Impact report
2022

UKCRIC

UK COLLABORATORIUM
FOR RESEARCH ON
INFRASTRUCTURE & CITIES

CONTENTS

Who we are and what we do

UKCRIC is an integrated research capability with a mission to underpin the renewal, sustainment and improvement of infrastructure and cities in the UK and elsewhere. We were founded by a collaboration of universities who recognised that governments struggle to think about infrastructure in a joined-up way and want to address the impacts that siloed planning can have on current and future infrastructure.

With considerable support from EPSRC, we have funded 13 cross-disciplinary infrastructure laboratory and urban observatory facilities, all of which are now up and running. We are collecting, collating, and curating large volumes of diverse data about current and proposed infrastructure. This data will enable policies, regulation, planning and capital investments and strategic, tactical, and operational decisions to be made on the basis of evidence, analysis and innovation.

We are working to benefit society by encouraging disparate areas of infrastructure to work collaboratively with each other; areas such as water, waste, transport, energy, connectivity, and data. We engage with stakeholders to better understand and address complex infrastructure challenges through collaborative research, and we are always looking for opportunities to help improve situations. UKCRIC does not have a single geographical home. Each academic partner leads a theme and contributes to others, creating a strong collaborative network with multiple centres and connections between them. This spreads the benefits across the UK and into teaching programmes throughout higher education in the UK and beyond.

Introduction

The 2015 budget saw the UK government announce a £138m investment in a collection of research and test facilities at universities across the country to deliver research to ensure that the UK's infrastructure is resilient and responsive to environmental and economic impacts. Matched funding from the host universities themselves to building these facilities brought the total capital investment closer to £250m, delivering a suite of nationally significant research capabilities across the sciences (see page 6). New facilities have come online regularly over the intervening years and this report draws attention to the impact and influence that UKCRIC has had over that period; ranging from the generation of new knowledge and understandings, through technology development, to helping to shape strategies and policies.

The motivations which underpinned the creation of UKCRIC remain urgent in a post-COVID world. The design, management, maintenance and progressive adaptation of infrastructure and city systems all require fresh thinking if we are to minimise the use of materials and energy as well as improve the accessibility and quality of networked services. Urban communities in particular have become hugely dependent on reliable and affordable transport, energy, water, and other services which sustain both lives and livelihoods. UKCRIC facilities are not only generating engineering and technology solutions. They are also exploring how, for example, behavioural change and new financing models can provide the impetus for innovative solutions.

Research impact of course comes in different forms and the following pages clearly illustrate the range of influence and benefits which UKCRIC has delivered to date. Close collaboration with innovators and industry characterises our research portfolio and several facilities have played a prominent role in the nation's response to the COVID pandemic. In addition to the successes achieved by the test facilities, laboratories, simulation platform and urban observatories, the Coordination Node has pursued a vigorous programme of outreach and support for regional and national initiatives as well as nurturing close ties with government bodies.

We would take this opportunity to formally recognise the efforts of those who have been involved in planning and constructing the UKCRIC facilities. Their commitment, enthusiasm, and professionalism has enabled us to bring together a genuinely national research community around a pressing national challenge. The research infrastructure they have fashioned will serve several generations of researchers and their collaborators and this report highlights the early benefits of their endeavours.

Professor William Powrie
UCKRIC Convenor

Julie Alexander
Chair of UKCRIC Management Board,
Places for People

UKCRIC's Resources

We develop and invest in research on infrastructure systems and cities; offering new ways of coping with the grand challenges of the 21st century such as climate and demographic change, resource scarcity and social justice.

UKCRIC is composed of three strands: infrastructure laboratories, Urban Observatories, and the Data & Analytics Facility for National Infrastructure (DAFNI).

The **infrastructure laboratories** are a collection of facilities conducting research on the basic science, technology and engineering that underpins the infrastructure sectors and delivers innovative solutions which meet sustainability and resilience criteria. While some of the laboratories are complete and operational, others are still in the very early build phases.
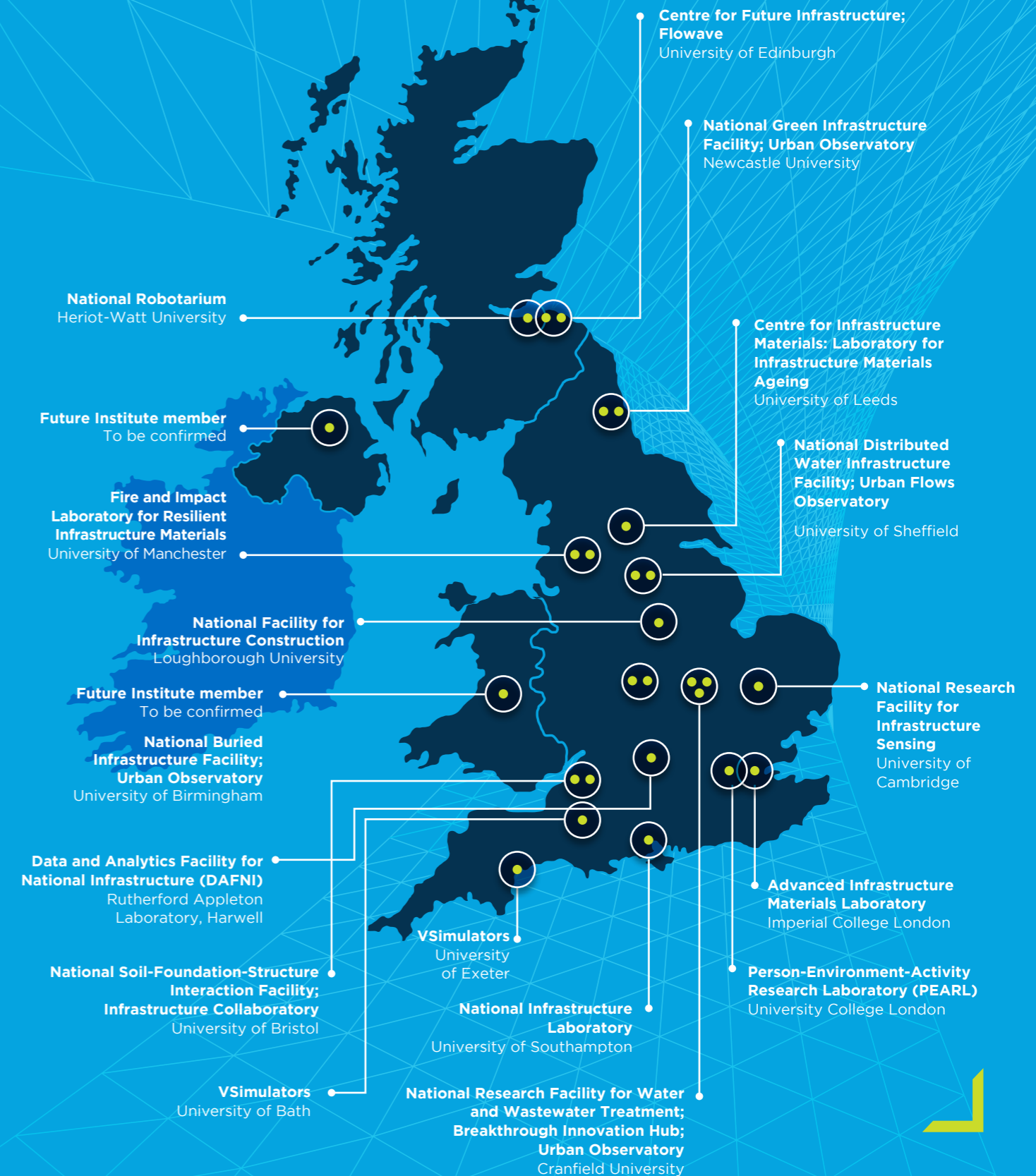
The **Urban Observatories** are a network of UK institutions collecting real-time environmental data – on everything from air quality to noise pollution – to build a picture of each city and the environment it creates. Each of the six observatories is linked to a university and the data collected is openly available. They are based in Newcastle, Bristol, Sheffield, Cranfield, Manchester and Birmingham, with the joint aim of developing a new understanding of cities.
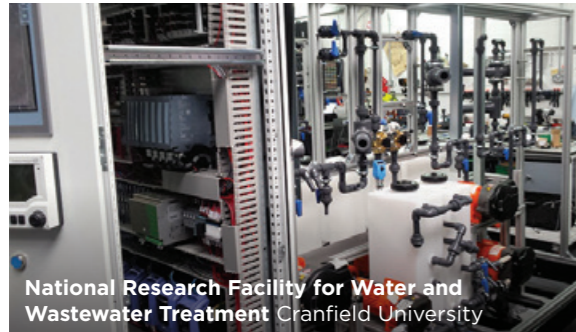
DAFNI, the **Data & Analytics Facility for National Infrastructure**, is the National Platform to satisfy the computational needs in support of data analysis, infrastructure research, and strategic thinking for the UK's long term infrastructure and cities planning and investment needs.

A **Coordination Node** provides governance and coordination on behalf of UKCRIC as a whole to ensure that the collective impact of the investments and research is achieved and communicated across and between sectors and communities.

Full information is available at **www.ukcric.com/facilities.**

Facilities map

Centre for Future Infrastructure; Flowave
University of Edinburgh

National Green Infrastructure Facility; Urban Observatory
Newcastle University

National Robotarium
Heriot-Watt University

Centre for Infrastructure Materials: Laboratory for Infrastructure Materials Ageing
University of Leeds

Future Institute member
To be confirmed

National Distributed Water Infrastructure Facility; Urban Flows Observatory
University of Sheffield

Fire and Impact Laboratory for Resilient Infrastructure Materials
University of Manchester

National Facility for Infrastructure Construction
Loughborough University

National Research Facility for Infrastructure Sensing
University of Cambridge

Future Institute member
To be confirmed

National Buried Infrastructure Facility; Urban Observatory
University of Birmingham

Data and Analytics Facility for National Infrastructure (DAFNI)
Rutherford Appleton Laboratory, Harwell

Advanced Infrastructure Materials Laboratory
Imperial College London

National Soil-Foundation-Structure Interaction Facility; Infrastructure Collaboratory
University of Bristol

VSimulators
University of Exeter

Person-Environment-Activity Research Laboratory (PEARL)
University College London

National Infrastructure Laboratory
University of Southampton

VSimulators
University of Bath

National Research Facility for Water and Wastewater Treatment; Breakthrough Innovation Hub; Urban Observatory
Cranfield University

National Research Facility for Water and Wastewater Treatment Cranfield University
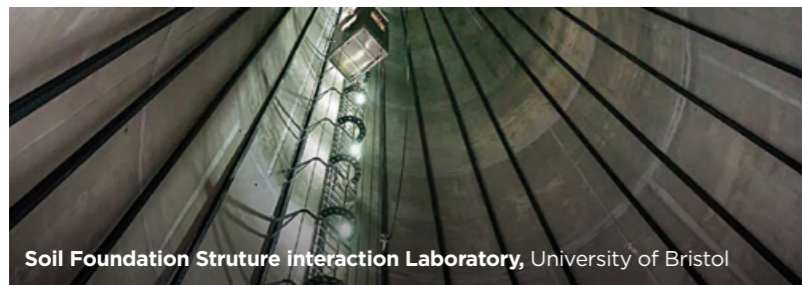

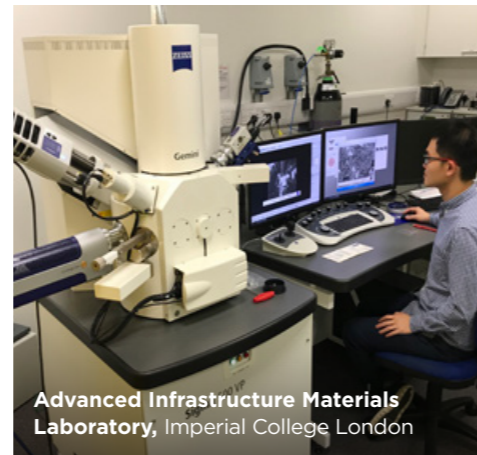**National Buried Infrastructure Facility** University of Birmingham

National Infrastructure Laboratory, University of Southampton

National Research Facility for Infrastructure Sensing, University of Cambridge

Soil Foundation Struture interaction Laboratory, University of Bristol

Advanced Infrastructure Materials Laboratory, Imperial College London

National Centre for Infrastructure Materials, University of Leeds

A world-class suite of infrastructure laboratories

UKCRIC's network of infrastructure laboratories is available for use by researchers and industry alike. The network comprises a series of bespoke, dedicated laboratories for research into the many aspects of infrastructure design and development.

- **The National Distributed Water Infrastructure Facility (NDWIF)** at the **University of Sheffield** provides a unique laboratory for research into the performance of distributed urban water infrastructure.

- **The National Research Facility for Water and Wastewater Treatment** at **Cranfield University** supports research on the inter-dependencies between treatment and distribution processes, condition monitoring and performance of technologies.

- **The National Green Infrastructure Facility** at **Newcastle University** is a 'living laboratory', underpinning research into Sustainable Drainage Systems, Green Infrastructure approaches, and making urban centres more resilient and sustainable for future generations.

- **The National Infrastructure Laboratory (NIL)** at the **University of Southampton** aims to find new and innovative ways to improve the efficiency of maintaining and upgrading existing infrastructure as well as developing more cost-effective ways of designing and constructing new infrastructure.

- **National Centre for Infrastructure Materials: Laboratory for Infrastructure Materials Ageing** at the **University of Leeds** aims to provide a networked suite of facilities to research the ageing and deterioration of a whole suite of infrastructure materials.

- **Advanced Infrastructure Materials Laboratory** at **Imperial College London** has state of the art equipment to undertake fundamental analysis, processing, imaging and testing of infrastructure materials.

- **The Fire and Impact Laboratory for Resilient Infrastructure Materials** at the **University of Manchester** consists of two facilities to enable investigations of the mechanical properties of materials exposed to extreme loading conditions caused by fire, impact and blast.

- **The Person-Environment-Activity Research Laboratory** at **University College London** is based in East London. PEARL is designed to enable fundamental and applied research on the ways in which people interact with infrastructure and cities.

- **The Soil-Foundation-Structure Interaction Laboratory** at the **University of Bristol** aims to integrate structural and geotechnical engineering for soil structure testing.

- **The National Research Facility for Infrastructure Sensing (NRFIS)** at the **University of Cambridge** focuses on the research and application of advanced sensor technologies for infrastructure monitoring and assessment.

- **The National Buried Infrastructure Facility** at the **University of Birmingham** is a 'one of its kind' facility for research, education and training in buried infrastructure-ground interaction.

- **The Centre for Future Infrastructure** at the **University of Edinburgh** will be an intellectual hub for ideas, and a workshop for forging those ideas into practical opportunities and applications, bringing together stakeholders from across the University sector, industry, government and beyond.

For full details on UKCRIC's facilities, visit www.ukcric.com/facilities

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Governance and structure

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Bridget Rosewell, Commissioner, National Infrastructure Commission

Missions and propositions

A framework for delivering the benefits listed above is provided by UKCRIC's four scientific missions, designed to facilitate the delivery of interconnected, integrated and multi-disciplinary research programmes and projects.

UKCRIC's four missions are:

1. INFRASTRUCTURE AND URBAN SYSTEMS FOR ONE PLANET LIVING

Accelerating sustainability through substantial advances in responsible consumption, resource efficiency and sustainable growth and helping the UK meet its carbon targets.

2. OWNERSHIP, GOVERNANCE AND BUSINESS MODELS FOR INFRASTRUCTURE AND URBAN SYSTEMS

Developing innovative models for coping with greater system interdependencies, changing patterns of use and new, disruptive technologies while at the same time delivering social justice and affordability.

3. TRANSFORMATIONAL INFRASTRUCTURE AND URBAN SYSTEMS FOR A CHANGING WORLD

Pioneering methods in infrastructure and urban systems design to meet the challenges of climate change, changing patterns of use, societal expectations and emergent technologies.

4. INFRASTRUCTURE AND URBAN SYSTEMS AS DRIVERS OF EQUITY, INCLUSION AND SOCIAL JUSTICE

Providing the underpinning, transdisciplinary research platforms for forging healthy, happy and productive lives for all through urban design, planning, policy and infrastructure.

Each mission targets two concise propositions to further guide research and other activities.

Immediate research priorities for Mission 1 are Low Carbon Material and Lean Infrastructure; For Mission 2 they are Digital Twins and Smart Infrastructure and Ground resilience – soil, trees and water; For mission 3, Immediate research priorities are Balancing Risks and Responsibilities and Responsiveness to innovation and change; and for Mission 4, they are Accessible, Affordable Urban Mobility and Socially Just Utility Service Provision.

Our Missions bring into focus problem-specific societal challenges that require many different sectors to interact to find a solution. This focus on problems, rather than on sectors, means that solutions can be applied to multiple challenges faced by society.

UKCRIC's Missions, and the way that we use them, continue to evolve through discussion and workshops and in response to shifting societal needs.

2020-2021 in numbers

78
RESEARCH AWARDS
secured by **UKCRIC members**
which utilise the facilities

£220m
RESEARCH FUNDS INVESTED
(public sources)

£40m
RESEARCH FUNDS LEVERAGED
(commercial sources)

88
SMES
involved in **UKCRIC**
projects and activites

406
POSTGRADUATE RESEARCHERS
using or being trained
on **facilities**

149
PEER REVIEWED JOURNAL PUBLICATIONS
acknowledging **UKCRIC**

DAFNI-ROSE

A collaboration to explore the rich interaction between the built, human, and natural environments.

The Data & Analytics Facility for National Infrastructure (DAFNI) - developed thanks to an £8 million capital investment from EPSRC as part of UKCRIC - improves the efficiency, reliability, and sustainability of infrastructure through better sharing and use of data, exploitation of simulation and optimization techniques, and engagement with stakeholders through visualisation. Bringing together disparate data sources, high performance computing, analytics and visualisations into a collaborative platform, it allows research to be carried out more quickly, with larger research scope than otherwise, for models developed by researchers to be built on by others and enables online collaborations. Through DAFNI, researchers can use state-of-the-art modelling, simulation, and visualisation to better inform and develop strategic thinking. Using cutting edge computers, models and simulations can be scaled to greater coverage and resolution. In addition, collaborators can use the platform as a shared workspace, and models from different sectors combined to explore their interactions using data from different sources. DAFNI also provides a legacy, a place where models and data can be used beyond the lifetime of a project and a place where researchers to share their findings in a more user-friendly way.

Officially launched in July 2021 after four years of development, DAFNI received at the same time an additional £1.2 million investment from the Engineering and Physical Sciences Research Council (EPSRC) Resource-Only Strategic

Equipment (ROSE) to provide resources essential to make the platform freely available for researchers and continue its development at the cutting edge of compute and data-intensive computing. This new investment enables DAFNI's operational growth and provide the means to increase usage and capability to support research in EPSRC's Engineering Programme and related fields. It also allows DAFNI to build on its commitment to changing and sustainable infrastructure needs for major projects including the UK Centre for Greening Finance and Investment and the OpenCLIM climate impacts modelling framework. Finally, it marks the beginning of a new phase of training and development for future generations of infrastructure engineers.

The ROSE grant from EPSRC will enable DAFNI to:

- Increase its user base across current and additional universities across the UK
- Increase skills and develop the next generation of infrastructure engineers through Centres for Doctoral Training and other opportunities
- Underpin the development of a digital blueprint of the UK's infrastructure services – e.g.: transport, water, energy, environment, and digital communications
- Encourage multi-disciplinary research across infrastructure sectors and research areas
- Develop further partnerships in government and industry using the DAFNI platform.

Q CASE STUDY

Automating Concrete Construction

**National Research Facility for Infrastructure Sensing (NFRIS),
The University of Cambridge**

The Automating Concrete Construction (ACORN) project is a collaboration across the Universities of Bath, Cambridge and Dundee, and a growing number of industry partners, exploring digital designand production methods to decarbonise construction by rethinking the way that concrete is used in buildings.

The project which aims to drive a new industry culture to improve whole-life sustainability and productivity is exploring the fabrication of concrete shells as a sustainable design alternative for building floors. The concrete shells consist of segments that are produced 'off-site' using automation and robotics which are then transported and assembled on site with the option of repurposing at the end of life of a building's life.

Using robotics to develop an integrated fabrication tool for the concrete shell

segments, the research team based in Cambridge, led by CSIC Investigator Dr John Orr, have successfully constructed a full-sized 4.5 m x 4.5 m 'thin shell' vaulted floor slab demonstration with 60% less embodied carbon than an equivalent flat slab in the UKCRIC funded National Research Facility for Infrastructure Sensing (NRFIS) laboratory.

The robot-manufactured new vaulted style of floor, which uses 75% less concrete than a traditional slab floor is featured in the RIBA Journal in an article presenting the engineering behind the project and ACORN's approach that "could be the secret to unlocking net zero buildings".

With this demonstrator and the release of an end-to-end design and fabrication tool, the research fuses the digital and physical realms and hopes to drive the acceptance of a new culture in the construction industry, to use enough material – and no more.

Visit the project website at **automated.construction**

To use the Robotic Arms at NRFIS, contact **enquiries@nrfis.cam.ac.uk**

CASE STUDY

Origami paper sensors to detect pathogens in wastewater

Advanced Sensor Lab, Cranfield University

Pathogen detection is important for both infectious disease diagnostics and wastewater based health surveillance. The current gold standard method for pathogen detection is the polymerase chain reaction (PCR) process, but it requires centralised facilities and skilled personnel, hence the need for rapid and sensitive platforms to identify and quantify pathogens. As part of the National COVID-19 Wastewater Epidemiology Surveillance Programme (N-WESP) researchers from Cranfield University are developing origami paper sensors (i.e. low cost and deployable paper-based devices) for the detection of pathogens in samples taken from sewerage infrastructure. More recently, a novel paper-based device was developed for rapid and on-site monitoring of SARS-CoV-2 for field-testing in quarantine hotels with the support from UK Health Security Agency. Its use has also been extended to the monitoring of influenza and other infectious diseases to build resilience for future pandemics

The paper device is folded and unfolded in steps to filter the nucleic acids of pathogens from wastewater samples, then a biochemical reaction with preloaded reagents detects whether the nucleic acid of SARS-CoV-2 infection is present, which is visible to the naked eye. The field testing in quarantine hotels and local wastewater treatment plants demonstrated a comparative sensitivity and specificity with the gold-standard polymerase chain reaction (PCR) method, which usually requires well-equipped laboratories and skilled personnel. This device is not only cheap (costing less than £1) but also proved easy to use by non-experts for on-site monitoring, hence having a clear potential for a wide deployment in developed countries or low-and middle-income countries.

Overall, these paper-based lateral flow devices can quantify species-specific pathogens (e.g., SARS-CoV-2, malaria, E.coli, influenza etc.) in wastewater, providing a rapid method for monitoring genetic biomarkers, hence allowing rapid detection of SARS-CoV-2. Being paper-based, these devices are cost-effective, portable and user-friendly while remaining highly selective and sensitive. They also have the potential to be integrated as point-of-care biosensor systems with mobile health for wastewater-based epidemiology for early warning of infectious diseases, screening and diagnosis of potential infectors, and improving health care and public health.

Visit the project website at **nwesp.ceh.ac.uk**

To use the Advanced Sensor Lab, contact **zhugen.yang@cranfield.ac.uk**

CASE STUDY

Achieving zero emissions for social housing

Centre for Future Infrastructure, The University of Edinburgh

Delivering the mass roll out of energy retrofit for existing housing is a major challenge if we are to achieve ambitious net zero carbon targets. With Europe needing to retrofit 11.6 million homes and the UK 850,000 per year, the task ahead is immense and will require all available expertise, working nationally and internationally to forge the pathways, innovations and solutions for net zero buildings. The University of Edinburgh, working with the ZEST Group (Zero Emissions Social housing Task Force) representing Scotland's 32 local authorities and over 100 housing associations, has developed a pathway for social housing and recommendations for the formation of a national Retrofit Technical Steering Group to deliver net zero for 2045 government targets. The Scottish Government published the pathway recommendations in full within their strategic policy framework for housing and Net Zero. This technical pathway from the Centre for Future Infrastructure and School of Engineering at the University of Edinburgh, were unanimously adopted by the social housing providers and published in the ZEST group report in August 2021. Enabling the 'pooling' of key energy expertise from across Scottish Universities (such as via the Energy Technology Partnership, ETP) the steering group will interlink in the delivery of demonstrable technical solutions which will then provide pathways for mass retrofit net zero solutions and innovations. The pathways are focused on six primary housing archetypes which represent 85% (2.2 million) of all homes in Scotland. This provides the key underpinning knowledge for future skills, jobs and industry investment aligned to the Climate Emergency Skills Action Plan (CESAP) established by the Scottish Government, where the University is also contributing in an advisory role.

To get involved in the network of experts co-created by the Centre for Future Infrastructure, please contact **gordon.masterton@ed.ac.uk**

CASE STUDY

The design of HS2 tunnel entrance hoods to prevent sonic booms

Transient Aerodynamic Investigation (TRAIN) Rig facility, The University of Birmingham

When trains enter and travel through tunnels, a number of aerodynamic effects occur, including micro-pressure wave (MPW) emissions into the ambient surroundings at the tunnel portals. Whilst these effects take place in every tunnel, issues can arise when pressure emissions occur at audible frequencies with sufficient amplitude, creating loud, booming noises and rattling windows, doors and shutters at buildings near to the portal. MPWs (sometimes known as sonic booms) must be mitigated against in the design of high-speed railway tunnels, typically through the use of perforated tunnel entrance "hoods". The required performance of tunnel entrance hoods for the new High Speed 2 (HS2) railway line is demanding, due principally to high train speeds. Typical entrance hoods on existing tunnels for train speeds of 250-300 km/h are up to 50 m long. However, as design speeds for new railways increase to 350 km/h or more, the hoods must become significantly longer. This produces emerging issues to achieve optimal performance of the tunnel portal hood without presenting significant additional challenges or costs in the final design and construction.

An investigation through 1D modelling techniques, by engineers at Arup and Dundee Tunnel Research, into novel portal designs for HS2, was validated using the University of Birmingham Transient Aerodynamic Investigation (TRAIN) rig facility. The internationally

significant TRAIN rig is a unique 150m moving model testing facility, specifically designed to examine the aerodynamic properties of ground vehicles. The advantage of such a facility is the ability to correctly model the relative motion between a moving body and the static ground/ infrastructure, whilst also achieving the correct Mach number; in this case vital for modelling the passage of a train through a tunnel. The development of MPWs along the tunnel were monitored by a bespoke pressure monitoring system created through UKCRIC funding. A novel portal configuration with a tapered cross-sectional area tested at the facitlity was shown to provide the best practically achievable results for implementation on the new HS2 route. The experiment results also validated the use of simple 1D analysis methods, a tool already widely used for other purposes in tunnel design, to assess the performance of tunnel portal designs in relation to MPW development. This was a particularly important finding in light of the work required in design and implementation for a new railway line, such as HS2, whereby every tunnel will have different design requirements which will necessitate the configuration of the entrance portal to be 'tuned' to these specific characteristics. The tunnel building works for HS2 began in 2021 and will implement final designs that were supported through the experimental works conducted at the University of Birmingham TRAIN rig facility.

Visit the project website at **birmingham.ac.uk/research/railway/research/train-rig.aspx**

To use the TRAIN rig facility, please contact **d.soper@bham.ac.uk**

CASE STUDY

Micro-robots for buried pipe infrastructure management

National Distributed Water Infrastructure Facility, The University of Sheffield

The replacement value of UK buried water and wastewater pipes, a network with a length of approximately one million kilometres, is between £300 billion and £600 billion. Similar figures can be assigned to the gas supply network. While pipe inspection technologies used by these industries have progressed, the lack of comprehensive knowledge about the condition of buried pipes results in sporadic, unforeseen failures. As a result, there are 1.5 million road excavations per year in the UK causing full or partial road closures at a cost of at least £5.5 billion per year. The EPSRC funded Pipebots research project is developing the science of pervasive sensing for buried pipes. The idea is to use multiple, autonomous micro-robots which can inspect the thousands of kilometres of buried wastewater and clean water pipes using sonic and optical technologies The team designs robots to navigate, communicate, cooperate, and sense in a complicated network of buried pipes with little or no human intervention.

Testing these robots in an environment which replicates closely a real buried pipe network is a key to the success of the project. For this purpose, the UKCRIC National Distributed Water Infrastructure Facility at Sheffield has been adapted to provide access to wastewater and water supply pipes that are realistic in terms of their size and operational conditions. The pipes laid in this facility have been used to experiment with a range of novel robot locomotion, control, sensing, communication and navigation concepts.

Pipebot's research has demonstrated that sonic waves (audio and ultrasound) are an effective way to communicate and sense over hundreds of meters. This new information has been used to design robust sensing and communication solutions, which enable individual robots to measure and classify the conditions in pipes, exchange messages and receive instructions from above ground.

Pipebots is a collaborative project led by the University of Sheffield, working with the Universities of Bristol, Birmingham and Leeds.

Visit the project website at **pipebots.ac.uk**

To use the National Distributed Water Infrastructure Facility facility, please contact **s.f.thornton@sheffield.ac.uk**

CASE STUDY

Virtual reality and vibration testing for lightweight walkways

VSimulators, The University of Exeter

From wood, stone, brick and mortar, and iron and steel, construction materials have significantly evolved over the centuries. Today's constructions use lightweight materials like aluminium, titanium and composites with polymer, metal, and ceramic matrices. These materials provide aesthetically pleasing public structures like footbridges and walkways and corridors between buildings at airports and shopping malls. However, understanding how people interact with lightweight structures and how such structures respond to dynamic loadings from pedestrians is required for future design improvement.

The design for structural vibration induced by human walking is based on the pedestrian footstep loading obtained on rigid surfaces, regardless of the vibrating structures. It is largely unknown how footstep forces would be modified if the surfaces are vibrating, especially when the step frequency is near the natural frequency of pedestrian structures (e.g., footbridges). The state-of-the-art vibration simulation platform, VSimulators, enables the generation of vibration conditions and simulation of visual scenery. Research at

this UKCRIC affiliated facility has been the first to establish how vertical vibration and visual stimuli influence pedestrian walking and resulting dynamic force. Pilot testing studies show that an increasing level of vibration results in a significant increase in step-to-step variability for most parameters of human gait like step frequency. It implies the current design method based on deterministic force models can lead to large errors. Furthermore, extra self-excited forces associated with the vibrating surface were observed, which should be included in future force models. In addition, some notable adjustments can also be found in gait parameters such as heel rise and knee flexion.

This research opens new avenues for the development of performance-based vibration serviceability design that makes better and more sustainable use of construction materials. It will also lead the way in introducing more realistic, multi-sensory, factors in the assessment of serviceability and comfort in civil engineering infrastructure.

vPERFORM is funded under the Marie Skłodowska-Curie actions of the EU Horizon 2020 programme.

Visit the project website at **vsimulators.co.uk**

To use the VSimulators facility, contact **vsimulators@exeter.ac.uk**

CASE STUDY

Tackling air pollution in schools

Urban Observatory Manchester, The University of Manchester

The "Clean Air for Schools" programme was the largest of its kind to be launched in the UK, with 20 participating schools and 6000 students to be included in a 10-month study that started in October 2019 with the aim for schools to improve air quality as well as understand for the first time the impact of air pollution in schools by studying the varying levels of air quality in classrooms and how this affects children's' health. The programme which included a major contribution from UKCRIC's Manchester Urban Observatory, involved the installation of air purifiers in inner city schools to clean indoor air, combined with classroom activities on how communities can cut both indoor and outdoor air pollution. Live monitoring of air quality in schools alongside analysis of how cleaner air affects pupil health, educational attainment and improved knowledge and change behaviour around air quality was studied.

The results of the study clearly demonstrated that maintaining lower outdoor air pollution (NO2) levels could improve a child's ability to learn. The model developed as part of the study showed that maintaining lower air pollution levels in and around school grounds by 20% could enhance the development of a child's working memory by 6.1%; the equivalent of four weeks extra learning time per year. A central outcome of the project was the release of "The Clean Air for Schools Framework", a free online tool that provides teachers, headteachers, parents and local authorities with a bespoke blueprint of actions for tackling air pollution in and around a school. Its database of actions include interventions that can be taken both inside and outside school grounds including implementing 'school streets', improving indoor ventilation, and consolidating deliveries. At a time when schools are urgently reviewing their operations, implementing major changes to the movement of pupils and parents on their premises, the partners called on all schools across the UK & Ireland to adopt and implement the framework, with support from local and national government.

The University of Manchester has partnered with the Philips Foundation and the Global Action Plan (GAP) to launch the 'Clean Air for Schools' programme, a unique collaboration of industry, charity, public sector and academia to clean the air children breathe in schools to a level that meets World Health Organisation standards.

Visit the project website at **urbanobservatory.manchester.ac.uk**

To use the Urban Observatory equipment or data, contact **muo@manchester.ac.uk**

CASE STUDY

Smart monitoring of existing infrastructures

Bristol Infrastructure Collaboratory, The University of Bristol

The UK's bridges are vitally important for the movement of people and freight. However, many bridges are old and carry far more traffic than they were designed to; moreover, climate change and adverse weather event could exacerbate processes of deterioration or aging. It is therefore very important to monitor these structures and understand their response to external loads.

In that context, a UKCRIC team from the University of Bristol is developing a monitoring system for improving management and maintenance of bridges. The first trial of the system was run on the Clifton Suspension Bridge in early 2017. The system uses wireless technology and big-data management techniques to collect information about the bridge and its environment (temperature, wind, stress and strain). The data is then displayed to users – structural engineers or bridge management personnel – via a visual dashboard. Six sensors monitored the bridge for a month, allowing the team to learn about how the bridge responses to e.g. vehicles, pedestrians and weather. Whilst six sensors were needed to monitor the Clifton Suspension Bridge, the technology can scale to measure vibrations and displacements on far larger bridges. The data is being used at the University of Bristol by civil engineers to improve its structural models of the bridge and mathematic engineers to design a system to classify vehicle traffic. Currently, there

are plans to install more sensors and explore in more depth the relationship between the bridge's response and external actions, using a finite element model of the bridge.

Recent work has developed a step-by-step workflow process for developing a Digital Twin for the bridge. It proposes a framework for developing the physical-virtual architecture which underpins a Digital Twin for bridge management. Through the case study of the Clifton Suspension bridge, it provides the foundation for integrating data to optimise asset management, and understand the socio-economic benefits. Ultimately, it contributes to accelerate the digital advancement in Civil Engineering, in particular contributing to the digital transformation of the UK's infrastructure.

This project has also provided an effective way to engage the public in understanding what Digital Engineering can achieve through the development of an 82-string harp tuned in relation to the bridge's natural frequency of 12.9Hz. The unique installation takes the form of a two-course harp resembling the Clifton Suspension Bridge, which is played by two robotic arms, each strumming the strings on different sides of the harp: one represents data collected on the north side of the bridge, the other on the south side.

Visit the project website at
bristol.ac.uk/engineering/research/ukcricbristol/collaboratory

For more information on the Bristol Infrastructure Collaboratory, contact
theo.tryfonas@bristol.ac.uk

Q CASE STUDY

Simulating the energy, transport, digital communications, water and waste networks of the future (NISMOD-DAFNI)

Data and Analytics Facility for National Infrastructure (DAFNI)

DAFNI has been developed so researchers can run models on a common computing system with a central repository of data. Using cutting edge computers, models and simulations can be scaled to greater coverage and resolution. In fact, collaborators are not only able to use the platform as a shared workspace to integrate models and data from different sectors but are also provided with a suite of tools and capability to reduce many of the interoperability issues researchers face when accessing information from disparate sources. One of the models integrated on the DAFNI platform is the National Infrastructure Systems Model (NISMOD) developed by the Infrastructure Transitions Research Consortium (ITCR) to simulate the energy, transport, digital communications, water, and waste networks of the future.

It uses scenarios of population, economics, urban development, climate, and hydrology to explore the ways in which demands for infrastructure services might evolve and be managed in the future. Among the regions benefitting from the utilisation of NISMOD, is the Oxford-Cambridge Arc, one of the UK's fastest growing regions and as such designated by the UK government as a key economic priority. Using a scenario-based

approach, the model specifically evaluated the implications that changes in the region's demographics, economic growth and new transport infrastructures would have on road transport, energy, water supply and green infrastructure services. Focusing on the transport dimension of the NISMOD scenario-based modelling exercise looking at the development of the road and rail networks between Oxford and Cambridge, the study showed that road expansions and the development of an Expressway if initially beneficial in terms of time savings for longer road journeys, would imply higher levels of congestion as population increases. Independently of any scenario tested, it was showed that congestion levels and travel times would increase in the longer term if steps were not taken to manage demand for road transport and transfer passengers onto other modes of transport including rail. In March 2021, the government announced that the Oxford to Cambridge expressway project was cancelled, as extensive analysis and local engagement reveals the expressway would not be cost-effective for the taxpayer and alternative plans to boost transport connectivity in the Arc would be further investigated, alongside delivering the transformational East West Rail.

Visit the project website at **dafni.ac.uk**

To collaborate with DAFNI, contact **info@dafni.ac.uk**

CASE STUDY

Developing efficient design standards and new techniques to support the affordable decarbonisation of transport

National Infrastructure Laboratory, The University of Southampton

In 2017 the Southampton group carried out a fundamental review of design methods for railway overhead line equipment (OLE) foundations. This led to full-scale site trials of piled foundations in a railway embankment at the UKCRIC National Infrastructure Laboratory based at the University for Southampton.

Following characterisation of the ground, novel instrumentation was used to measure deformations and displacements at service loads, at various return period wind loads, through to failure. This allowed the rail industry to adopt a significantly more cost-efficient method for specifying OLE foundations, enabling large savings in material cost, programme time and carbon. It was translated into a new Network Rail (NR) specification, Design and Installation of Overhead Line Foundations, mandatory for use on all NR projects from March 2018. The researchers explained its use in NR staff workshops.

The main beneficiaries are the Department for Transport and NR. UK railway electrification became a sensitive political issue when the Great Western Electrification Project (GWEP) suffered projected cost over-runs of the order of £1.9Bn. The scheme was cut back, other schemes were delayed or axed, and the government sought alternatives such as bi-mode trains that were less effective in terms of reliability, cost and carbon. The new design standard cut scheme costs and reduced embedded and emitted carbon.

The research contributed materially to the decision to restart the suspended electrification programme. The Technical Director of the Railway Industry Association attributes savings of £600M resulting from? the three years of this research. He further comments: 'In terms of opportunity cost, without the research it is unlikely that the GWEP and MML [Midland Main Line] projects would have been completed, at a cost to the economy which I estimate with reference to the MML business case of being in excess of £5.5bn.'

Visit the project website at
southampton.ac.uk/engineering/research/facilities/national-infrastructure-laboratory.page

To use the National Infrastructure Laboratory, contact **david.white@soton.ac.uk**

Strategic framework with HS2

HS2 Ltd has signed a Framework Agreement enabling it to access UKCRIC's world-leading research capabilities, knowledge, and facilities in support of its innovation programme. The Framework deals with research, innovation, training, and skills development. It will enable HS2 to develop ideas and commission research projects quickly with UKCRIC's centres of academic excellence, helping drive new insights and technologies across the broad range of disciplines involved in building affordable, low carbon modern infrastructure. It will also provide a channel for the academic institutions to put forward research findings that could be employed on the project.

Co-ordinated by the Universities of Loughborough (for training and skills development) and Southampton (for research, post-doctoral investigation, and the generation and application of knowledge), the Framework includes procedures for agreeing the scope and price of individual projects. It sets out contract conditions and staff day rates, saving time and costs in setting up each project.

The Framework is designed to enable teams to come together across more than one university and to include industry partners, from HS2's large, first tier JV suppliers to SMEs and social enterprises. Projects currently under discussion or in development include a study into the potential use of PiezoGen technology; a fundamental understanding of developments in low carbon sprayed concrete technology; more general research into low carbon concrete; a Citizen Science biodiversity project; generator emissions monitoring; and improving track performance and track/ground interaction.

All UKCRIC founder universities are eligible to accede to the Framework. At present eight are either in contract or imminently will be, and others are expected to join during 2022. UKCRIC has now been approached by National Highways about joining the Framework as an additional client body, as they see the benefits from access to UKCRIC and significant synergies in working with HS2.

Integration and influence through the UKCRIC Coordination Node

UKCRIC differs from other national research centres in that it does not have a single physical centre. Its geographical and thematic diversity has obvious benefits but also drives a need for a coordinating function to ensure that our collective vision and capabilities can be effectively communicated and delivered. The UKCRIC Coordination Node (CN) has provided this function, delivering a strong collaborative network with multiple centres and connections between them. The CN has overseen delivery of the capital investment programme and is supporting many of the research initiatives which are now being delivered through the various facilities. The strategic research agreement which UKCRIC now has with HS2 is a prime example of how the CN is able to catalyse opportunities for research teams across the consortium.

In addition to providing strategic direction for UKCRIC, expanding its membership, and engaging with complementary international initiatives (through an International Advisory Board) the CN has been responsible for many of the Influence and Outreach initiatives listed on page 12. It has also shaped and supported successful bids for UKRI research funding (such as the Pipebots project) and postgraduate research programmes (such as the WIRe and WaterWiser Centres for Doctoral Training). Sandpit style development workshops for early career researchers have brought together interdisciplinary communities and catalysed funding bids with some proposals being seed-funded by UKCRIC itself.

Through engagement with a range of bodies, the UKCRIC CN informs national debates and policy formulation on pressing issues such as infrastructure futures, carbon neutrality, resilient regional development, and climate adaptation. This is achieved through responses to calls for evidence or consultation processes with recent examples being the National Infrastructure Commission's consultation on Improving Competitiveness and the Department for Business, Energy & Industrial Strategy's consultation on their R&D Roadmap.

The CN is essential to the successful realisation of the scientific and societal benefits which the UKCRIC investments are intended to deliver. It provides a convening function for the co-development of research agendas and projects, and both fosters and supports trans-disciplinary working across UKCRIC's research portfolio. With a suite of test, monitoring, and experimental facilities that are open to a wide variety of infrastructure sectors and academic disciplines, the CN serves an important integrative function; cultivating collaboration and focusing advocacy.

Collaboration highlights

NET ZERO COALITION

In 2019, UKCRIC joined Mott Macdonald, Anglian Water, Skanska, Transport for London, and the UK Green Building Council to become a founding member of the Net Zero Coalition. The coalition aims to identify and address key transformational challenges faced by the infrastructure industry, to support realisation of UK Net Zero targets. The coalition released reports on Building a Net-Zero Economy (2019), The Path to Zero Carbon Heat (2020), Is our Carbon Wallet Empty? (2021) and A place-based approach to net-zero (2021).

C-DICE

The Centre for Postdoctoral Development in Infrastructure, Cities and Energy (C-DICE) brings together 18 higher education institutions from the members of the Energy Research Accelerator (ERA) and UKCRIC. It offers a unique collaboration, an inclusive space to harness significant UKRI, university and industry investment in facilities and doctoral training, by bringing together the intellectual capital of hundreds of postdoctoral researchers and early career sector professionals. The Centre offers a wide ranging suite of fellowship, placement, research development, and training opportunities.

THE LIVERY CLIMATE ACTION GROUP

The Livery Climate Action Group was formed in October 2021 to assist City of London Livery Companies and Guilds to manage their impact on climate change and the environment by reducing carbon emissions and making responsible use of resources.

THE DIGITAL FRAMEWORK TASK GROUP

This group is part of the National Digital Twin programme run by the Centre for Digital Built Britain to coordinate the adoption of a digital framework for infrastructure data.

THE NATIONAL PREPAREDNESS COMMISSION

The commission aims is to promote better preparedness for a major crisis or incident. One of the outputs of this collaboration is the release in October 2021 of a discussion paper on Strategic Issues setting out the global context and key strategic issues for the Commission's future work.

THE CARBON REDUCTION CODE FOR THE BUILT ENVIRONMENT

Developed by the Achieving Net Zero Cross-Industry Working Group and convened by the Cambridge Centre for Smart Infrastructure and Construction (CSIC), the Carbon Reduction Code for the Built Environment aims to facilitate action and collaboration by relevant parties towards reducing carbon emissions (CO2eq) related to design, construction, maintenance, operation and decommissioning of built assets.

Exploiting UKCRIC's potential

The projects showcased in this report offer inspiring examples of how science and engineering can be harnessed for the benefit of our communities. They also demonstrate the deeply collaborative nature of our work with partnerships that bring together industry and academia as well as groups of universities to tackle major research challenges.

UKCRIC is delivering the kind of research and innovation that will be vital if we are to transition to a more sustainable and resilient society. New insights into structural dynamics, material properties and behaviours, buried infrastructure-ground interactions, water treatment and distribution, and the flows of energy, resources and people through urban environments are providing a foundation for novel approaches to infrastructure design and management. In doing so UKCRIC is playing an important role in supporting government initiatives on 'Build Back Better', the green recovery, and achievement of net zero carbon emissions.

In doing so we are, of course, part of a wider ecosystem of research and innovation capabilities. In this context the UKCRIC facilities are a national resource; open to all who wish to make use of them (see https://www.ukcric.com/facilities/ for details). Whether you are from the university, commercial, or voluntary sector, we are keen to hear about your research needs and aspirations and facilitate access to appropriate equipment, platforms, and skill sets. The propositions listed earlier in this document (see page 12) reflect our own take on priority topics but are not intended to constrain what the facilities can be used for.

UKCRIC offers a multi-site and multi-functional opportunity space for scientists, researchers, and practitioners to collaborate, create, learn, and discover. Its unique facilities coupled with leading edge scientists and a collaborative approach to knowledge generation provides a distinctive and readily accessible platform for problem solving. The original vision for UKCRIC was impact driven and it is already making a difference.

Enquiries about use of the UKCRIC facilities or collaboration can be made via **hello@ukcric.com**

Image credit: Belinda Cave (Pixabay)

Appendix

Appendix 1 - Selection of ongoing projects being delivered through the UKCRIC facilities

UKCRIC facility	Research organisation	Project title	Duration (years)	End date	Funding source
The National Distributed Water Facility, The Integrated Civil and Infrastructure Research Centre (ICAIR)	The University of Sheffield	Distributed Fibre-optic Cable Sensing for Buried Pipe Infrastructure (Pipebots)	3	Oct 22	UKRI / EPSRC
		Pervasive Sensing for Buried Pipes	5	Feb 24	UKRI
UKCRIC Soil-Foundation-Structure Interaction Laboratory (SOFSI)	The University of Bristol	Plexus lus	1	Mar 22	UKCRIC
		Green loop	3	Apr 25	Horizon Europe
The Advanced Infrastructure Materials Laboratory	Imperial College London	Low carbon M-S-H cements manufactured from olivine	4	Sept 22	EPSRC CDT
		Transforming waste plastics into viable building materials in developing countries	4	Oct 22	Zoomlion Ghana ltd
		Carbonation and corrosion in concrete	4	2025	Innovandi GCCA
		Characterisation of hydrothermally aged cements	4	2025	NDA/RWM
		Transformative Science and Engineering for Nuclear Decommissioning	5	Sept 23	EPSRC / Nuclear Consortia
		MX3D Bridge project	5	Feb 23	The Alan Turing Institute
		Interdisciplinary Circular Economy Centre for Mineral-based Construction Materials	3	Dec 24	EPSRC
		Industrial Residue Activation for Sustainable Cement Production (ReActiv)	4	Oct 24	EU Horizon 2020
		Developing the next generation of hydrogen assisted fracture models	4	May 23	EPSRC DTP CASE Award & TWI
		Next Generation Electro-Chemo-Mechanical Models for Hydrogen Embrittlement (NEXTGEM), EPSRC,	3	April 24	EPSRC
		Nanovoids for Developing New Hydrogen-resistant Materials (NanoHMAT)	2	Dec 22	EPSRC
		Next Generation FFT-based Multi-Physics Models to predict the durability of metallic structures	3	Aug 23	Marie Sklodowska-Curie Actions

UKCRIC facility	Research organisation	Project title	Duration (years)	End date	Funding source
The National Research Facility for Water and Wastewater Treatment	Cranfield University	Water-WISER - EPSRC Centre for Doctoral Training in Water and Waste Infrastructure Systems Engineered for Resilience	8	Sept 27	UKRI / EPSRC
		WiRe - EPSRC Centre for Doctoral Training in Water Infrastructure and Resilience	8	Sept 27	EPSRC
The Advanced Sensor Laboratory	Cranfield University	Low-cost paper-based biosensors for rapid monitoring of water quality in LMICs	4	2024	UK Royal Academy of Engineering under Frontier Follow-on
		Automation for wastewater surveillance	1	2022	UK Home Office /ACE
		Smart living grand challenge	1	2022	Research England / Cranfield University
		Diagnostic evaluation of removal protozoan oocysts within slow sand filters	3	2023	UKRI EPSRC DTP
The Point of use Laboratory	Cranfield University	UV-LED/Chlorine as an advanced oxidation process to removed persistent organic contaminants.	3	2024	EPSRC, Typhon Treatment Systems, Anglian Water.
		Understanding water biostability	1	Sep 22	Anglian Water
The Test and Control Sewer Loops Rig	Cranfield University	Managing sewer fat, oil and grease (FOG) deposits with the bio-additive products.	4	2022	Severn Trent Water / EPSRC
Cranfield Urban Observatory	Cranfield University	Air pollution solutions for vulnerable groups research network (CLeanAir4V)	3	2023	NERC
		The health and equity impacts of climate change mitigation measures on indoor and outdoor air pollution exposure (HEICCAAM)	3	2023	NERC
The National Green Infrastructure Facility (Newcastle)	The University of Newcastle	ACHILLES – Assessment, Costing and Enhancement of long lIfe, Long Linear assEtS	4	Dec 22	EPSRC
		PYRAMID: Platform for dYnamic, hyper-resolution, near-real time flood Risk AssessMent Integrating repurposed and novel Data sources	2	Oct 22	NERC
		Water Security and Sustainable Development Hub		Feb 24	UKRI / GCRF
The National Centre for Infrastructure Materials	The University of Leeds	CMMI-EPSRC RENACEM: Response to CO2 exposure of concrete with natural supplementary cementitious materials	3	Jul 22	EPSRC

UKCRIC facility	Research organisation	Project title	Duration (years)	End date	Funding source
The National Centre for Infrastructure Materials	The University of Leeds	International Exchanges Cost Share 2019 China NSFC	2	Mar 22	The Royal Society
		UKRI Interdisciplinary Circular Economy Centre For Mineral-based Construction Materials	3	Dec 24	EPSRC
		UKRI Trustworthy Autonomous Systems Node in Verifiability	4	Apr 24	EPSRC
The National Research Facility for Infrastructure Sensing	The University of Cambridge	GEOLAB	4	Jan 25	EU Horizon 2020
		Performance of polymer support fluids for piling and diaphragm walls	4	Sept 22	EPSRC
		ACORN	3	Mar 22	UKRI
The National Buried Infrastructure Facility	The University of Birmingham	Pervasive Sensing for Buried Pipes	5	Feb 24	EPSRC
		UK National Quantum Technology Hub in Sensing and Timing	5	Nov 24	EPSRC
Transient Aerodynamic Investigation (TRAIN) Rig facility (Derby)	The University of Birmingham	The aerodynamic interaction of platooning and overtaking vehicles	2	June 2023	EPSRC
		CLEAR2: Air Quality on Trains-HVAC and Exhaust Interactions Study (Ref: T1234)	1	Feb 2002	RSSB
Manchester Urban Observatory	The University of Manchester	Data Integration Model for Estimating Exposure funded by Meteorological Office	2	2022	Meteorological Office UK
		Monitoring Impacts of Sustainable Travel Interventions, Manchester City Council	1	2022	Manchester City Council
		The Internet of Things (IoT), as a tool for decision support in environmental system	4	2025	Bolashak Group
		The Relationship Between Health and Social Mobility, Social Cohesion and Social Capital	2	2022	Health Foundation
		Using big data to understand wellbeing and public spaces	4	2024	Economic and Social Research Council
DAFNI	The University of Southampton	Open Climate Impacts modelling framework (OpenCLIM)	2	2022	NERC
	The University of Newcastle	Centre for Digital Citizens – Next Stage Digital Economy Centre	2	2025	EPSRC
		PYRAMID: Platform for dYnamic, hyper-resolution, near-real time flood Risk AssessMent Integrating repurposed and novel Data sources	2	2022	NERC
	The University of Leeds	TRACK: Transport Risk Assessment for COVID Knowledge	2	2022	EPSRC

UKCRIC facility	Research organisation	Project title	Duration (years)	End date	Funding source
V-Simulator	The University of Exeter	Developing advanced vibration performance assessment for new generation of lightweight pedestrian structures using motion platform and virtual reality environments (vPERFORM).	2	2022	EU Marie Curie Fellowship.
		Dynamics of human-structure interaction	4	2023	EPSRC
		How active humans perceive and interact with vibrating structures.	4	2023	EPSRC

Appendix 2- Responses to consultations by the UKCRIC Coordination Node

Consultation title	Date	Consultation lead on behalf of the UKCRIC Coordination Node
EPSRC consultation for Engineering Healthier Cities.	September 2020	Prof. Chris Rogers, University of Birmingham
The British Standards Institute (BSI) PAS 186 National Consultation, Smart cities – Supplying data products and services for smart communities – Code of practice	December 2020	Dr. Tom Dolan, University College London
National Infrastructure Commission (NIC) - Resilience Consultation (p261-266)	September 2019	Dr. Tom Dolan, University College London
Government consultation - UK Research and Development (R&D) Roadmap	August 2020	Dr. Tom Dolan, University College London
National Infrastructure Commission Discussion Paper on Supporting Sustainable Economic Growth	March 2021	Dr. Tom Dolan, University College London
National Infrastructure Commission (NIC) Discussion Paper on Improving Competitiveness	October 2020	Dr. Tom Dolan, University College London With input from: Prof. Paul Jeffrey, Cranfield University Dr Joanne Leach, University of Birmingham Prof. Brian Collins, University College London Prof. John Beckford, Consulting

Additional projects on which UKCRIC has been consulted

- Infrastructure Pathways - **infrastructure-pathways.org/overview**
- UK: National Engineering Policy Centre and Royal Academy of Engineering Kwami, C. (2020). Sustainable Living Places: A systems perspective on planning, housing and infrastructure - **raeng.org.uk/publications/reports/sustainable-living-places-(1)**
- National Infrastructure Commission Resilience Study
- National Infrastructure Commission Natural Capital Study (we held a workshop with them, shared input into report were asked to review the final report)
- Southwest Infrastructure Partnership (SWIP) Integrating Net Zero Route Map (2021). UK: South West Infrastructure Partnership (SWIP) - **southwestinfrastructurepartnership.co.uk**

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