in innovative ways. A key target area will be the electronic devices industries allowing much smaller and adaptable sensors to be developed, resulting in a better connected nation through the internet of things.

EPSRC also has supported Network Plus proposals to further develop and scope with a key focus of enhancing the understanding of the complex interdependencies in complex systems which will allow introducing engineering solutions to manage the risk. These Network Plus grants aim to network relevant communities to further scope the challenge (networking, feasibility studies, and for initial research questions and ideas that evolve during the network

Challenge 4: Identifying risk and building resilience into engineered systems

Building resilience into risk management (BRIM)

Guangtao Fu, <http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010329/1>

To better understand the tipping points of systems, particular infrastructure, by modelling complex scenarios (e.g., the 2014 winter floods' impact on the social and transport networks). This will allow for addressing the challenges encompassed in understanding of complex interdependencies, cascade effects and tipping points of engineered systems. The intent is to engage the community to through a series of managed events (e.g., workshops, sandpits, study groups, etc.) to help frame research questions, develop collaborative projects and disseminate outcomes. The focus is on developing novel modelling tools and adaptive frameworks to understand the interdependencies of complex systems and enhance overall system resilience.

Engineering Complexity Resilience Network Plus

Martin Mayfield (University of Sheffield)

<http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N010019/1>

To identify, develop and disseminate new methods to improve the resilience and sustainable long-term performance of complex engineered systems, initially including Cities and National Infrastructure, ICT and Energy Infrastructure and Complex Products (Aerospace: both Jet Engines and Space Launch and Recovery Systems) and later to explore the inclusion of Nuclear Submarines, Power Stations and Battlefield Systems. The intention is to create shared learning from [1] the manner in which naturally complex systems cope with risk and uncertainty to deliver resilience (ecosystems, climate, finance, physiology, etc.) and how such strategies can be adapted for engineering systems; [2] how the tools and concepts of complexity science can contribute towards

developing a greater understanding of risk, uncertainty and resilience, and [3] distilling world-class activity within individual CES domains to provide new insights for the design and management of other engineering systems.

Adaptation in the energy sector (2011–2016)

Delivering energy in a changing climate: Policy Briefing: <http://www.arcc-network.org.uk/delivering-energy-in-a-changing-climate-policy-briefing/>

Adaptation and Resilience in Energy Systems (ARIES)

Gareth Harrison (University of Edinburgh): <http://www.arcc-network.org.uk/project-summaries/aries/#.VlhyML-E1yF>

Exploring through modelling the effect of climate and future conditions on energy demand, supply (including large-scale renewable energy generation) and infrastructure – implications that are caused or exacerbated by climate change

Resilient Electricity Networks (RESNET)

Kevin Anderson University of Manchester): <http://www.arcc-network.org.uk/project-summaries/resnet/#.VlhzNb-E1yE>

Has provided a comprehensive approach to analysing climate-related changes in the reliability of the UK's electricity system, and tools for quantifying the value of adaptations to enhance resilience to climate and socio-technological changes.

Adaptation and Resilience of Coastal Energy Supply (ARCoES)

Andy Plater (University of Liverpool): <http://www.liv.ac.uk/geography-and-planning/research/adaptation-and-resilience-of-coastal-energy-supply/>

Aims to identify the challenges facing the future security of the UK nuclear energy sector and coastal energy supply as a result of a changing. ARCoES is focusing on developing a decision-support tool that will enable sustainable coastal energy. The intention is to identify how coastal power stations, substations and distribution grid can be adapted to future climate change impacts and thus become more resilient.

**NERC Environmental Risks to Infrastructure Innovation Programme
(2014–2020)** <http://www.nerc.ac.uk/innovation/activities/infrastructure/envrisks/>

Looking to manage risks to Britain's infrastructure system from environmental hazards such as extreme weather, flooding and landslips.

Translation projects (Jan 2016 – Jun 2017)

NE/N013034/1	Dr S Dawson	Assessing the risk to the coastal and rural road network in Scotland due to the effects of storms and extreme rainfall events
NE/N012909/1	Professor RJ Nicholls	Coastal landfill and shoreline management: implications for coastal adaptation infrastructure
NE/N012984/1	Dr GA Blackburn	Delivering resilient power, road and rail networks by translating a tree failure risk model for multi-sector applications.
NE/N013026/1	Dr AM Tye	Environmental influences in pipe corrosion (EPiC)
NE/N013042/1	Dr F Cigna	InSAR for geotechnical infrastructure: enabling stakeholders to remotely assess environmental risk and resilience
NE/N013018/1	Dr D Hughes	InSAR for geotechnical infrastructure: enabling stakeholders to remotely assess environmental risk and resilience.
NE/N012917/1	Professor JW Hall	Multi-Hazard Resilience Estimation and Planning for Interdependent National Infrastructure Networks
NE/N013050/1	Dr D Yu	Piloting a real-time surface water flood risk mapping service within ResilienceDirect to support local emergency decision-making
NE/N012992/1	Dr S Wilkinson	Real-time assessments of wind related damage to electricity infrastructure Societal Theme Sustainability
NE/N01300X/1	Dr SM Mudd	Software for quantifying shallow landslide hazards to transportation infrastructure under changing climate and forest management
NE/N012852/1	Professor RJ Dawson	Storm Risk Assessment of Interdependent Infrastructure Networks
NE/N012933/1	Dr JE Chambers	The Proactive Infrastructure Monitoring and Evaluation (PRIME) System: Automating Decision-Support and Enabling Intelligent Earthworks Management
NE/N01295X/1	Dr T Fujiyama	Toolkit to improve resilience of critical ports and dependent national supply chain systems against extreme sea level rise (storm surge) events
NE/N012941/1	Dr D Jaroszweski	Weather-induced single point of failure assessment methodology for railways
NE/N012798/1	Dr P Talling	What threat do turbidity currents and submarine landslides pose to strategic submarine telecommunications cable infrastructure?

Pilot projects (2014-2016)

NE/M008 479/1	Jonathan Chambers	The Proactive Infrastructure Monitoring and Evaluation System: Technology Demonstrator for Remote Monitoring of Transportation Earthworks
NE/M008 851/1	Jim Hall	Flood risk: Building Infrastructure Resilience through better Understanding and Management choices
NE/M008 355/1	Lee Chapman	Dynamic heat risk management to reduce the costs of propagating hot weather delays on the railway network.
NE/M008 614/1	George Blackburn	Quantifying the risks of tree failure to guide proactive management and increase the resilience of electricity distribution networks.
NE/M008 444/1	David Gunn	Wind Turbine Foundation Ultrasonic Spectral Characterisation
NE/M008 878/1	Jeremy Phillips	Volcanic Ash Hazard to UK Nuclear Generating Facilities
	Rachel Dearden	Modelling the geological factors in pipe failure for better infrastructure management
NE/M008 312/1	Christopher Jackson	Assessing the risk of groundwater-induced sewer flooding to inform water and sewerage company investment planning
NE/M008 86X/1	Iain Jonathan Rae	Understanding the effects of space weather on water sector infrastructure
NE/M008 061/1	Andrew Plater	Sandscaping for Mitigating Coastal Flood and Erosion Risk to Energy Infrastructure on Gravel Shorelines
NE/M008 150/1	Taku Fujiyama	Examining Risks of Coastal Flooding to Port Systems
NE/M008 746/1	Thorsten Wagener	Quantification of risks to bridges from erosion and blockage: An elicitation of expert views
NE/M008 320/1	Dr Simon Jude	Vulnerability of proximal infrastructure to sand washout from burst water pipes and leaking sewers
NE/M008 703/1	John Wainwright	Communicating And Visualizing Erosion-associated Risks To Infrastructure
NE/M008 169/1	Ana Mijic	Improved techno-economic evaluation of Blue Green Solutions for managing flood risk to infrastructure
NE/M007 987/1	Dina D'Ayala	Groundwater and Flood Risk in the London Rail Infrastructure Network: Building Resilience into Existing Masonry Infrastructure Assets

NE/M008 487/1	Huapeng Chen	Risk Based Performance Forecast of Flood Defences Affected by Changing Environments
NE/M008 770/1	Dapeng Yu	Evaluating the resilience of critical infrastructure for emergency response to extreme flood events in Leicester
NE/M008 401/1	Christian Wagner	Towards managing risk from climate change through comprehensive, inclusive and resilient UK infrastructure planning
NE/M008 428/1	Douglas Crawford- Brown	Climate science support for robust decision making in wind energy investments and policies
NE/M008 274/1	Nevil Quinn	Co-creating railway flood resilience: applying the science of blue-green-grey infrastructure
NE/M008 517/1	Jason Sadler	A tool to improve prediction of real time environmental risk to UK rail infrastructure

International

Resilient Cities and Infrastructures (RESIN) (2015-2018)

Peter Bosch (TNO, The Netherlands: <http://www.resin-cities.eu>)

Project aimed at standardizing approaches and delivering decision support tools for cities to support the development of climate change adaptation strategies linking critical infrastructure with other elements of cities (built-up spaces and public spaces). The target audiences for these outputs are city administrators, the operators of urban infrastructure networks and related stakeholders. RESIN aims to create a common unifying framework that allows for comparing strategies, results and identification of good practices, including linking the existing approaches for climate change adaptation of cities with disaster risk management of critical infrastructure.

RESIN is delivered by a European consortium of 17 partners from 8 different European countries (includes the University of Manchester with Greater Manchester), experienced in urban resilience and climate change.

EU-CIRCLE, (2015–2016)

Athanasios Sfetsos (National Centre for Scientific Research “Demokritos”, Greece)

<http://www.eu-circle.eu/>

This project is aiming to provide a Pan-European framework for strengthening critical infrastructure resilience to climate change by deriving an innovative framework for supporting the interconnected European Infrastructure’s resilience to climate pressures. The intention is to develop a validated Climate Infrastructure Resilience Platform (assess impacts due to climate hazards, monitoring through new resilience indicators; and support cost-efficient adaptation measures). Coastal flooding case study (surface water, highway, sewer and watercourse flooding) across Torbay.

EU-CIRCLE is delivered by a European consortium of 20 partners from 9 EU countries and from the UK includes the University of Exeter, University of Salford and Torbay Council