CSIC Cambridge Centre for
Smart Infrastructure & Construction

Annual Review 2016

Implementing innovation

UNIVERSITY OF CAMBRIDGE

Innovation

when ideas generate economic value in the form of new and improved products and services

Smart infrastructure

when physical and digital infrastructure converge

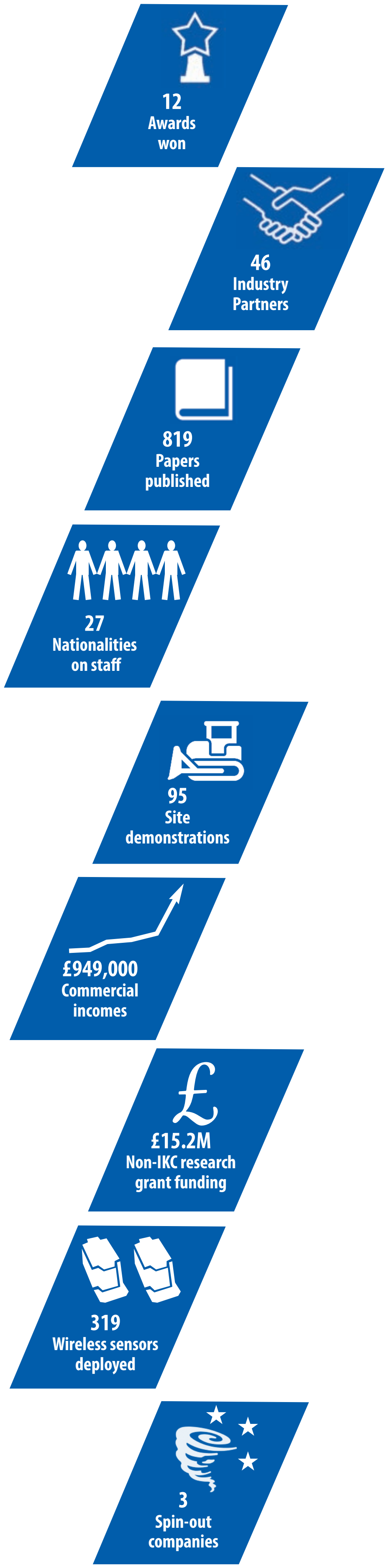
Optical fibre fusion splicer being operated in the CSIC lab

Contents

Steering Group

International Advisory Group

Cover photograph of CSIC technician Jason Shardelow installing monitoring on a masonry arch by Dr Sinan Açıkgöz



Cumulative figures from 2011 to April 2016

Executive updates

"The UK must continue to be world-leading in engineering innovation. We cannot afford to slip behind. The capability and capacity to innovate is the key to prosperity in the 21st century."

CSIC Research Associates Niamh Gibbons and Liam Butler

Innovation brings opportunities to smart infrastructure

Professor Lord Mair
Head of CSIC
Sir Kirby Laing Professor of Civil Engineering

The Cambridge Centre for Smart Infrastructure and Construction (CSIC) is transforming the future of infrastructure and construction through smarter information enabling better decision-making. Developing and deploying emerging technologies from world-leading research at the University of Cambridge, CSIC collaborates with more than 40 Industry Partners across a wide range of projects to implement innovation in this crucial sector of the economy.

There has already been substantial impact of CSIC's activities in terms of the wide variety of new tools and technologies, including fibre optic strain measurement, UtterBerry ultra-low power wireless sensor motes, vibration energy harvesting devices, the CSattAR photogrammetric monitoring system, computer vision and data management tools. These can be used in combination to offer a whole-life approach to infrastructure - from design to construction, operation, maintenance and decommissioning - ensuring that infrastructure assets provide best value throughout their life. These innovations have been tested and proved on some of the largest civil engineering projects in the UK, including Crossrail, National Grid London Power Tunnels, London Underground station upgrades, and the Staffordshire Alliance West Coast Mainline railway bridges for Network Rail.

Jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and Innovate UK, CSIC is a hub for the infrastructure and construction industry, bringing together leading academics and industrialists, developing a faster route for innovation adoption, providing an ecosystem for building confidence in new innovations and enabling their timely implementation and exploitation.

Change happens when academia and industry drive innovation. The digital revolution has opened the door for smarter infrastructure. We have the technology to understand exactly how a building, a tunnel, a bridge, or a railway line is actually performing during construction and throughout its lifetime. This will lead to improved asset management, as operators will know how to prioritise what needs to be replaced and when, and how to manage it all much more efficiently. Smart infrastructure also enables more economic design, reduced costs and greater efficiencies, both in the capital cost of construction and in the subsequent operating costs, delivering benefits to multiple stakeholders.

Upcoming major infrastructure projects, including Thames Tideway and HS2, are adopting innovation as a driving force, but there needs to be wider industry take-up for change to be truly transformative.

Even in these stringent times, investment in new infrastructure, such as Crossrail, and money spent on research into new technology, is money very well spent. It is vital for our economy to invest in the future; the economy of this country depends on having modern, fit-for-purpose infrastructure.

Engineering impacts all our lives in so many ways. It accounts for at least 20% of gross value added (GVA) for the UK economy, and some estimates are significantly higher. Building a stronger economy relies on engineering innovation and also requires addressing the problem of the growing engineering skills crisis. Investment needs to be underpinned by Government-funded university research in science and engineering. I welcome the Government's National Infrastructure Delivery Plan, which includes a £138 million investment in United Kingdom Collaboratorium for Research in Infrastructure and Cities – a consortium of leading UK universities doing research in infrastructure and cities, of which Cambridge is a founding member. This investment will result in substantial benefits for industry. Implementing the latest innovations from such research in its construction and operation will be highly beneficial for projects such as HS2, as it will be for other large infrastructure projects.

The world is changing very rapidly and it is therefore vital for the economy to have a high level of UK research and development (R&D) investment in science and engineering – the UK must continue to be world-leading in engineering innovation. We cannot afford to slip behind.

The capability and capacity to innovate is the key to prosperity in the 21st century. Innovate UK, the UK's innovation agency and one of CSIC's funders, funds, supports and connects innovative businesses to accelerate sustainable economic growth. Innovate UK's schemes show substantial leverage, with an average of £6 returned to the economy in GVA for every £1 invested.

As the case studies in this *Annual Review* show, CSIC's ability to demonstrate the value of smart infrastructure to the construction industry, and help facilitate wider industry adoption of innovative technologies and tools, is already proving to be of great advantage to the UK engineering base.

Innovation will secure the UK's future growth. CSIC will continue to focus on cutting edge R&D and integrate these innovations to benefit industry and support the UK to be leading in the design, development and delivery of smart infrastructure.

CSIC Research Associate Paul Fidler operating
a 3D Laser Scanner in The James Dyson
Building at the University of Cambridge

About CSIC

Transforming the future of infrastructure through smarter information

CSIC brings together world-class engineering research, academic excellence and commercial industry with the key aim of transforming infrastructure and achieving sustainability in construction through smart information.

Innovation is crucial to delivering smarter infrastructure for the future. Collaboration and knowledge sharing are vital to this goal, and CSIC currently works with 41 Industry Partners, including Crossrail, Arup, Toshiba and CERN. CSIC also works with industry bodies including the Construction Leadership Council (CLC) and the Institution of Civil Engineers (ICE) to unite the industry in smart innovation.

CSIC engages with its Industry Partners to develop commercial technologies, tools for data analysis, visualisation and management, best practice guidance codes and specifications for scale-up and standardisation. By working directly with Industry Partners, CSIC enables the latest innovations to be adopted quickly into the supply chain, helping to grow the market for commercially viable smart infrastructure products and services.

These are implemented by industry through a range of activities including deployment on live sites, industry training, developing supply chain networks, input to standards and dissemination.

By collaborating with Industry Partners CSIC is able to accelerate the process of bringing technologies to commercial readiness. We aim to deliver value to industry by improving margins, reducing costs, enhancing returns and extending the productive life of assets.

There are substantial UK and international markets for exploitation of these new technologies and tools by the construction and infrastructure industry – particularly for contractors, consultants, specialist instrumentation companies and owners of infrastructure. Working closely with industry enables CSIC to develop technologies and tools that respond effectively to real industry challenges. CSIC is actively involved with many of the country's largest and most challenging engineering projects including Crossrail, National Grid Power Tunnels and the Northern Line Extension, working to innovate the future of the infrastructure industry.

Strategically CSIC focuses on four spatial scales of activity in order to integrate developments across these areas and deliver holistic and cohesive solutions to industry challenges: Cities and infrastructure systems; Asset management; Data analysis and interpretation; and Sensors and data collection.

The impact of CSIC's strategic activities and industry collaborations, combined with wide application of its tools and technologies, will enable major transformations in the approaches to the design, construction and use of complex infrastructure.

This impact will lead to step changes in greater efficiency in design and performance, a low-carbon society, sustainable urban planning and management, and improved health and productivity.

CSIC's work will help the UK become a world leader in the fields of sensing technology, asset management and smart city development.

Working with industry is the key to our success and we always welcome approaches from industry professionals seeking to collaborate.

Get in touch with CSIC
Email: csic-admin@eng.cam.ac.uk
Tel: +44 (0)1223 746 976
www.centreforsmartinfrastructure.com
@CSIC-IKC

Working with industry to implement innovation

"Now is the time for the whole construction and infrastructure industry to get behind the innovation platforms and work together to establish the UK as the world leader, and to realise the significant benefits that can be won for the industry and all its customers."

CSIC PhD Students Chang Ye Gue, Mehdi Alhaddad and Matthew Wilcock on site at Crossrail

John Pelton, MBE
Strategic Projects Director, Crossrail
CH2M Programme Partner MD

The UK's construction industry, despite initiatives such as the Egan and Latham reviews, is still characterised by a multitude of different companies operating at different stages of infrastructure life cycles and the value chain. There are many highly capable engineers and other professionals working in the industry yet investment in innovation and R&D, at around 0.05% of revenue, remains at least two orders of magnitude lower than the manufacturing sector. The Construction 2025 strategy throws down the gauntlet to the industry: this situation cannot be allowed to go on if the UK is to remain competitive.

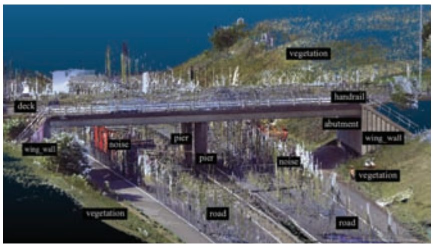
But all is not lost. From a few glimmers on Terminal 5 and elsewhere, the major programmes are now beginning to lead the way in developing a systematic approach to innovation in construction. Crossrail launched its highly successful Innovate18 innovation programme in 2013 and has attracted 10% of the entire programme work force to engage in delivering over 1,000 innovations and a range of benefits including tens of millions of pounds in time and cost savings. Anglian Water has taken a different approach through setting a challenging 50% reduction target in the embodied carbon of new assets. The Staffordshire Alliance has set new standards for alliancing and driven innovation into the supply chain resulting in, for example, some of the first remotely monitored bridges in the UK. The old myths that innovations were too immature to be fielded; that innovation wastes money; that the process causes disruption; that it is a white elephant that no-one will want to engage with have all been shattered. Even intellectual property barriers have fallen to the 'pinched with pride' mantra for sharing, with Crossrail's Innovate18 innovation programme providing the engine room for exchanging and building on new ideas as they are developed and introduced across the project.

CSIC has been at the heart of this revolution from the start. Innovations arising from its research teams and spin-off start-ups are featured across the Crossrail programme, enabled through Innovate18, and others are actively taking forward the sensor and data processing technologies. Fibre Bragg gratings, MEMS and UtterBerry are becoming common terms on major programmes as the manifest benefits of the early stages of smart infrastructure start to be realised and the full power of industry working in collaboration with academia becomes more evident than ever.

Innovate18 is now spreading its wings into an industry-wide platform to enable sharing and further innovation across the industry. Increasingly the industry is developing a common view on priorities for investment allowing the UK to start taking the lead in a global market. Through demonstrating the potential on UK infrastructure projects, we have been able to both showcase the technologies but also the skills needed to apply them and integrate them into the complexity of modern smart infrastructure solutions. The opportunity is there now: other major programmes are picking up the baton, specifically Thames Tideway and HS2; academia, such as CSIC, and the Innovate UK Catapult community are also rising to the challenge. Now is the time for the whole infrastructure and construction industry to get behind the innovation platforms and work together to establish the UK as the world leader, and to realise the significant benefits that can be won for the industry and all its customers.

News

Deep learning: key to the future of BIM?



Semi-supervised semantic segmentation and depth estimation from videos of concrete bridges

Creating a BIM (Building Information Modelling) model for an existing asset of any type (buildings, bridges or industrial plants) requires a lengthy process of data collection and processing, involving extensive manual intervention and expensive equipment – the costs outweigh the benefits. CSIC Researcher Dr Viorica Pătrăucean has developed a semi-supervised machine learning architecture to help create BIM models from videos obtained with consumer cameras, reducing supervision effort and cost.

The potential of this method is vast, but the transition from prototype to deployment is strictly limited by the availability of training data – videos of bridges and laser-scanning point clouds to facilitate the data labelling. CSIC will be collaborating with national agencies involved in the infrastructure sector and professional surveying companies to gather the information needed to develop this exciting method.

Harnessing heat from London Underground for district heating

Old and deep Underground train lines suffer from overheating problems, particularly during summer. Modelling by CSIC's Adnan Mortada, Dr Ruchi Choudhary, and Prof Kenichi Soga has demonstrated how geothermal boreholes offer a potential energy efficient cooling solution compared to energy intensive conventional cooling. The waste heat of the subway tunnel can be harnessed to provide heating to residential and commercial blocks above the tunnels. Simulations have shown that retrofitting the Central Line with boreholes will result in a 5ºC and 4.5ºC temperature drop in tunnels and platforms respectively during summer and that a single 100m borehole in the Central Line can provide an equivalent of 1.25 times the UK household annual heat demand and an addition of 3250KWh of cooling.

Battery free sensors a step closer

Yu Jia installing the energy harvester at the Forth Road Bridge

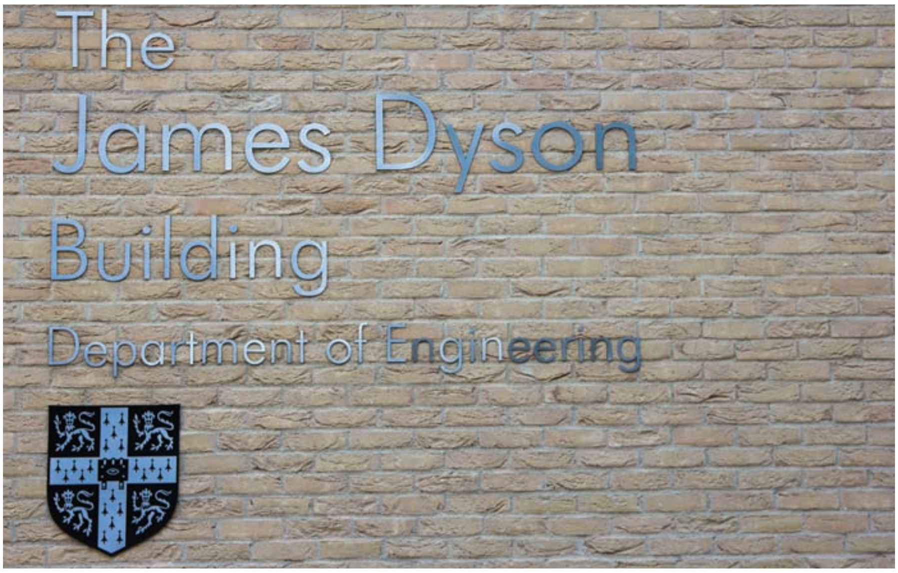
A CSIC-developed, patented, low-cost, wireless, battery-free energy harvesting device was tested on the Forth Road Bridge in Scotland where, powered only by traffic and wind induced bridge vibrations, it was demonstrated successfully powering a wireless mote which transmitted data to a receiver mote. "Our macro-Vibration Energy Harvesting (VEH) prototype has demonstrated the potential to generate substantially more power than devices based on more conventional approaches to vibration energy harvesting and could provide a convenient, self-sustaining on-board power solution to complement emerging wireless sensor technologies – the smarter power backbone to the ever-growing wireless infrastructure," says Dr Yu Jia. A spin-out company, 8Power, founded by CSIC academics Dr Ashwin Seshia, Prof Kenichi Soga, Dr Yu Jia and Dr Jize Yan, with the IP Group and Cambridge Enterprise, is being formed to commercialise the technology. A paper detailing CSIC's macro-VEH prototype and field trial, titled *A vibration powered wireless mote on the Forth Road Bridge*, has been published in the Journal of Physics: Conference Series.

The digital revolution is coming – the infrastructure industry could lead or follow. Which will it be?

Professor Lord Mair and CSIC hosted a timely industry event to foster discussion among key decision makers on the future of smart infrastructure and construction at the Royal Academy of Engineering in March. The event, chaired by Andrew Wolstenholme, CEO of Crossrail, aimed to focus industry-wide attention on the current tipping point in the history and future of our infrastructure.

The discussion concluded that the digital revolution is coming and innovation is available to drive the necessary change to modernise our infrastructure industry. But there is pressing need for collaboration and knowledge transfer at every level in order to succeed and, ultimately, secure the UK's position as world-leader in smart infrastructure.

CSIC offices get smart



CSIC's new office at the Department of Engineering, The James Dyson Building, is Cambridge's first smart building. CSIC has worked alongside contractor Morgan Sindall to integrate a range of novel technologies into the fabric of the building; distributed fibre optic strain sensors and fibre Bragg sensors have been embedded within a section of the building's reinforced concrete frame, columns, beams and slabs. These fibre optic sensors will collect data from the infrastructure enabling researchers to learn more about the structure's health and behaviour. The building has been captured using the latest 3D laser scanning technology to create a point cloud of data to virtually model the building and track future changes to its structure. Industry professionals, researchers and students will benefit from this innovative building that offers a 'living lab', giving those working inside it a chance to use their surroundings for research and teaching.

CSIC experts write industry best practice and technology guides for ICE

CSIC's leading experts across the fields of asset management, wireless sensors, distributed fibre optic strain sensing and bridge monitoring have written a series of industry best practice and technology guides to be published in conjunction with the Institution of Civil Engineers (ICE).

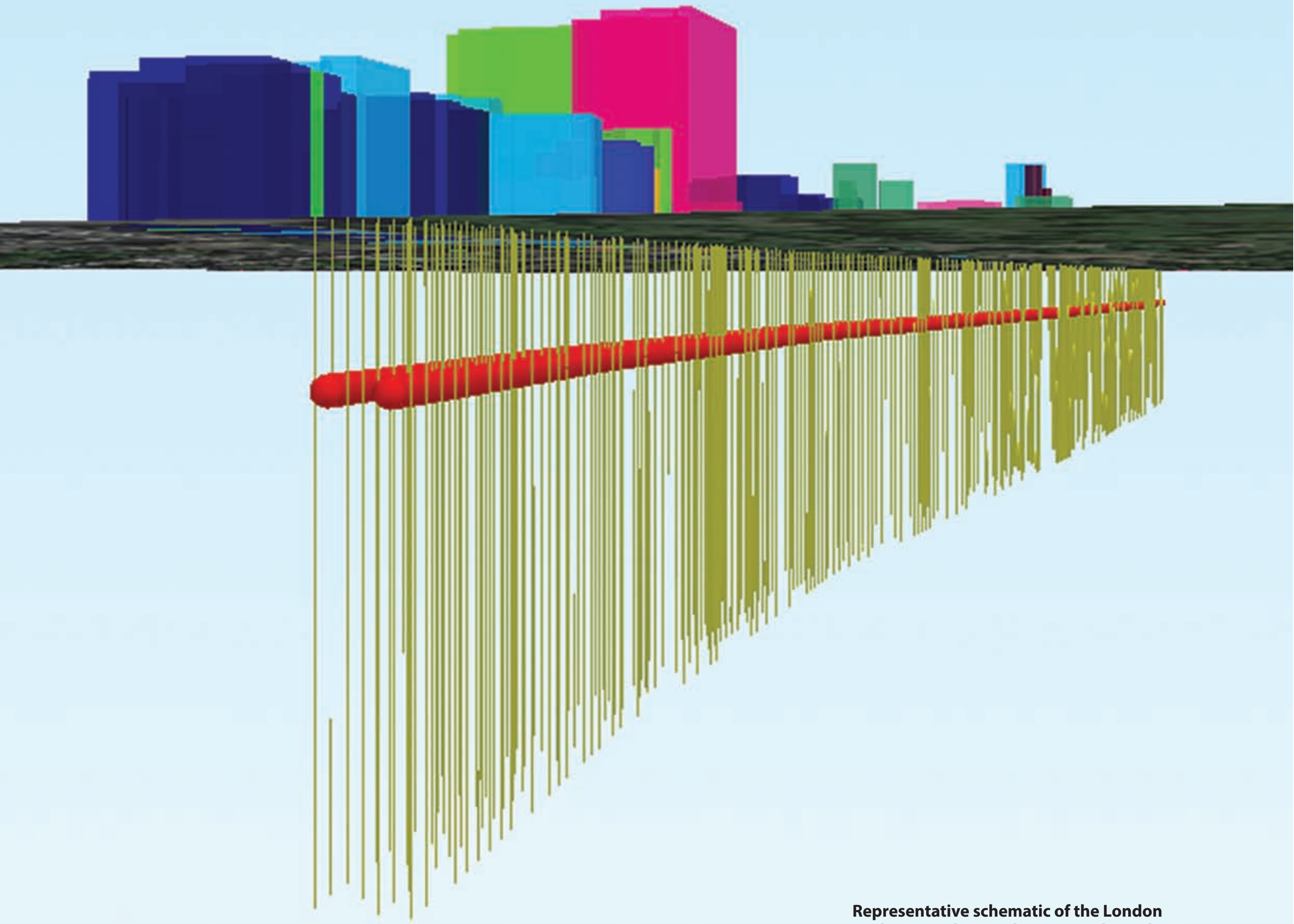
The four guides are intended to be far-reaching, informing and supporting the construction industry, infrastructure owners and operators, manufacturing, electrical and information sectors in the installation and operation of novel sensing technologies for asset monitoring and management.

The titles include:

- *Whole-Life Value-Based Decision Making in Asset Management* by Rengarajan Srinivasan and Ajith Parlikad. Publication date: 8 June 2016
- *Wireless Sensor Networks for Civil Infrastructure Monitoring: A Best Practice Guide* by David Rodenas-Herráiz, Kenichi Soga, Paul Fidler and Nicholas de Battista. Publication date: 4 July 2016
- *Distributed Fibre Optic Strain Sensing for Monitoring Civil Infrastructure: A Practical Guide* by Cedric Kechavarzi, Kenichi Soga, Nicholas de Battista, Loizos Pelecanos, Mohammed Elshafie and Robert Mair. Publication date: 29 July 2016
- *Bridge Monitoring: A Practical Guide* by Campbell Middleton, Paul Fidler and Paul Vardanaga. Publication date: 9 August 2016

All titles will be available to purchase from the ICE Bookshop www.icebookshop.com

Overview of CSIC's cities and infrastructure systems research



Representative schematic of the London Underground Central Line (Westbound & Eastbound) equipped with boreholes in the City of Westminster by CSIC PhD student Adnan Mortada

Cities and infrastructure systems

Dr Ying Jin
Co-Investigator CSIC
Senior University Lecturer
Department of Architecture
University of Cambridge

"We're now incorporating the new advancements of CSIC's city-level modelling in our planning and design proposals – it will find significant applications in the fast growing developing-country cities, as well as in the UK."

Dr Chen Wu RIBA MRTPI,
Design Principal,
BIAD, Beijing

CSIC's studies of cities and infrastructure systems are not only about gaining a better understanding of the complex challenges in building sustainable cities, but also to develop tools and guidance that can be directly adopted by businesses, communities and government agencies in harnessing the promise of new technologies and new channels of pervasive data generation.

Working in this area is not without big barriers: there are a myriad of stakeholders to engage with, and currently case studies and planning guidance are ad hoc and fragmented and as a result the best practice has not found its way to the majority of new projects.

Our overarching aim is to produce coherent tools and advice on city-scale developments which are shown to be critically important for realising the full value of disparate investments in infrastructure.

CSIC has proved to be a great research community, providing opportunities for getting colleagues in sensing, asset management, city planning and urban design to work collaboratively. Smart sensing is key to the development of a user-friendly system for gathering city level data and to scale up new analytical solutions.

In the past year CSIC engaged with London Bridge Station, Network Rail, and the smart infrastructure and data-sharing committees of BSI & ISO to beta-test our tools and draft advice. Some of the research has now been incorporated in industry advice.

The CSIC team has been active in the development of smart city standards with BSI and the work has now been extended to ISO committees. Working with BIS, BSI and industry and academic colleagues, a range of publicly available standards (PAS) have now been published online by BSI including PAS 180, PAS 181, PAS 182, PD 8100 and PD 8101 which cover leadership guides, terminology, frameworks and data concept models for smart cities.

A prominent emphasis of the PASs is harnessing the power of new data sources in the city and creating smart data management standards.

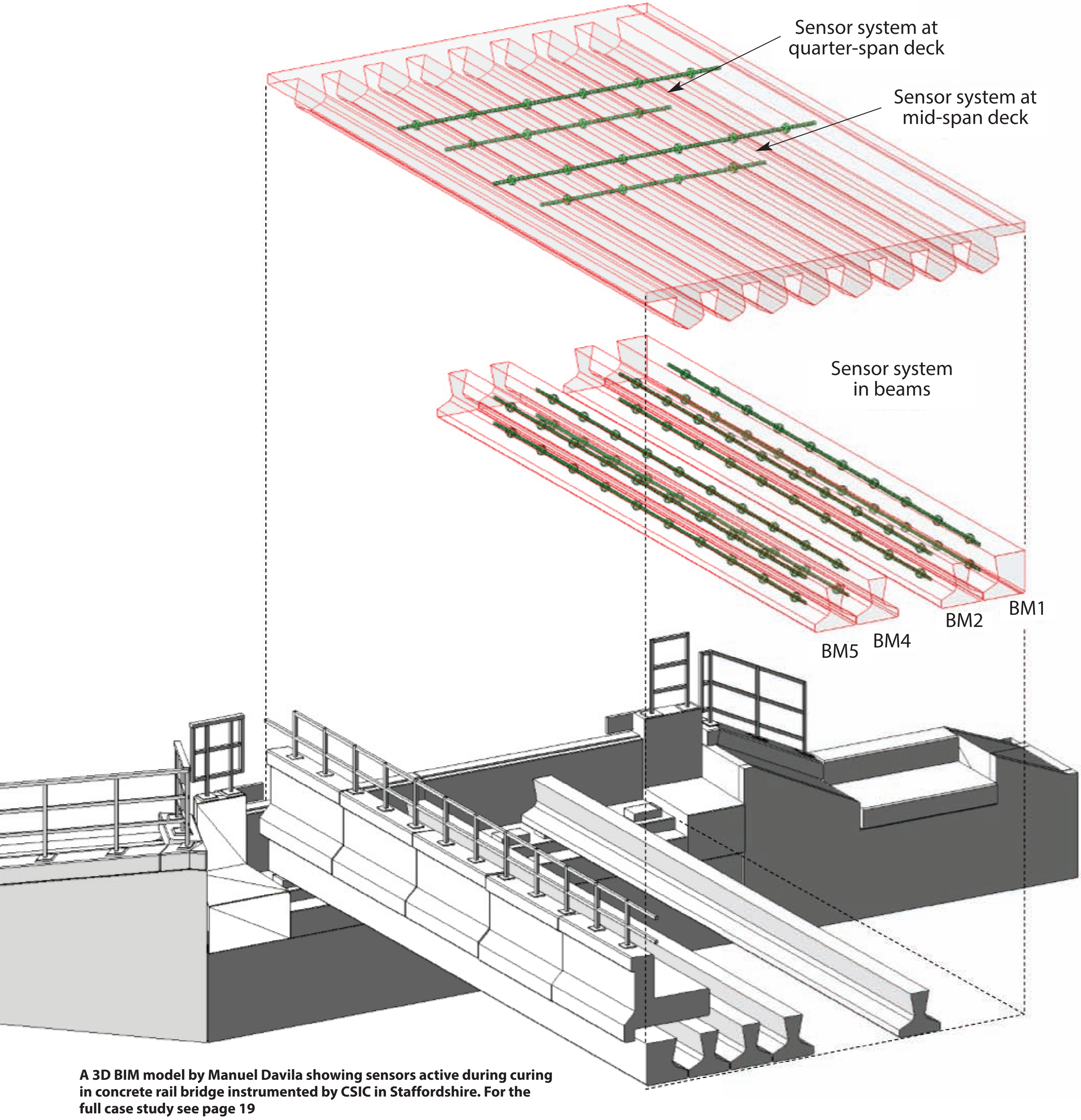
A further area of work is to alpha-test new city-scale land use, transport and infrastructure planning models which have been developed by CSIC, including demand forecasting, adaptive zoning and spatial economic modelling. Such modelling advances have not only attracted the attention of UK government agencies, but also urban master planners and designers in China.

On the integration of city-scale and project scale design of infrastructure, CSIC has developed a novel methodology on future option modelling of ground source heat pump systems in typical urban office buildings. The method is to appear in Computer-Aided Civil and Infrastructure Engineering (CACAIE), a top journal of the related fields.

Going forward CSIC Cities and Infrastructure Systems research will focus on the following four areas:

- smart cities, linked data and infrastructure monitoring: completing alpha- or beta-tests of smart data models and tools and, in close consultation with Industry Partners, BSI and ISO, and United Kingdom Collaboratorium for Research in Infrastructure and Cities, deploying them in practical projects
- develop high model validation standards, with user experiences that match contemporary user expectations of ease of interpretation
- develop authoritative advice on developments within walking distance of major public transport hubs
- engage with UKCRIC and National Research Facility for Infrastructure Sensing on incorporating the infrastructure engineering aspects, particularly in minimising construction costs and embedding options for future capacity expansions.

Overview of CSIC's asset management research



A 3D BIM model by Manuel Davila showing sensors active during curing in concrete rail bridge instrumented by CSIC in Staffordshire. For the full case study see page 19

Asset management

Dr Ajith Parlikad
Co-Investigator CSIC
Senior Lecturer
Institute for Manufacturing
University of Cambridge

The digital era has fundamentally changed the way different industry sectors operate and asset management is no exception. Smart infrastructure brings substantial value to whole-life, value-based asset management – taking a long-term view of an asset and its value. Data generated by sensor technologies enables the continued monitoring of an asset throughout its productive lifecycle, producing information useful to owners wanting to optimise value for money.

CSIC's Asset Management team has helped to set the agenda for taking a whole–life, value-based approach to asset management, and making information futureproofing a key component of the process. This expertise has resulted in collaboration between myself, Rengarajan Srinivasan, and the Institution of Civil Engineers (ICE) to publish a guidance document produced for infrastructure owners and operators, titled *Whole-Life Value-Based Decision Making in Asset Management* (see page 9).

Maintaining high-quality, resilient and sustainable infrastructure is key to economic growth. CSIC continues to work collaboratively with organisations, both in the public and private sectors, to identify and respond effectively to industry challenges and concerns. Infrastructure assets have a long lifecycle, often operating for many decades, and whole-life value asset management secures the continued and productive use of an asset over time. Asset Management workshops, held for CSIC Industry Partners in the past year, confirmed the benefits of value-based asset management to a range of asset-owning organisations. Workshop outcomes identified value in optimising the usage phase of an asset through improved reliability, maintenance, decision-making and operational effectiveness.

Good information enhances asset management decisions. CSIC has developed technologies and tools to turn data into valuable information that enables effective decision-making. Information management is a key focus area for CSIC and working collaboratively allows us to deliver meaningful solutions.

Information futureproofing is an integral part of whole-life value asset management. Understanding the risks an organisation faces with the long-term storage of data (including changing standards, software, hardware, owners and managers) and the potential consequences (loss and/or deterioration of information) for the asset owner is key to developing a strategy to safeguard data that informs asset management decisions.

CSIC's Information Quality Risk Assessment Tool quantifies the risks held by a company as a result of poor quality and incomplete data. Over the past year, CSIC has worked with Cambridgeshire County Council, applying the tool to its bridge portfolio, the results of which could enable the organisation to build an informed business case to present to funders in order to improve the council's information system.

BIM continues to be a major focus for the Asset Management team. While industry has concentrated on 3D BIM models for new assets – developing standards and models for design and construction phases – CSIC brings focus to using BIM for improved asset management. CSIC's work investigates integrating through-life information about an asset with the BIM model, including sensing data and inspection and maintenance records. CSIC is working with Staffordshire Alliance's bridge team to develop standards for integrating sensing data with BIM and this project will continue into next year.

Managing existing assets presents challenges for BIM. New assets account for only a small part of the current asset stock but BIM does not work effectively for existing assets as costs for the required technical process outweigh the benefits. CSIC is building a tool that uses deep machine learning to automatically develop BIM models for existing infrastructure.

The next five years will see CSIC focus on three areas:

- building a suite of decision-making tools to support asset managers
- better understanding how to quantify the benefits of smart infrastructure solutions
- pushing the development of BIM for supporting through-life asset management.

Collaboration with Industry Partners to turn this research into commercial services will help to grow a new industry segment. The potential of CSIC's work is vast and will enhance the future of asset management.

Overview of CSIC's data analysis and interpretation research

CSIC Co-Investigator Dr Matthew DeJong reviewing monitoring results on site in Leeds

Data analysis and interpretation

Professor Lord Mair
Head of CSIC
Sir Kirby Laing Professor of Civil Engineering
University of Cambridge

There is a compelling case for the uptake of sensing and data analysis by the infrastructure and construction industry. The engineering, management, maintenance and upgrading of infrastructure requires fresh thinking to minimise use of materials, energy and labour while still ensuring resilience. This can only be achieved by a full understanding of the performance of infrastructure through structural health monitoring, both during its construction and throughout its design life, by means of innovative sensor technologies and other emerging technologies.

The Data Analysis and Interpretation team at CSIC is developing cutting edge sensing and data analysis models, which will offer a powerful platform for providing data to enable smarter and proactive asset decisions, both during new construction and for existing infrastructure, especially ageing infrastructure. CSIC has applied conventional and advanced technologies to a large number of construction projects, including innovative sensors, wireless sensor networks, fibre optics, laser scanning, photogrammetry, and computer vision, to capture, analyse and interpret the right data at the right time to enable better decision making.

CSIC has led the development and installation of fibre optic sensors on a wide range of construction projects. The data from the fibre optic sensors has provided completely new insights into the structural behaviour of these components, both during construction and after completion.

CSIC's recent R&D development in Wireless Sensor Networks (WSN) includes open source WSN software and hardware for infrastructure structural health monitoring, a network diagnostic tool and a 'BIM friendly' WSN planning and maintenance tool ('BIM' being Building Information Modelling).

Recent examples of CSIC's successful application of fibre optic and WSN technologies to structural health monitoring of infrastructure include:

Fibre optics

- performance monitoring of deep shafts and retaining walls at Crossrail's Pudding Mill Lane, Limmo, Stepney Green and Paddington Station sites
- monitoring of a very deep diaphragm wall (84m) at the Abbey Mills shaft for Thames Water (Schwamb et al, 2014)
- assessment of National Grid and Crossrail tunnel lining behaviour during tunnel construction in London by embedding optical fibre in the precast concrete lining segments when being made in the factory
- monitoring of tunnel performance for the Large Hadron Collider at CERN, Switzerland
- monitoring of masonry arches at London Bridge Station to observe the movements during extensive piling work beneath
- field testing of thermal piles to evaluate the thermo-mechanical response of piles during heating and cooling for ground source heat pump systems, carried out at London's Shell Centre, at a major new London embassy and at a site in Houston, USA with Virginia Tech and the US National Science Foundation
- field testing of large diameter piles by integrating fibre optic strain measurement with O-Cell loading test technology, for example for the new Francis Crick Institute in London
- monitoring of beams for new Network Rail concrete and steel bridges in Staffordshire, instrumented while being manufactured offsite in a factory.

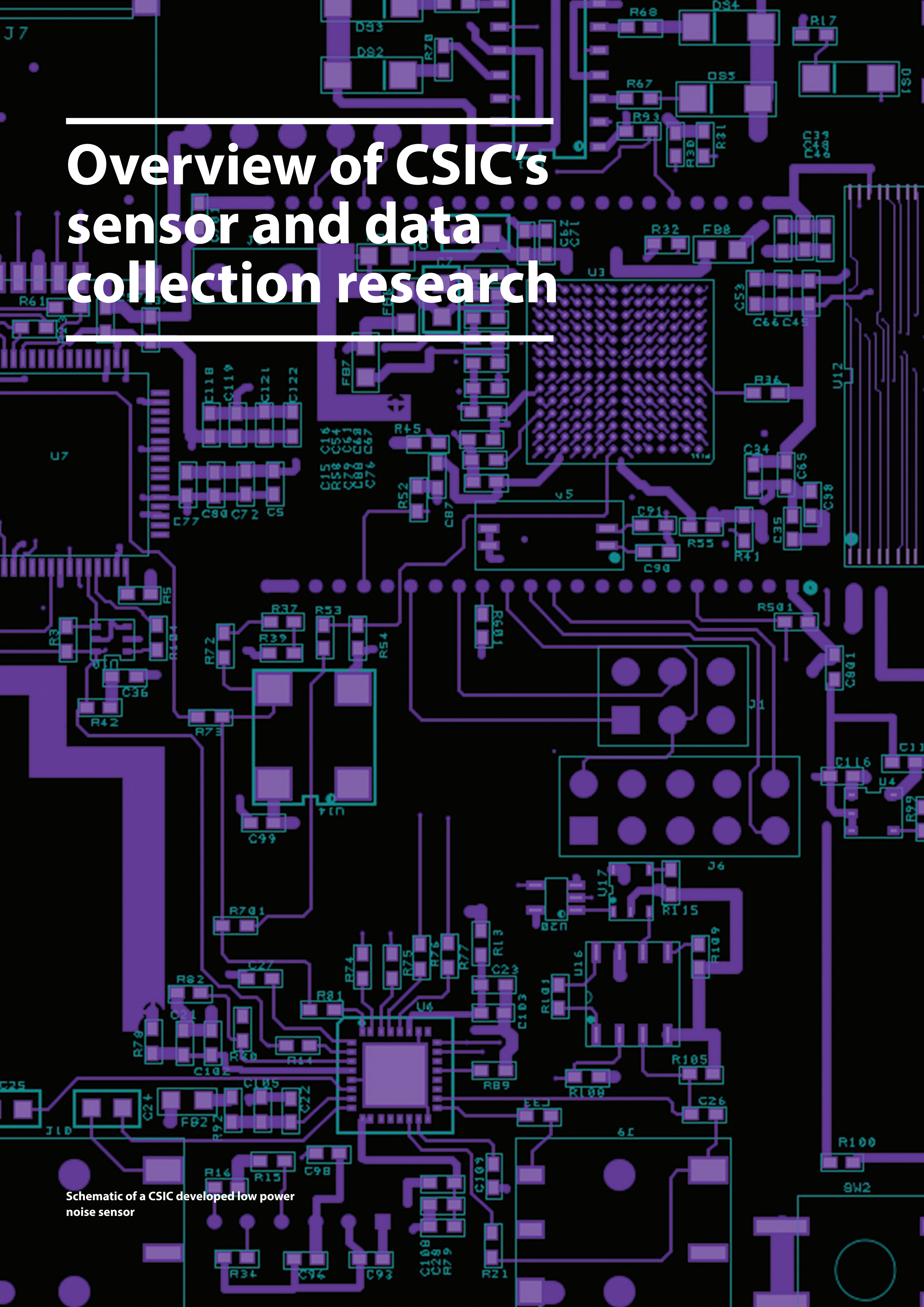
Wireless Sensor Networks

- a large scale WSN system in the 100-year-old former Royal Mail Railway tunnel to measure its behaviour and movement during construction of a large diameter platform tunnel very close beneath it as part of Crossrail's Liverpool Street Station project
- a WSN system at London Underground's Tottenham Court Road station to monitor the performance of timber-based temporary works
- development and deployment of a miniature, ultra-low power 'UtterBerry' WSN mote by CSIC PhD student Heba Bevan, successfully used on a number of Crossrail sites.

Future challenges will bring focus to establishing smart sensor methodologies for infrastructure that are robust and reliable, and able to perform in extremely confined conditions as part of intensive construction activities. This will make sure that systems (both sensor and communication) are accurately calibrated, ensuring that data is reliable and reported in such a way to allow proper analysis and interpretation. This integrated approach will generate data that can be used to make informed decisions that deliver improved efficiency and value to industry.

CSIC's progressive work in the field of data analysis and interpretation has focused on the need for clear presentation of sensor data coupled with considered analysis and interpretation. An important strand of this work has been the development of user-friendly dashboards, which present the data clearly in relation to construction activities, enabling proper analysis and interpretation. Establishing high-quality data analysis and interpretation brings considerable benefits to the infrastructure and construction industry, and opportunities for better informed, whole-life asset management.

Overview of CSIC's sensor and data collection research



Schematic of a CSIC developed low power noise sensor

Sensor and data collection

Dr Ashwin Seshia
Co-Investigator CSIC
Reader in Microsystems Technology
University of Cambridge

As an international centre of excellence in the development of sensors, CSIC is leading the way in the deployment of innovative solutions to industry challenges. Collaborating with industry has enabled CSIC to make valuable contributions to some of the most important and challenging civil engineering, transport and infrastructure projects happening today. CSIC has developed a range of sensing technologies that can be used in combination to meet a variety of demands specific to the site environment, from high temperatures to very constrained or difficult-to-reach spaces.

CSIC has successfully developed several new applications for sensing technologies in civil engineering, transport and infrastructure, and the potential of this market, both nationally and internationally, is vast. CSIC has pioneered the use of fibre optic sensors to monitor the whole-life performance of an asset and this continues to be an area of significant focus. Structural integration of fibre optic sensing systems represents a new branch of engineering and its application represents a significant contribution to structural health monitoring. The underpinning technology involves a unique marriage of fibre optics, optoelectronics and composite material science. CSIC has developed a distributed fibre optic strain and temperature measurement system to enable performance-based design, construction monitoring and structural health monitoring.

This has led to the release of *Distributed Fibre Optic Strain Sensing for Monitoring Civil Infrastructure: A Practical Guide* by Cedric Kechavarzi, Kenichi Soga, Nicky de Battista, Loizos Pelecanos, Mohammed Elshafie and Robert Mair to be published this summer by the Institution of Civil Engineers (ICE).

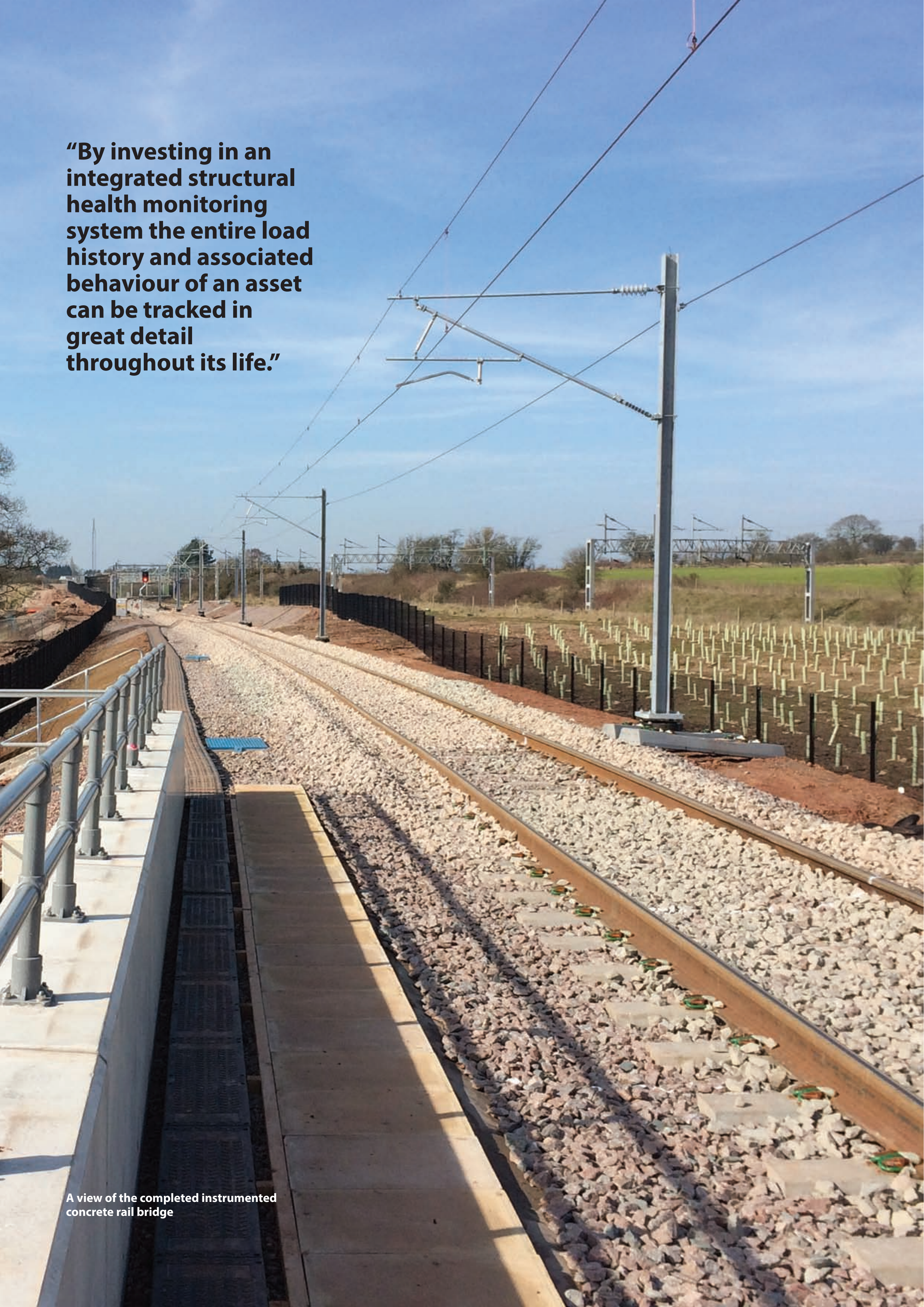
CSIC is advancing research and development of energy harvesting, in particular vibration energy harvesting (VEH), both at the micro-electro-mechanical systems (MEMS) and macroscopic scales. Vibration-powered wireless monitoring technology has the potential to enable maintenance free, autonomous measurement of the behaviour of key structural elements of infrastructure, even in the most difficult-to-reach areas, providing the owner with an approach to significantly reduce costs involved in obtaining the data required to develop an understanding of the actual capacity and level of safety of an asset. These technologies potentially provide a self-sustaining on-board power solution to complement emerging wireless sensor technologies used for structural health monitoring.

Conventional resonant approaches to scavenge kinetic energy are typically confined to narrow and single-band frequencies. CSIC's vibration energy harvesting device combines both direct resonance and parametric resonance in order to enhance the power responsiveness towards more efficient harnessing of real-world ambient vibration. In a deployment on the Forth Road Bridge in 2015, the packaged electromagnetic harvester designed to operate in both of these resonant regimes, with an operational volume of ~126cm^3, was capable of recovering in excess of 1mW average raw AC power from the traffic and wind-induced vibrations in the lateral bracing structures underneath the bridge deck. The harvester was integrated with a power conditioning circuit and a wireless mote. Duty-cycled wireless transmissions from the vibration-powered mote were successfully sustained by the recovered ambient energy. CSIC is continuing to innovate in this area by exploring approaches for energy harvesting on transport-related infrastructure where existing solutions are limited or unreliable, as well as actively seek deployment opportunities for its new technology in collaboration with Industry Partners and infrastructure owners and operators.

CSIC's Sensor team is also developing new MEMS sensors to meet the challenges of the infrastructure industry. MEMS represent small, integrated devices or systems that combine electrical and mechanical components varying in size from micrometres to millimetres. These can merge the function of computation and communication with sensing and actuation to produce a system of miniature dimensions, which has huge potential to produces low-power, low-cost sensors for remote structural health monitoring of infrastructure. CSIC has developed a low-power MEMS strain gauge with an accuracy of better than 10 nε, a dynamic range of nearly 2000 με at a power dissipation of under 10 μW.

CSIC is also actively exploring energy harvesting at the MEMS scale using approaches that could allow for the generation of sufficient power to sustain low-power wireless sensors for structural health monitoring applications. An ongoing Innovate UK funded project is specifically investigating applications for MEMS energy harvesters to high-end automotive and aerospace industries. Battery technologies cannot often operate in high-temperature conditions associated with condition monitoring for these applications (e.g. close to a jet engine). In addition, there are issues that demand miniaturisation of the technology due to limited access or constrained volumes associated with the monitoring locations.

A spin-off, 8Power Ltd, has been set up to commercialise the low-power MEMS and VEH technologies and CSIC will be collaborating with 8Power to further deploy the technologies and investigate applications for the technologies beyond infrastructure monitoring.



“By investing in an integrated structural health monitoring system the entire load history and associated behaviour of an asset can be tracked in great detail throughout its life.”

A view of the completed instrumented concrete rail bridge

Monitoring and modelling dynamic strain of railway bridges using fibre optic sensor networks and BIM

Authors: Liam Butler, Manuel Davila

Additional researchers: Niamh Gibbons, Ioannis Brilakis, Mohammed Elshafie, Campbell Middleton

The project

CSIC is working with the Staffordshire Alliance on the £250m Stafford Area Improvements Programme to deliver the most comprehensively instrumented new rail bridges in the UK. Two rail bridges, one concrete and one steel, have been instrumented during their construction with an advanced network of fibre optic sensors capable of recording data up to 250Hz. Data collected from the beginning of the structure's life enables a 'state-of-the-asset' report to be generated at handover and performance-guided asset maintenance using finite element modelling, BIM and fibre optic strain sensors across its lifetime.

The monitoring system represents the first time that bridges of this type have been instrumented in such detail to understand their behaviour from the time they are constructed. Alongside the instrumentation, CSIC has developed methods to model structural performance monitoring systems, manage and include sensor data onto open data BIM models, visualise sensor data directly on BIM models and to develop open data models.

The innovations

- fibre optic cables installed into main prestressed beams and sleepers off-site at Laing O'Rourke's Explore Manufacturing facility. This allowed faster installation of monitoring systems on site
- a new and highly robust temperature compensating sensor packaging system capable of capturing real-time thermal strain changes was internally developed
- CSIC has designed a method to allow the outputs related to strain changes in structural elements during their construction to be included and visualised in BIM for the first time
- integrating structural performance monitoring data into BIM models to reflect actual measured behaviour for whole-life asset management.

Impact and value

- based on the data already collected, the CSIC project team can identify aspects of structural behaviour that have not been captured previously such as the real-time time dependent behaviour of prestressed concrete girders and sleepers; the development of thermal and concrete shrinkage strains in bridge decks; and the effect of construction traffic on the overall bridge response – this will improve future design with potential cost, material and time savings
- by investing in an integrated structural health monitoring system the entire load history and associated behaviour of an asset can be tracked in great detail throughout its life
- clients will be able to compare data captured from instrumentation to the reference state-of-the-asset report to track the performance of an asset over its entire life.

Timeline of whole-life value

Fabrication

- Sensors instrumented off-site speeds up their installation and gathers data on the manufacturing process and the integrity of the components during transportation and installation.

Construction

- Measurements can be taken at critical stages of construction to track structural response and compare against nominal design values
- Based on strain data gathered during construction, a comprehensive 'state-of-the-asset' report can be generated at the time of commissioning and used as a baseline for assessing long-term behaviour and establishing trends.

Operation

- BIM and finite element models continuously updated to allow asset owners to make informed maintenance decisions
- Reducing the frequency of visual inspections and eliminating 'human error' while having a system by which to compare visual observation to measured behaviour
- Potential to modify and optimise future designs of similar assets leading to a 'closed loop' asset life cycle.

Decommission

- Asset owners can decide to decommission the asset based on information acquired from measured data, rather than presumed wear, potentially extending its life.

Industry Partners

Network Rail, Atkins, Laing O'Rourke, VolkerRail, Cemex

“The station provides CSIC the opportunity to demonstrate the value of new sensing technologies on a real site, including innovative monitoring of masonry vaults and passenger flow.”

Integration of sensing technologies in the London Bridge Station Redevelopment Project

Authors: Sinan Açıkgöz, Claudio Martani

Additional researchers: Loizos Pelecanos, Jize Yan, Kenichi Soga, Simon Stent, Steve Denman, Ying Jin

The project

The London Bridge Station Redevelopment Project (LBSR) is part of the Thameslink upgrade which will increase the capacity of the north-south routes through London. The main objective of the redevelopment is to increase the number of through-tracks and extend the capacity of the platforms, which required demolition of several historic vault structures and the construction of new viaducts and a new concourse. CSIC developed new monitoring techniques to tackle construction challenges on the project. The station, the fourth busiest in the UK, is being kept operational during the construction works, providing CSIC the opportunity to demonstrate the value of new sensing technologies on a real site, including innovative monitoring of masonry vaults and passenger flow.

Engineers on the project, led by CSIC Research Associate Sinan Açıkgöz, were faced with the task of predicting the response of historic brick vaults under the active platforms to piling induced settlements. Using traditional instrumentation, it is difficult to quantify the response of these viaducts to settlements and evaluate their safety. In order to ensure safe operation of the vaults and the tracks above, CSIC utilised two novel distributed sensing technologies to investigate the vault response to settlements in unprecedented detail. The distributed fibre optic sensor system, which employs Brillouin Optical Time Domain Reflectometry (BOTDR), was used to examine the strain development at several sections along the vault. This highlighted the location and magnitude of emerging cracks. The second system utilised laser scanners to generate georeferenced 3D point clouds, before and after piling, which were compared to provide global deformation estimations for all visible surfaces. The rich information led to the development of more efficient damage assessment techniques for evaluating settlement-induced damage on masonry vaults.

In parallel, CSIC tested low-cost infrared sensors and cameras to monitor pedestrian flow around a platform of the new station. This exercise allowed researchers to evaluate the accuracy of these low-cost sensors and to determine how the pedestrian flows change as the station is being constructed. This information was linked with pedestrian prediction models which run faster than real time. By combining the modelling and sensing information, CSIC aims to develop a technology which can identify imminent congestions and help station managers identify issues concerning pedestrian flows and respond effectively.

The innovations

- new cloud comparison techniques were developed to detect the 3D structural movements with high accuracy from laser scan data
- the pioneering use of fibre optic sensing in masonry vaults led to the critical identification of crack locations and magnitudes and effective quantification of damage
- effective linking of modelling and sensing tools enables a better understanding of the performance of our assets
- the rich data provided by the cheap and efficient sensing techniques holds the key to improving the efficiency of our asset assessment and management techniques.

Impact and value

- development of new data analysis techniques to retrieve critical engineering information from sensing data
- provide efficient methods to use the data to improve asset assessment and management
- reduce risks due to uncertainties (e.g. concerning the ground settlements and passenger flows) by providing cheap and/or distributed monitoring techniques
- improved fundamental understanding of the mechanical behaviour of masonry assets and their long term behaviour.

Industry Partners

Network Rail, Costain, Topcon

"The CSIC model should be encouraged. Working with CSIC has enabled both partners to jointly develop the technology and roll out on demonstration projects. CSIC provided the support and training such that Cementation Skanska now has a full and independent commercial capability to deliver distributed fibre optic sensors."

CSIC trained Cementation Skanska technician Maria Scott installing fibre optic sensor cable on a reinforced cage of a diaphragm wall at Battersea Station. Image courtesy of Cementation Skanska

CSIC and Cementation Skanska – when project collaboration becomes commercial reality

Authors: Cedric Kechavarzi, Andrew Bell
Additional researchers: Kenichi Soga, Peter Knott, Jason Shardelow, Echo Ouyang

The project

The Transport for London Northern Line Extension project will extend the London Underground Northern line from Kennington to the disused Battersea Power Station. Construction on the £1bn extension began in 2015 and the new line could be open by 2020. Cementation Skanska is using distributed fibre optic sensing techniques on an unprecedented scale for pile and wall integrity testing during current excavation work constructing the new stations and tunnels on the extended line. This novel application of fibre optic sensing emerged from research at the University of Cambridge and was standardised by CSIC to technology readiness levels required for industry adoption. The commercial application of distributed fibre optic sensing by Cementation Skanska has allowed the company to add a new specialist service to its portfolio, called CemOptics. The new technology is already shortlisted for two industry awards.

Work to build the new Battersea Station requires Cementation Skanska to:

- construct more than 600m of deep basement diaphragm walls – 1.2m thick diaphragm walls, up to 60m deep
- construct 74 large diameter bearing piles, up to 2.4m diameter and 60m deep
- install in excess of 50 km of FO cable to completely replace cross hole sonic logging in both the piles and diaphragm walls.

The background

In 2014 Echo Ouyang, a geotechnical engineer at Cementation Skanska and PhD student of CSIC Co-Investigator, Professor Kenichi Soga, worked with CSIC on a number of projects investigating the use of distributed fibre optic temperature sensing for pile and wall integrity testing; fibre optics (FO) was used for measuring concrete temperature during curing and assessing the integrity of the element. The work was led by Andrew Bell, Chief Engineer at Cementation Skanska.

The potential long-term economic and safety-enhancing benefits of using FO more widely was recognised by Cementation Skanska. Over the next two years CSIC delivered training and on-site support enabling the company to reach commercial readiness with the FO technology, CemOptics.

The innovation

Thermal methods for testing the integrity of piles and wall elements by identifying anomalies are gaining prominence. Distributed fibre optic temperature sensing provides a non-intrusive, safe and cost effective technique. It is a robust alternative to point sensing methods, which require the connection of numerous sensors. Low-cost standard telecommunication fibre optic cables are simply attached to several sides of the reinforcement cage of the element and temperature measurements obtained at close spatial intervals along the cage. The measurements are taken at short time intervals to record the evolution of the temperature profile of the element during concrete curing.

The principle behind this method is based on the properties of the spectrum of the backscattered light within an optical fibre. The method uses standard optical fibres into which a laser pulse is launched and the spectrum of the backscattered light analysed. Temperature is inferred from the properties of some of the components of the spectrum.

The training

CSIC training in the use of distributed fibre optics was developed to meet the specific needs of Cementation Skanska:

- a two-day bespoke training workshop delivered to six Cementation Skanska operatives, including pilers, engineers and technicians, at the company's Doncaster site. The programme covered how to splice FO cables, handling cables on site and attaching cables to pile cages
- Maria Scott, a technician at Cementation Skanska, spent two weeks working with and learning from members of CSIC's deployment team at the University of Cambridge where she was taught everything she needed to know about FO for pile and integrity wall testing. This collaboration equipped Maria with the knowledge and skills to independently install FO on Cementation Skanska projects, including the Northern Line Extension
- software was developed in collaboration with Cementation Skanska that allows processing of the data and visualising of temperature profiles to happen automatically.

Impact and value

Cementation Skanska is now using fibre optics for pile and wall integrity testing on an unprecedented scale. There is potential to extend the method worldwide, across the company's entire project portfolio. CemOptics has now been proven to improve safety, quality and increase production (thus reducing costs) on site.

CemOptics:

- replaces traditional cross hole sonic logging method
- delivers visible improvement in safety
- brings technical, quality and safety benefits acknowledged by all stakeholders
- is shortlisted for two industry awards – Ground Engineering 2016 Award for Technical Excellence and Product and Equipment Innovation.

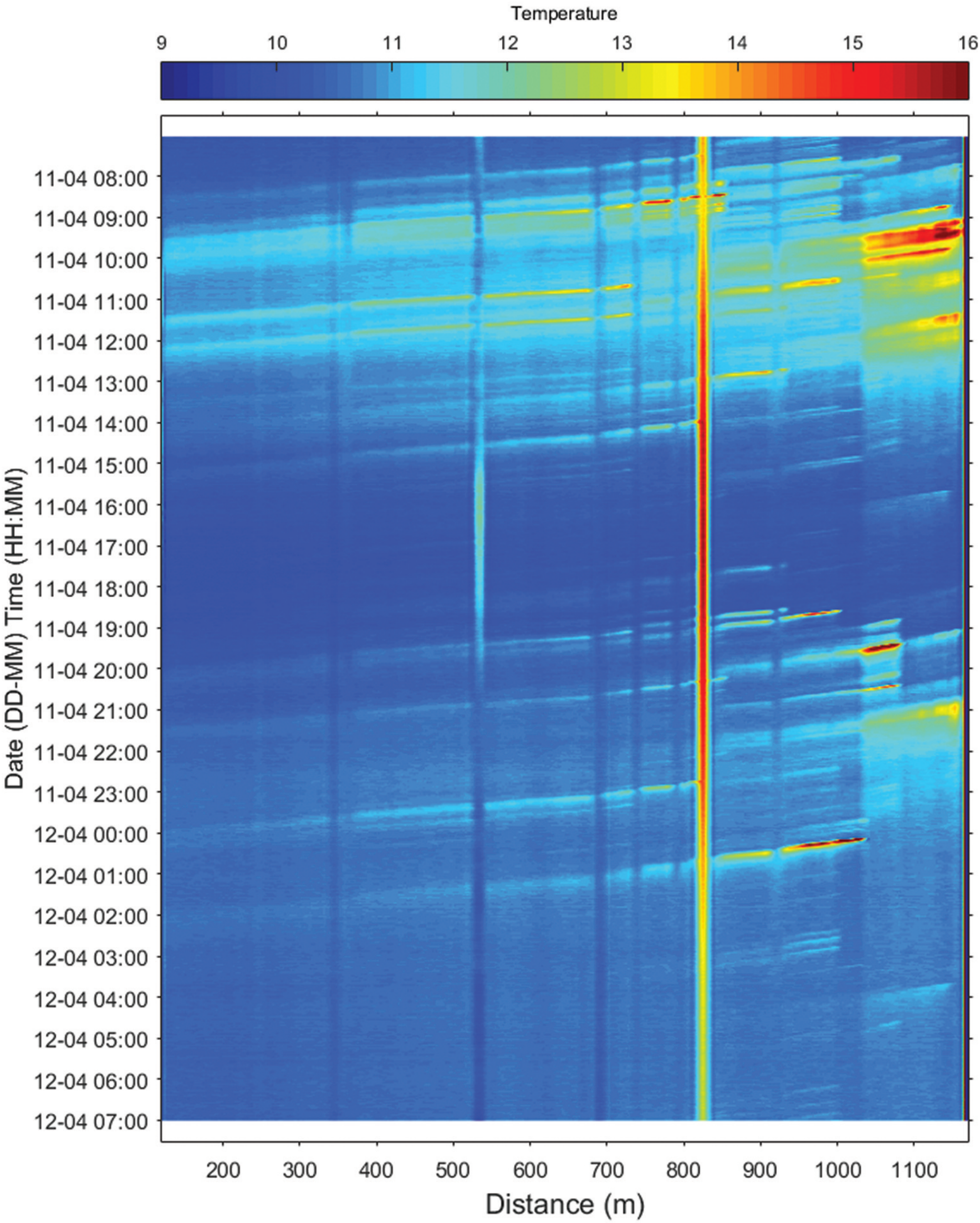
Cementation Skanska reports multiple benefits of the collaboration with CSIC:

- enabled partners to jointly develop the technology and roll out on demonstration projects
- fostered and encouraged a collaborative approach to research and shared recognition
- delivered 'industry level' training in the use of new technology
- provided excellent support to Cementation Skanska in move to commercialisation
- accelerated change
- allowed Cementation Skanska to achieve its vision of improved safety and delivering innovative solutions that make a difference
- Cementation Skanska now has a full and independent commercial capability to deliver distributed fibre optic sensors.

Industry Partner

Cementation SKANSKA

Cementation Skanska is one of the UK's largest piling and ground engineering contractors and a CSIC founding Industry Partner.



The graphic shows the temperature behaviour of the 1.2km of sewer being monitored over a 24-hour period. The deep blue colour is indicative of the ambient temperature of the sewer (10^{O}C) in April. The green – yellow-red colours are of increasing temperature liquid joining the sewer from domestic connections, with flow in the sewer moving right to left. The (mostly) red vertical line is the air temperature inside a manhole, reaching around 16^{O}C.
Courtesy of Dr Y Rui

Monitoring storm water inflow in a foul sewer using distributed fibre optic temperature sensing

Author: Phil Keenan

Additional researchers: Cedric Kechavarzi, Peter Knott

The project

Surface water infiltration into sewers and illicit connections, most often unintended, of storm water to foul sewers and of foul sewage to storm sewers, is a major problem associated with separate sewer systems.

Unwanted infiltration can lead to sewer and treatment plant design capacity being exceeded. This can potentially result in over spilling and local flooding or the release of untreated sewage in surface water and the wider environment. Eradicating unwanted infiltration and removing illicit connections is beneficial to consumers, both in terms of hygiene and financial cost. However, effective remedial action requires precise knowledge of the location of infiltrations.

The innovation

Unwanted discharges are intermittent and their detection requires monitoring systems with good spatial and temporal resolution that can be deployed over kilometres of sewer networks. Distributed fibre optic temperature sensing meets these requirements. The system helps to accurately pinpoint anomalies in operation by detecting the sudden changes in temperature of the sewer liquid which is due to differences in foul and storm water temperature. The technology is autonomous and measures temperature continuously along the entire length of the optical fibre.

CSIC has demonstrated the system (initially pioneered by Delft University in the Netherlands) near Gloucester, by installing an armored fibre optic temperature sensor along a 1.5km-length of sewer. A pilot rope with a sensor cable and float attached was lowered down a manhole. While the float had travelled downstream, it was retrieved periodically at manholes in order to pull the cable into the sewer. This installation method ensured that the cable did not suffer excessive pulling forces.

The cable was connected to a fibre optic analyser enabling real time temperature monitoring of 1.5km of sewer, 24 hours per day, throughout the three-month survey period.

Whenever fluid entered the sewer, its native temperature caused the ambient temperature of the fluid in the sewer to change. The sensor detected this subtle difference in temperature along the entire length of sewer being monitored, and the data collected over the three-month period was plotted into waterfall charts.

This novel sensing method enabled the accurate detection of the time and location of discharges into the sewer, identifying whether discharges came from domestic connections, illicit connections, or surface rainwater infiltration.

Impact and value

- this project demonstrates the commercial viability of distributed fibre optic temperature sensing in detecting sewer operation and malfunction
- data visualisation shows sewer operation patterns indicative of certain sewer events (illicit discharge, domestic sewer operational patterns, sewer blockages, manhole overflow events) of value to asset owners and managers
- a network of fibre optic sensors can provide asset managers with a real-time view of the condition of their critical assets
- this innovative monitoring provides information that informs planning to ensure asset integrity is maintained, and prevents the interruption of service due to failure.

This demonstration has proved the commercial viability of this sensing system in sewers. CSIC is investigating further demonstration and training opportunities with industry to commercialise this method and see it taken up by the supply chain.

"This novel sensing method enabled the accurate detection of the time and location of discharges into the sewer, identifying whether discharges came from domestic connections, illicit connections, or surface rainwater infiltration."

Industry Partner

SEVERN TRENT WATER

"The project presented the opportunity for CSIC to collaborate with industry leaders to challenge traditional engineering design assumptions to find new techniques to save the project time and money."

CSIC Technician Peter Knott and Research Associate Nicky de Battista instrumenting the spray concrete lining at Liverpool Street Station's Moorgate shaft

Fibre optic sensing innovations on Crossrail

Authors: Nicky de Battista, Zili Li

Additional researchers: Kenichi Soga, Robert Mair, Mohammed Elshafie, Cedric Kechavarzi, Peter Knott, Jason Shardelow

The project

Crossrail is currently the largest construction project in Europe. It includes 10 new rail stations, six of which are under central London, and 42km of new rail tunnels weaving through the city's congested sub-terrain. The project presented two opportunities for CSIC to collaborate with industry leaders on innovative applications of fibre optic cables to challenge traditional engineering design assumptions in order to save future tunnelling and excavation projects time and money. Crossrail's strong innovation policy allowed CSIC to set up 'laboratories' on site.

The first project, led by Research Associate Nicky de Battista, focused on measuring the additional strains induced in the sprayed concrete lining (SCL) at junctions in the tunnels at Liverpool Street Station. A tunnel's SCL is thickened at these junctions in order to sustain the stresses caused by the excavation of the cross-passages. Tunnel lining design is based on finite element models but there is a lack of experimental data to calibrate these. By embedding FO cables within the SCL at one of the junctions at Crossrail's Liverpool Street Station concourse, CSIC was able to map the strain build-up in the lining at every stage of the cross-passage excavation and, for the first time, observe the behaviour of the SCL during the excavation sequence.

The second project, led by Research Associate Zili Li, monitored the deformation of a Diaphragm wall (D-wall) during deep excavation at Paddington Station. As the only train station in the Crossrail project constructed using a top-down excavation, the Paddington site provided the opportunity to evaluate the effect of the excavation of an existing tunnel on D-wall behavior using fibre optic cables for the first time. Fibre optic cables were embedded in diaphragm wall panels allowing CSIC to monitor the changes in strain conditions during three key stages of construction; tunnel, concourse and base excavation. This was the first time FO cables have been used to validate finite element model assumptions about this scenario.

The innovation

On Crossrail, CSIC demonstrated innovative applications of distributed FO sensors to collect new data about commonly used construction techniques with the potential to refine and improve future design.

Both projects used Brillouin Optical Time Domain Reflectometry (BOTDR) embedded in concrete to measure strain and temperature changes within the material at key stages in construction. CSIC's FO technologies enable strain measurements in the tens of microstrain range in a continuous manner over lengths of up to 10km, offering an unprecedented level of detail on the concrete's behavior during excavation.

Impact and value

An improved understanding of the performance of infrastructure during excavation, margins of safety, and resilience enables better, leaner future design.

While further research is needed, the results of both studies indicate areas for significant potential savings in future designs. The results of the monitoring of the SCL at Liverpool Street Station showed that the effects of cross-passage excavation on the parent tunnel's lining are localised in the vicinity of the cross-passage openings. These preliminary findings indicate that there are significant savings to be made in materials, labour, and plant as well as environmental benefits associated with reduced material use and improved site safety due to a decrease in working at heights to erect steel reinforcement and spray concrete. Similar studies could translate these findings into real savings for similar projects such as Crossrail 2. Preliminary results of the Paddington Station monitoring indicate that the measured D-wall displacement is about 60% of the design D-wall displacement. The incremental bending and deflection profiles generated through the fibre optic cable's continuous strain readings indicated that the effect of the removal of an existing tunnel on the D-wall deflection and ground heave during deep excavation can be significant, but was less than predicted. This research can be used to improve and refine future D-wall design, presenting the possibility of savings in materials and cost through more accurate modelling.

These ground-breaking studies should serve as a catalyst for infrastructure owners and researchers to carry out similar studies on different types of SCL tunnel and D-wall construction techniques.

Industry Partners

Crossrail

Mott MacDonald

"Smarter information confirms operations are safe for construction and better informs asset managers/owners to make decisions about the project."

Futureproofing and safeguarding heritage structures through sensing

Authors: Sinan Açıkgöz, Loizos Pelecanos

Additional researchers: Matthew DeJong, Kenichi Soga, Robert Mair

The project

There are many historic buildings, monuments and structures in the UK that require measures to protect and conserve them. CSIC is working alongside industry to deliver sensing innovations to help asset owners better understand the behaviour of existing structures in order to safeguard them against new construction activity and to futureproof to enable continued use. This work includes monitoring the Victoria and Albert Museum (V&A) in London during deep basement excavations and monitoring masonry vaults at sites around the UK.

During deep basement excavation work at the V&A, the safety of the adjacent exhibits and building was paramount. CSIC, led by CSIC Research Associate Loizos Pelecanos, installed fibre optic (FO) cables to measure movement and temperature at critical locations in the building's foundations. Seven readings have been taken at significant points during the construction process, to assess basement heave, detect any changes to the foundation slabs, and to monitor the performance of the tension piles. This project marks the first time this type of monitoring has been possible.

Masonry vault structures form an important part of the UK's legacy infrastructure in tunnels and across the rail network. These structures are vulnerable to high service loads and ground settlements so understanding the behaviour of these assets will be key to securing their continued effective use. CSIC's masonry vault research, led by Co-Investigator Matthew DeJong with Research Asssociate Sinan Açıkgöz, aims to quantify the vulnerability of these structures and provide detailed and accurate data to better inform maintenance programmes and asset management. Conventional point sensors (e.g. strain and displacement gauges) only measure the behaviour of the material at the sensor location and do not provide sufficient information. CSIC has developed distributed sensing techniques using fibre optics, laser scanning and photogrammetry which sense continuous response along the structure, both under static and dynamic loads. These techniques enable sensitive detection of local damage, as well as a comprehensive description of global deformations.

The innovation

CSIC instrumented two piles and a part of the foundation slab at the V&A with two pairs of FO cables, one for measuring changes in strain and the other temperature. Any applied load or temperature causes changes in the frequency content of light propagated through an optical fibre. By measuring this frequency change, CSIC is able to back-calculate the induced load or temperature to deliver detailed information about the integrity of the underground structure and additional assets of the museum that no other sensor device can provide.

CSIC is using distributed sensing to deliver unprecedented detail concerning the response of masonry arches to short and long term effects. Various FO cables attached to the structure can measure the strain experienced along their length, providing detailed information on the dynamic behaviour, as well as long term static changes in the structure due to structural degradation and ground settlements. In particular, the novel use of Brillouin Optical Time Domain Reflectometry (BOTDR) for assessing the dynamic loads on the structure, represents a new technical advancement.

The non-contact laser scanning and photogrammetry sensing solutions provide further new insight on the response of masonry vaults. In particular, by investigating the precise 3D geometry quantified by laser scanners, it is possible to quantify the historic displacements experienced by the structure. New software has been developed for this purpose. Furthermore, CSIC utilises commercial photogrammetric tools, to detect the 3D movements of the masonry structures during dynamic loading. Overall, the sensing data from these new technologies complement one another and provide engineers with data to calibrate mechanical models of masonry to better understand the response of the critical masonry assets.

Impact and value

- the construction team at the V&A receives detailed information about the integrity of the underground structure which is of value to the contractor (safety), consultant (checks and improves design), and asset owner (ensures safety of heritage building)
- future use of this method could inform adjustment of design prior to construction, based on the actual performance of the tension piles, resulting in savings in material costs and greater confidence in design
- CSIC's ongoing research on new technologies of monitoring masonry arches improves the use of FO, laser scanning and photogrammetry techniques to offer effective and pervasive sensing that delivers a better understanding of assets and their state
- in general, new sensing techniques provide an unprecedented level of detail and a better appreciation of structural response to a range of factors. Asset owners can use this information to calculate risk and monitor complex engineering works carried out in the vicinity of historic structures
- smarter information confirms operations are safe for construction and better equips asset managers/owners to make decisions about the project.

Industry Partners

V&A ARUP Wates NetworkRail COSTAIN TOPCON

CSIC Technician Jason Shardelow training Research Associate Hesham Aldaikh on fibre optic splicing in the CSIC lab

Training and industry engagement update

As an Innovation and Knowledge Centre (IKC), the key aim of CSIC is to undertake world-leading research to transform the future of smart infrastructure and construction and industry-collaborative projects to establish the UK as a global leader in this field.

Sharing information, skills and knowledge is key to advancing industry adoption of innovative solutions to engineering challenges.

CSIC is a hub for academia, industry and government organisations to work together at a range of scales to transform the way in which we deliver infrastructure and ensure the value and benefits from our world-class research outputs, activities and impact reach a wide audience.

CSIC hosts, attends and presents at events, conferences and workshops both nationally and internationally. CSIC brought the international community together, hosting the Cambridge Conference on Fibre Optic Sensing in Civil Infrastructure and the Cambridge Conference on Wireless Sensor Networks in Civil Infrastructure, precursors to this year's International Conference for Smart Infrastructure and Construction. CSIC also hosted a series of Future Technologies Workshops with topics including the Internet of Things and the use of Big Data in the context of infrastructure and construction. These interactive events, which offer a chance to discuss specific challenges and identify potential solutions, are open to Industry Partners and other organisations, including SMEs and developers. During 2015, CSIC took part in more than 25 external conferences – including New Civil Engineer's UK Roads, UK Rail, Piling and Foundations and Basements and Underground Structures, as well as the Infrastructure Forum, and Institution of Civil Engineers' (ICE) BIM 2015 and Asset Management conferences. CSIC's presence at these events provides a showcase for its research and enables us to meet new industry contacts – a number of these meetings have resulted in new and collaborative project work.

CSIC also works to raise industry awareness through dissemination, developing training for industry in the use of innovative techniques and tools. We provide input to standards and CSIC's leading experts have written a series of industry best practice and technology guides in conjunction with ICE. CSIC receives funding from Innovate UK, the Engineering and Physical Sciences Research Council (EPSRC), and works with the Knowledge Transfer Network (KTN) and other strategic partners, including the Department for Transport (DfT), to support them in showcasing the very latest developments in engineering sensing technologies for a UK and an international audience.

In the past five years we have collaborated closely with more than 40 Industry Partners working on many major engineering projects, including Crossrail, Staffordshire Alliance and London Bridge Station Redevelopment Project. These collaborations have led to the development of new skills and techniques to deliver smarter infrastructure: innovative sensors and technologies that can provide clear evidence of where significant savings can be made in the future, successfully deployed on some of the largest infrastructure projects in the UK; using data to develop whole-life, value-based decision-making frameworks for asset management; and looking at how infrastructure investments bring value to cities and communities.

As well as pursuing a research agenda, CSIC supports businesses to exploit commercial opportunity and collaborations have resulted in a number of spin-outs and patent applications including the low-power, miniature, wireless sensor, UtterBerry and vibration energy harvesting power-solution technology, 8Power. Our collaboration with Industry Partner Cementation Skanska has resulted in the company being able to fully commercialise a new industry method for integrity testing which it is now putting to full use on the new Battersea Station project that is part of the Northern Line Extension (see more details on page 22) and is shortlisted for two industry awards.

These exportable technologies, techniques, skills, products and services are of great benefit to the British economy, and offer substantial markets for commercial exploitation. They are signature components of 'the CSIC effect' – where the Centre acts as a catalyst to implement cutting edge tools and techniques from research into the infrastructure industry and supply chain.

Our people

CSIC Phase One Investigators

Professor Lord Robert Mair, CBE
Sir Kirby Laing Professor of Civil Engineering
Lord Mair is Head of CSIC. He is a Vice-President of the Institution of Civil Engineers, a Fellow of the Royal Academy of Engineering, and a Fellow of the Royal Society. He was formerly Master of Jesus College, Head of Civil Engineering at the University of Cambridge and Senior Vice-President of the Royal Academy of Engineering. In the 2010 New Year's Honours list he was awarded a CBE and was appointed an independent crossbencher in the House of Lords in October 2015. Before he was appointed to a Professorship at Cambridge in 1998 he worked in industry for 27 years, and was a founding partner of the Geotechnical Consulting Group. His research group at Cambridge specialises in the geotechnics of tunnelling and underground construction. He has advised on numerous tunnelling and major civil engineering projects in the UK and worldwide, including the Jubilee Line Extension, Crossrail and HS1. He is Chairman of the Science Advisory Council of the Department for Transport and Engineering Adviser to the Laing O'Rourke Group.

Professor Roberto Cipolla
Professor of Information Engineering
Roberto Cipolla joined the Department of Engineering, University of Cambridge, in 1992 as a Lecturer and a Fellow of Jesus College. He became a Reader in Information Engineering in 1997 and a Professor in 2000. His research interests are in computer vision and robotics to include: the recovery of motion and 3D shape of visible surfaces from image sequences; object detection and recognition; novel man-machine interfaces using hand, face and body gestures; real-time visual tracking for localisation and robot guidance and applications of computer vision in mobile phones.

Dr Mohammed Elshafie
Laing O'Rourke Lecturer of Construction Engineering
Mohammed Elshafie is a Fellow of Robinson College and a member of the geotechnical research team at the University of Cambridge, which is at the forefront of applying optical fibre strain sensing technology on a wide range of civil engineering infrastructure assets. The team's work has been recognised by a number of awards including the Fleming Award 2013 for Geotechnical Engineering Excellence from the ICE and the BGS in London, the Ground Investigation and Monitoring Award 2014 sponsored by the International Tunnelling and Underground Space Awards, and the ICE Russell Crampton Award for the best paper in the ICE Proceedings of Geotechnical Engineering for 2014. He previously worked as a geotechnical engineer at Geotechnical Consulting Group (GCG) in London.

Dr Ying Jin
Senior University Lecturer
Ying Jin leads the urban modelling group at the Department of Architecture. His research interests are focused on the understanding and modelling of physical planning and urban design interventions through activity sensing, logistics monitoring, spatial analytics, machine-learning and real option theory. Past projects include strategic planning of London and surrounding regions, local planning in English Midlands, freight and logistics across Britain, transport and energy scenarios for EU, and urban and transport plans in China and South America. In 2015 he was a co-author of a best paper at Computational Science and Its Applications (2015) on adaptive zoning. He is a member of the British Standards Institute Committee for Smart Community Infrastructure (SDS/001/08), the Steering Group for PAS180 (Smart Cities – Vocabulary), and ISO ad hoc committee on transportation and information sharing under TC 268/SC01.

Professor Cecilia Mascolo
Professor of Mobile Systems
Cecilia Mascolo was a faculty member in the Department of Computer Science, UCL, prior to joining the University of Cambridge in 2008. She is Fellow of the British Computer Society (BCS) and a Fellow of the Royal Statistical Society. Her research interests include mobile and sensor systems, mobility modelling, mobile applications, and mobile data analysis. She has worked on systems to improve efficiency of mobile and wearable devices, sensing systems, and models able to cater for spatio-temporal aspects related to human mobility.

Professor Duncan McFarlane
Professor of Industrial Informational Engineering
Duncan McFarlane is Head of the Distributed Information and Automation Laboratory within the Institute for Manufacturing, University of Cambridge. He has been involved in the design and operation of industrial automation and information systems for 20 years. His research work is focused in the areas of distributed industrial automation, reconfigurable systems, RFID integration, track and trace systems, and valuing industrial information. Most recently he has been examining the role of automation and information solutions in supporting service environments and in addressing environmental concerns.

Professor Cam Middleton
Professor of Construction Engineering
Campbell Middleton is the Director of the Laing O'Rourke Centre for Construction Engineering and Technology. He is Chairman of the UK Bridge Owners Forum that identifies research needs and priorities for bridge infrastructure, and Principal Investigator for the EPSRC Future Infrastructure Forum Network Grant for Resilient and Sustainable Infrastructure. He previously worked in bridge and highway construction and design in Australia and London. He contributes to the development of bridge codes of practice and acts as a specialist bridge consultant. Main areas of interest include: computational collapse analysis; risk and reliability analysis; computer vision for structural evaluation; non-destructive testing and inspection; wireless sensor networks for structural health monitoring, and sustainability evaluation of constructed facilities.

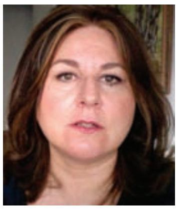
Dr Ajith Parlikad
Senior Lecturer
Ajith Parlikad is the Deputy Director of the Distributed Information and Automation Laboratory and leads the Asset Management research group at the Institute for Manufacturing. Ajith oversees research activities on engineering asset management and maintenance, with particular focus on examining how asset information can be used to improve asset performance through effective decision making, to include: value-based approach for identifying information requirements for infrastructure asset management; futureproofing of infrastructure, and performance measurement of asset management systems. He actively engages with industry through research and consulting projects.

Dr Ashwin Seshia
Reader in Microsystems Technology
Ashwin A. Seshia is a Fellow of Queens' College, a Fellow of the Institute of Physics, a Fellow of the Institution for Engineering and Technology and a senior member of the Institute of Electrical and Electronics Engineers. His research interests include microengineered dynamical systems with applications to sensors and sensor systems. He serves on the editorial boards of the IEEE Journal of Microelectromechanical Systems, the IOP Journal of Micromechanics and Microengineering and the IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control.

Professor Kenichi Soga
Chancellor's Professor, University of California, Berkeley
Kenichi Soga is formerly Professor of Civil Engineering at the University of Cambridge. He is Fellow of the Royal Academy of Engineering and Fellow of the Institution of Civil Engineers. His current research activities include: innovative monitoring and long-term performance of civil engineering infrastructure; energy geomechanics, and modelling of underground construction processes. He is recipient of several awards including George Stephenson Medal and Telford Gold Medal from the Institution of Civil Engineers and Walter L. Huber Civil Engineering Research Prize from the American Society of Civil Engineers.

CSIC Phase One Core Team

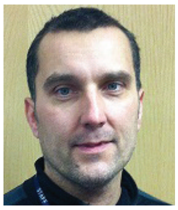

Dr Jennifer Schooling
Director


Samantha Archetti
Administrator


Amelia Burnett
Communications Manager


Paul Heffernan
Former Director


Dr Cedric Kechavarzi Training and Knowledge Transfer Manager


Peter Knott
Senior Technician


Phil Keenan
Business Development Manager


Lisa Millard
Communications


Larissa Moore
Former Administrator


Ellen Mumford
Former Administrator


Helen Needham
Former Communications Manager


Jason Shardelow
Technician


Tianlei Wu
Finance Manager


Sandy Yatteau
Industry Partner Liaison Manager

Research Phase One Associates


Sinan Açıkgöz


Hesham Aldaikh


Emmanuelle Arroyo


Liam Butler

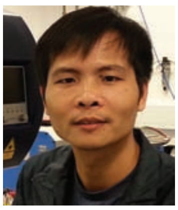

Phil Catton


Rachel Cuthbert


Manuel Davila Delgado


Nicky de Battista


Steve Denman


Cuong Do


Christos Efstratiou


Paul Fidler


Martin Floeck


Andrea Gaglione


Niamh Gibbons


Alex Hagen-Zanker


Ankur Handa

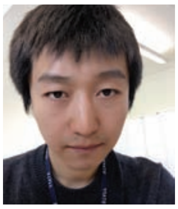

Simon Hartley

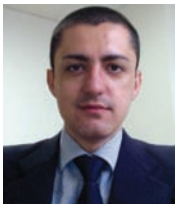

Yu Jia


Krishna Kumar


Varindra Kumar


Zili Li


Zhenglin Liang


Claudio Martani


Tariq Masood


Sarfraz Nawaz


Viorica Pătrăucean


Loizos Pelecanos


Pasquale Ponterosso


David Rodenas Herraiz


Yi Rui


Hyungjoon Seo


Raj Srinivasan


Kiril Stanilov


Paul Vardanega

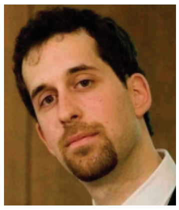

Ian Williams


Chris Williamson


Michael Williamson


Xiaomin Xu


Jize Yan


Vassilis Zachariadis

CSIC would like to acknowledge the contribution of the following current and former PhD students, trainees, secondees and knowledge transfer partners who helped deliver our Phase One research agenda

Mehdi Alhaddad
Mohamed Alserdare
Mélanie Banes
Heba Bevan
Jules Birks
Gerald Casey
Emmanuel Chimamkpam-Okonkwo
Shao-Tuan Chen
Xuesong Cheng
Debbie Deng
Vanessa Di Murro
Sijun Du
Andreja Erbes
Njemile Faustin
Jimeng Feng
Tao Feng
Emanuele Giglio
Saleta Gil-Lorenzo
Chang Ye Gue
Ping He
Tim Hillel
Hsintzu Ho
Kaveh Jahanshahi
Koson Janmonta
Xihe Jiao
Yingyan Jin
Vivien Kwan
Vitaly Levdik
Chi Ming Leung
Bo Li
Zhonglu Lin
Katie Liu
Ying Wan Loh
Linqing Luo
Mingfei Ma
Ying Mei
Nao Minakata
Yuto Minakata
Tsukasa Mizutani
Adnan Mortada
Takuma Nakamura
Masanari Nakashima
Giuseppe Narciso
Tatsua Nihei
Bella Nguyen
Jhon L.L. Nuqui
Masahito Omori
Echo Ouyang
Mahul Patel
Yuchen Qian
Zhihao Qui
Stefania Radopoulou
Stefan Ritter
Xiao Rong
Satoko Ryuo
Tsubasa Sasaki
Tina Schwamb
Sakthy Selvakumaran
Munenori Shibata
Taichi Shimizu
Simon Stent
Hani Taha
Seda Torisu
David Turner
Li Wan
Fei Wang
Kelly Wang
Graham Webb
Matthew Wilcock
Jinlong Xu
Seiji Yamada
Kyosuke Yasuda
Gökçen Yilmaz
Yang Yu
Yifei Yu
Dan Zhang
Yi Zhang
Bingyu Zhao
Hong-Hu Zhu

Looking ahead

The future looks smart for infrastructure and construction

Dr Jennifer Schooling
Director of CSIC
University of Cambridge

"As an industry we must continue to break down barriers and engage at all levels to foster innovation, placing it at the heart of infrastructure planning. No single organisation can do this alone, but if we work together, we all benefit."

This is a time of great opportunity in the worlds of infrastructure and construction, particularly for innovation and 'smart' solutions. With an increased focus by government on infrastructure and construction, the setting up of the National Infrastructure Commission and a number of major organisations establishing innovation programmes, the time is ripe for transformation in our industry.

We are delighted that EPSRC and Innovate UK have confirmed their support for CSIC over the next five years, and that the Chancellor's 2016 Budget established the Government's commitment to UKCRIC (see page 40), which will provide a forum for inter-disciplinary collaboration between the UK's leading researchers in infrastructure and cities.

Preparations for the launch of CSIC's second phase are under way, and we are currently developing the themes emerging from the UKCRIC scoping workshops to help shape our proposed research agenda for the next five years.

While CSIC's work to date has delivered a number of achievements in promoting innovative solutions for smart infrastructure, an industry survey carried out by the Knowledge Transfer Network (KTN) highlighted key ongoing challenges:

- lack of integrated solutions for smart infrastructure
- limited industry appetite for innovation – reliability and safety concerns
- lack of a strong business case for smart infrastructure solutions
- lack of choice in the supply chain.

Responding to these industry challenges will, in part, shape CSIC's agenda and build on achievements arising from our collaborative work with leading partners in the infrastructure and construction markets. In addition to continued innovation in new technologies and approaches, CSIC will seek to expand and integrate the work of Phase One in order to bring holistic and smart solutions that can be easily deployed by industry to address real needs.

Over the next five years CSIC is keen to increase its industry reach and support the UK to become a world leader in the fields of sensing technologies, asset management and smart city development. To achieve this, we plan to develop our model for industry partnership, and work closely with a range of partners, including SMEs, to deliver robust solutions and help to develop the supply chain's capabilities.

Thames Tideway and HS2 have confirmed their commitment to implementing innovation, and are running focussed programmes to engage their supply chain and academia in shaping and delivering this. We look forward to exciting opportunities to work with both organisations.

To strengthen CSIC's level of impact, we will work with a range of world-leading academic organisations to bring the best new thinking in relevant areas to our partners. This includes the addition of a number of new Co-Investigators to the CSIC team.

Through UKCRIC we are developing new links with related EPSRC programmes, including International Centre for Infrastructure Futures (ICIF), Infrastructure Business Models Valuation and Innovation for Local Delivery (IBUILD) and Multi-scale Infrastructure Systems Analytics (MISTRAL). Internationally we are working with the University of California at Berkeley, the Centre for Advanced Infrastructure and Transportation at Rutgers University, USA, the University of Tokyo, Japan, the National University of Singapore, and Tongji University, China.

CSIC will also 'spin-in' technologies from other fields, working with other UK universities and the Catapults in Transport Systems, Future Cities, Advanced Manufacturing and Digital Economy to engage their partners in these emerging areas in delivering smart infrastructure solutions.

Collaboration will be key to success. CSIC is working with industry bodies including the Construction Leadership Council (CLC) and the Institution of Civil Engineers (ICE) to unite the industry in smart innovation.

There is more yet to be done. As an industry we must continue to break down barriers and engage at all levels to foster innovation, placing it at the heart of infrastructure planning. No single organisation can do this alone, but if we work together, we all benefit.

CSIC's new Phase Two Investigators

Dr Giovanna Biscontin
Lecturer in Geotechnical Engineering
Giovanna Biscontin was awarded her MS and PhD in geotechnical engineering from the University of California, Berkeley (USA). She was an academic at Texas A&M University until joining the Department of Engineering at the University of Cambridge in 2013. Her work focuses on characterising and modelling the response of soils, especially when subjected to cyclic loading, such as earthquakes. Her research interests are also related to offshore deposits and soft marine clays in particular. She received the CAREER Award from the US National Science Foundation in 2004. Her work also includes constitutive modelling of the compressive response of Venice Lagoon soils, seafloor-riser interaction, correlations between strength and geophysical properties, design of mechanically stabilised earth walls, and probabilistic methods applied to geotechnical engineering. She is currently heading a project on design of foundations for offshore wind towers, sponsored by the National Science Foundation.

Dr Ruchi Choudhary
Reader in Architectural Engineering
Dr Ruchi Choudhary is leading the multi-disciplinary Energy Efficient Cities initiative (EECi) with colleagues in transport technologies and urban planning. She specialises in building simulation and environmental characteristics of the built environment. Her current research focuses on urban-scale energy simulation of built environments, with specific emphasis on uncertainty analysis and retrofits of existing buildings. The work investigates how simulation science can support pathways towards energy efficient cities, taking into account large variability among buildings, and a highly dynamic context associated with economics, regulations, and the influence of new emerging technologies. This research has led to new methods and tools including: a simulation platform for multi-period energy retrofits under economic uncertainties; stochastic urban-scale energy model that quantifies the impact of current UK policies, and spatial energy network optimisation tool to predict energy and emissions.

Professor Daping Chu
Head of the Photonics & Sensors Group
Daping Chu is Chairman of the Centre for Advanced Photonics and Electronics (CAPE) Steering Committee. He is a Director of Research and also a Fellow and Director of Studies at Selwyn College, a chartered engineer, a Fellow of the Institution of Engineering and Technology, a Chartered Physicist and a Fellow of the Institute of Physics. He joined the Engineering Department at the University of Cambridge in 1998 and Cambridge Research Laboratory of Epson in 1999, where he was the Executive Researcher. His research activity has encompassed theoretical and experimental condensed matter physics. Current research interests include: future display technologies - full colour high brightness trans-reflective displays and 2D/3D holography; GHz/THz tunable dielectrics; energy saving and radiation control for the built environment, metal oxide materials and transparent electronics and printable and flexible electronics and inkjet fabrication

Dr Matthew DeJong
Senior Lecturer in Structural Engineering
Matthew is a Fellow and Director of Studies in Engineering at St Catharine's College. Previously he was a Fulbright Scholar at the Technical University of Delft and completed his PhD at the Massachusetts Institute of Technology. In 2009 he won the Edoardo Benvenuto Prize for his research in mechanics of masonry structures. He has worked in industry, for a structural engineering design consultancy in California, and his current research interests include: earthquake engineering and structural dynamics; assessment and monitoring of existing infrastructure; masonry structures; computational modelling and soil-structure interaction.

Dr Elisabete Silva
Senior Lecturer in Spatial Planning

Elisabete Silva is a Fellow and Director of Studies at Robinson College. She is Director of the M.Phil in Planning Growth and Regeneration and Director of the Lab of Interdisciplinary Spatial Analysis (LISA Lab), a Geographic Information Lab that congregates data, software and expertise for spatial analysis in Land Economy's related subjects – planning, real estate and finance, environmental policy, environmental and climate change. Her 20-year research career, both in the public and private sector, brings focus to the application of new technologies to spatial planning, in particular city and metropolitan dynamic modelling through time, including: land use, transportation and metropolitan planning; regional and integrated planning (urban/transportation/environmental); geographic information systems and planning support systems, and computation and dynamic simulation – AI models.

Dr James Talbot
University Lecturer

James Talbot is Fellow and Director of Studies in Engineering, at Peterhouse. He is a chartered engineer and a Fellow of the Institution of Mechanical Engineers, a Member of the Institute of Acoustics and a Director of the International Institute of Acoustics & Vibration. His post-doctoral research focused on the control of noise and vibration from underground railways. He worked with engineering consultancy Atkins where he spent nine years working primarily in the fields of vibration engineering and structural integrity. His experience covers experimental work, theoretical analysis and design from across a wide range of industries. He returned to the University of Cambridge, where he completed his BA and MEng, in 2013 as a University Lecturer in the Structures Group of the Civil Engineering Division. His research interests lie broadly within the field of structural dynamics to include: dynamic models for the performance-based design of base-isolated buildings; analysis and control of ground-borne vibration and re-radiated noise from roads and railways, and dynamic measurements for monitoring structural integrity.

The International Conference on Smart Infrastructure and Construction (ICSIC)

The International Conference on Smart Infrastructure and Construction (ICSIC) 2016, organised and hosted by CSIC, will bring together world-leading academics and practitioners from the fields of infrastructure planning, asset management and sensing.

Key speakers at the three-day event, taking place from 27 to 29 June 2016, include: Professor Tom O'Rourke, Thomas R Briggs Professor of Engineering, School of Civil and Environmental Engineering, Cornell University, USA; Andrew Wolstenholme OBE, Chief Executive Officer, Crossrail, UK; Keith Clarke CBE, Vice President, Institution of Civil Engineers and David McKeown, CEO, Institute of Asset Management, UK.

Key topics for discussion will include infrastructure resilience, design for infrastructure adaptability, creating value from infrastructure and delivering smarter infrastructure. The unique combination of specialist fields and disciplines at ICSIC 2016 will bring focus to the power of smarter information with the aim of confronting persistent barriers and identifying and developing novel and proactive solutions.

ICSIC 2016 will provide a dynamic platform for researchers and academics working in the fields of geotechnical and structural engineering, structural health monitoring, asset management and city scale infrastructure planning the use of smarter data in cities. The conference will also be of interest to decision makers and analysts from industry and government responsible for: design, construction and operation of infrastructure assets; asset management and specification and procurement of major infrastructure assets.

Director of CSIC, Dr Jennifer Schooling, said:

"ICSIC 2016 is a significant step in the history of CSIC. The conference has attracted key speakers from industry and academia who are world-leading experts in their fields. This event will create a unique platform for discussion with the aim of furthering CSIC's key aim to transform the future of infrastructure through smarter information."

A number of topics related to the key theme will also be addressed, including: engagement with different stakeholders and wider society; the role of regulators and standards bodies; effective data management and interpretation and the value of smart infrastructure to society. Parallel session streams will discuss:

- Cities – the role of planning in enhancing resilience and adaptability of the urban environment; how investment in infrastructure promotes economic development
- Assets – whole-life approaches to asset management; futureproofing considerations for infrastructure asset management
- Sensors – how better information can inform flexible design, improved resilience and life extension; the role of sensing in performance-based design and condition-based maintenance.

The organisers of ICSIC 2016 include Head of CSIC, Professor Lord Robert Mair (Co-Chair), CSIC Co-Investigators Professor Kenichi Soga (Co-Chair), Dr Ying Jin, Professor Duncan McFarlane, Professor Cam Middleton, Dr Ajith Parlikad and Director of CSIC, Dr Jennifer Schooling.

ICSIC 2016 will be held at Robinson College, University of Cambridge from Monday 27 to Wednesday 29 June. The conference dinner will be held at St John's College on Tuesday 28 June.

For full details see:
www-icsic.eng.cam.ac.uk

For further information contact:
ICSIC 2016 Event Manager:
ifm-events@eng.cam.ac.uk
+44(0)1223 766141

The University of Cambridge partners with UKCRIC to further infrastructure research

Image of the National Research Facility for Infrastructure Sensing. Courtesy of Grimshaw Architects

The University of Cambridge is one of the founding members of the United Kingdom Collaboratorium for Research in Infrastructure and Cities (UKCRIC). UKCRIC will be one of the largest collaborative research programmes in the UK, connecting multiple communities of researchers working on clean water supplies, transport, social interaction, waste management, energy, sensors, flood defences, urban living, and data handling, amongst other areas, to provide a coordinated multidisciplinary and cross sectoral knowledge base. Current national and international partners include: Bristol City Council, Network Rail, Mott MacDonald, Buro Happold, Atkins, National Grid, Department for Transport, EDF and Thames Water, with many more partners to follow.

Initially spanning 14 universities, UKCRIC has received £138 million in capital funding from the Government on the basis that there is an urgent need, and a transformative opportunity, to develop and exploit major advances in scientific and engineering understanding and connect this with the evolving needs and ambitions of nations and cities within the UK. The funding will be used for 11 national laboratories that underpin transformative research for all partners and stakeholders. Further funding is being sought for a central Coordination Node, a series of linked 'Urban Observatories' and multi-level modelling and simulation facilities.

The University of Cambridge will receive £18 million in funding to build a National Research Facility for Infrastructure Sensing on the West Cambridge site, which will build upon the expertise of the Centre for Smart Infrastructure and Construction.

The interdisciplinary research facility, due to open in spring 2018, will focus on research in the application and development of advanced sensor technologies for the monitoring of the UK's existing and future infrastructure, in order to improve resilience and extract maximum whole-life value. The use of advanced sensors and appropriate data analysis will ensure better product quality, enhanced construction safety, and smarter asset management.

A dedicated deployment team will assist the installation, monitoring and maintenance of the newly developed sensor systems, enabling all UKCRIC partners to develop powerful sensing platforms that can be deployed in the field quickly and effectively. Sensors will be used through the construction and life of the building, to exemplify the possibilities of smart infrastructure technology.

The major new building (4280m^2) will house:

- double- and single-height laboratories for rapid prototyping and open-source microcontroller platforms to produce and develop novel sensor systems at a range of scales
- vibration isolated and severe environment laboratories to test and calibrate sensors under a range of environmental conditions and temperatures
- a Microelectromechanical systems (MEMS) lab
- an advanced structural dynamics lab with scaled and full-scale physical testing capabilities
- advanced facilities for data analysis and smart construction computation
- a field deployment team
- lecture and teaching space.

To learn more about the United Kingdom Collaboratorium for Research in Infrastructure and Cities visit: www.ukcric.co.uk

CSIC would like to thank our Phase One Industry Partners

Infrastructure clients (owners and operators)

Consultants, contractors and asset managers

Technology and information supply chain

Knowledge partners

Unless credited all photographs have been provided by staff and students at CSIC, Department of Engineering, University of Cambridge

CSIC

Cambridge Centre for
Smart Infrastructure & Construction

Email: csic-admin@eng.cam.ac.uk
Tel: +44 (0)1223 746976
www.centreforsmartinfrastructure.com
@CSIC-IKC

An Innovation and Knowledge Centre funded by

EPSRC
Engineering and Physical Sciences Research Council

Innovate UK

Printed on environmentally friendly paper