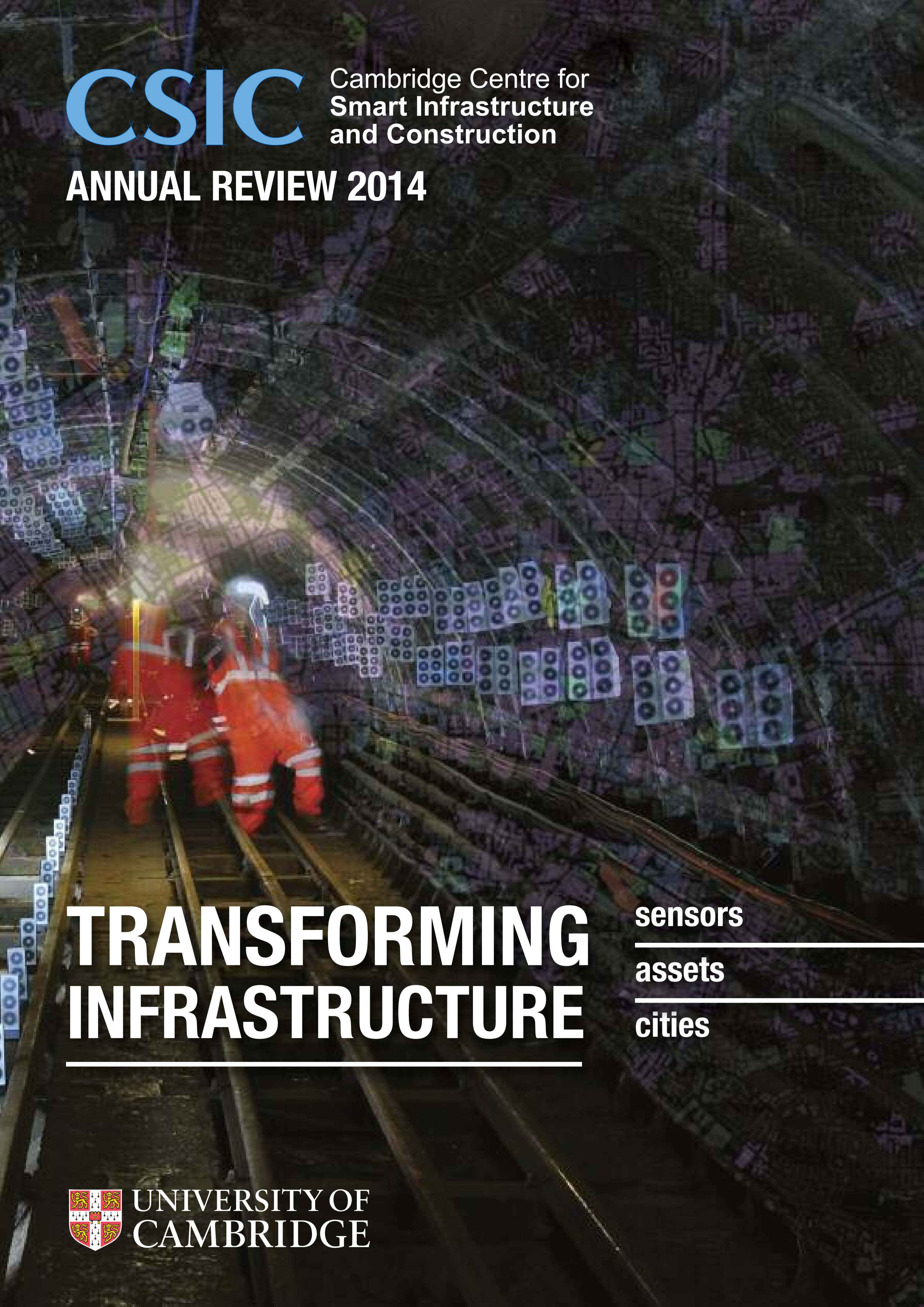


CSIC Cambridge Centre for **Smart Infrastructure and Construction**

ANNUAL REVIEW 2014

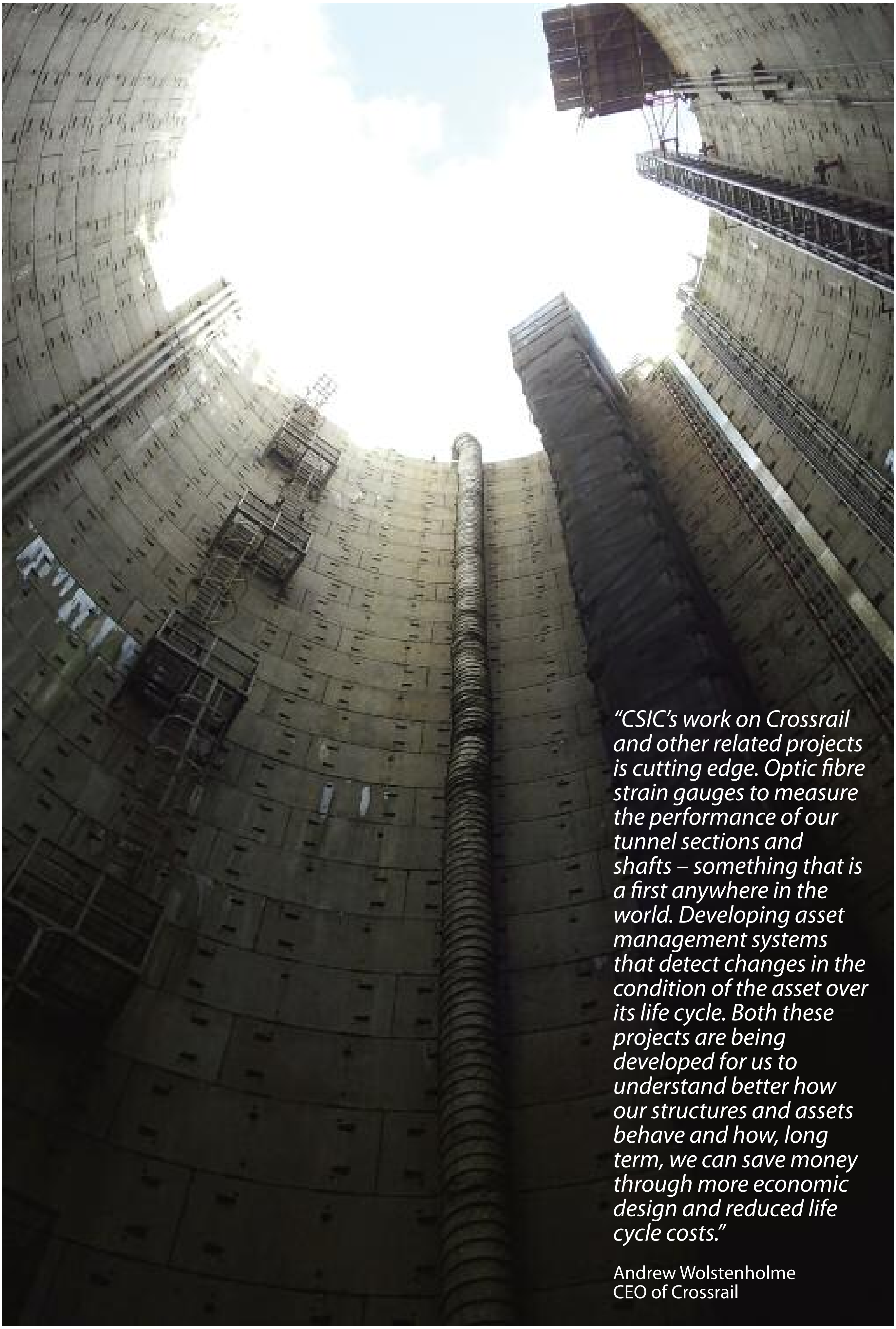
TRANSFORMING INFRASTRUCTURE

sensors

assets

cities

UNIVERSITY OF CAMBRIDGE



"CSIC's work on Crossrail and other related projects is cutting edge. Optic fibre strain gauges to measure the performance of our tunnel sections and shafts – something that is a first anywhere in the world. Developing asset management systems that detect changes in the condition of the asset over its life cycle. Both these projects are being developed for us to understand better how our structures and assets behave and how, long term, we can save money through more economic design and reduced life cycle costs."

Andrew Wolstenholme
CEO of Crossrail

Contents

Transforming the future of infrastructure through smarter information

Steering Group

Professor John Burland CBE, Imperial College (Chair)
Dr Keith Bowers, London Underground
Alan Couzens, Infrastructure UK
Tim Embley, Costain
Rab Fernie, ex Cementation Skanska
Tom Foulkes, Victoria BID
Steve Hornsby, ex IBM
Professor Robert Mair CBE, CSIC, University of Cambridge
Professor Duncan McFarlane, CSIC, University of Cambridge
Professor Andrew McNaughton, HS2
Professor Campbell Middleton, CSIC, University of Cambridge
Richard Ploszek, Royal Academy of Engineering & Infrastructure UK
Dr Jennifer Schooling, CSIC Director
Professor Kenichi Soga, CSIC, University of Cambridge
Dr Scott Steedman CBE, British Standards Institute (BSI)
John St Leger, Strainstall UK Ltd
Paul Westbury CBE, Buro Happold
Professor Ian White, Department of Engineering, University of Cambridge

International Advisory Group

Professor Tom O'Rourke (Chair), Cornell University, USA
Professor Yozo Fujino, University of Tokyo, Japan
Professor Bill Spencer, University of Illinois, USA
Professor Paul Wright, University of California, Berkeley, USA
Professor Hehua Zhu,Tongji University, China

CSIC in numbers

42
collaborative projects with industry to date

41
active industry partners

50
field demonstrations

158
trainees or students through the Centre

562
publications including academic papers

7
awards and shortlistings

1
patent

£753,615
income from commercial services

£10,425,874
non-IKC research grant funding

cumulative figures 2012 to February 2014

TRANSFORMING CONSTRUCTION AND MANAGEMENT OF INFRASTRUCTURE

Professor Robert Mair
Head of CSIC,
Head of Civil Engineering,
University of Cambridge

High-quality infrastructure, such as tunnels, bridges, roads, railways, buildings and utilities, is essential for supporting economic growth and productivity. It attracts globally-mobile businesses and promotes social well-being.

Modern construction and infrastructure must be robust, resilient and adaptable to changing patterns – particularly natural disasters and climate change. It also needs to be optimised in terms of efficiency, cost, low carbon footprint and service quality.

There is a compelling need for change – the UK construction industry is perceived:

- to be expensive, often late and of mixed quality
- as being 'old and slow' as opposed to the 'new and fast' technology sectors
- as having a fragmented supply chain
- as being resistant to innovation

The industry creates significant waste – an estimated 20% of 420m tonnes of material used each year is thrown away – contributing to 109m tonnes of construction and demolition waste produced annually – three times more than produced by UK households. Historically all these reasons have made transformation of the construction industry difficult to deliver.

The way forward

Modern infrastructure and construction can benefit enormously from the innovative use of emerging technologies in sensor and data management such as:

- fibre optics
- Micro Electro Mechanical Systems (MEMS)
- computer vision
- power harvesting
- radio frequency identification (RFID)
- wireless sensor networks

There are real opportunities for these new technologies to make radical changes to the construction and management of infrastructure, leading to considerably enhanced efficiencies, economies, resilience and adaptability.

Emerging technologies can be applied to advanced health monitoring of existing critical infrastructure assets to quantify and define the extent of ageing, ascertain the consequent remaining design life of infrastructure, ensure resilience and reduce the risk of failure.

Fresh thinking

The engineering, management, maintenance and upgrading of infrastructure require fresh thinking to minimise use of materials, energy and labour whilst still ensuring resilience. This can only be achieved by a full understanding of the performance of the infrastructure, both during its construction and throughout its design life, through the application of innovative sensor technologies and other emerging technologies.

The key aim of CSIC is that emerging technologies from world-leading research at Cambridge will transform the construction industry through a whole-life approach to achieving sustainability in construction and infrastructure in an integrated way.

This covers:

- design and commissioning
- the construction process
- exploitation and use
- eventual de-commissioning

Crucial elements of these emerging technologies are the innovative application of the latest sensor technologies, data management tools, manufacturing processes and supply chain management processes to the construction industry, both during infrastructure construction and throughout its design life.

The major objective of CSIC is to integrate these innovations for exploitation and knowledge transfer – something which is new to the UK construction and infrastructure industry. We believe that the outcome will be major transformations in the approaches to the design, construction and use of complex infrastructure leading to step changes in improved health and productivity, a low carbon society, and sustainable urban planning and management.

There will be a very substantial market for exploitation of these technologies by the construction industry – particularly contractors, specialist instrumentation companies and owners of infrastructure for both domestic and international markets.

With our industry partners, CSIC is pushing forward new frontiers of technology and innovative management in a sector of the economy which has traditionally had very little investment in research, particularly when compared to sectors such as computing or electronics.

CSIC draws on recent research in new techniques, new models of construction and new management approaches. Through this innovation in technology and management, supported by extensive training and development, deep-rooted attitudes and assumptions are being challenged by CSIC with the aim of revolutionizing construction and the public perception of it.

"With our industry partners, CSIC is pushing forward new frontiers of technology and innovative management in a sector of the economy which has traditionally had very little investment in research."

Professor Robert Mair
Head of CSIC

STRATEGIC DIRECTION – DELIVERING INDUSTRY'S NEEDS

Installing a steel reinforcement in a bored pile

Dr Jennifer Schooling
Director of CSIC,
University of Cambridge

"The last year has witnessed a sea-change in CSIC's activities, from producing potentially useful research outputs to developing those outputs into offerings that industry can use and benefit from – truly helping to transform the future of infrastructure and construction through smarter information, technologies and approaches."

Dr Jennifer Schooling
Director of CSIC

As an Innovation and Knowledge Centre (IKC), CSIC is in the privileged position of being jointly funded by the Engineering and Physical Research Council (EPSRC) and the Technology Strategy Board (TSB), with significant in-kind contribution from industry partners. This brings with it an expectation that we will go beyond the normal boundaries of research, and deliver outputs at a higher level of technology readiness that industry can take forward.

This development and delivery is a major focus of CSIC's current and future activities, and the award of our Tranche 2 grant in June last year reflects this. We are embarking on a range of exciting initiatives to achieve this ambition, including:

- focus on scale-up and standardisation – making our methodologies and technologies robust and repeatable
- recruiting a deployment team to test and improve these methods and technologies on site-based projects
- developing best practice guidance and industry training courses
- new collaborative projects
- holding industry partner meetings to present and test our findings
- exploring secondment of staff from our industry partners into our deployment team to bring the wisdom and experience of site-based work and industry analysis requirements to shaping our outputs and developing standards

The model of seconding staff into CSIC from our partner organisations has received strong support from industry partners and from our funders, as it is seen as an effective way of making sure that our work delivers to real industry needs. We plan to host these secondees for periods of six to twelve months, allowing us to vary the skill set in our deployment team as our requirements change and we progress our different technology offerings through the development phase. We have just welcomed our first two secondees from Arup and Mott MacDonald and are keen to discuss further secondments with other partner organisations.

We have a strong team supporting these activities. We have been delighted to welcome Helen Needham, our new Communications Manager, who has already made a real difference to our ability to reach out to industry partners and a wider audience. Helen's Flickr site on The Making of a Smart Tunnel has received around 4,000 viewings, and she is the architect of this Annual Review you are reading.

Other exciting milestones, for CSIC were our first two training courses for industry, expertly developed and delivered by our Training and Knowledge Transfer Manager, Dr Cedric Kechavarzi. You can read more about this and our plans for further training courses later in this Annual Review.

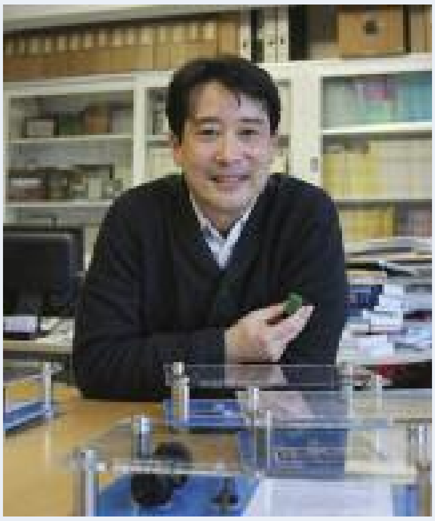
Phil Keenan, our Business Development Manager, is also continuing to provide first-rate support in developing our engagement with industry, and has been a driving force behind the development of our new dynamic sensing project, to be led by Dr Mohammed Elshafie. Phil is coordinating our efforts in the wider arena of Horizon 2020 and other EU and UK funding, as well as supporting our collaborative projects in assessing the market potential of their outputs.

The last year has witnessed a sea-change in CSIC's activities, from producing potentially useful research outputs to developing those outputs into offerings that industry can use, develop and benefit from – truly helping to transform the future of infrastructure and construction through smarter information, technologies and approaches. We welcome your continued involvement in this journey.

Secondees at work

INNOVATIVE MEASUREMENT TOOLS AND TECHNIQUES

Instrumentation of diaphragm walls for strain measurement, Abbey Mills shaft



Professor Kenichi Soga
Co-Investigator CSIC,
Professor of Civil Engineering,
University of Cambridge

A pre-tensioning clamp and fibre optic cable on a reinforcement cage

On-site application

CSIC's strength is applying new and innovative sensor technologies to real field environments involving construction and maintenance of infrastructure.

This year we have worked on more than 15 sites with our industry partners, deploying and testing CSIC's sensor technologies. The industry's pull for these technologies and systems is very strong – we have now had to invest in creating a special Deployment Team to respond to the high demand and quick response requirements.

As an international centre of excellence in sensors, CSIC is always pushing the boundaries of new sensor technologies.

Some of the current transformative tools and technologies CSIC has continued to develop over the past year include:

- fibre optic dynamic strain measurement
- new computer vision tools
- a MEMS strain sensor
- an ultra-low power wireless sensor
- a parametrically excited vibration-based energy harvesting device

Distributed fibre optics strain measurement

Structural integration of fibre optic sensing systems represents a new branch of engineering. It involves the unique marriage of fibre optics, optoelectronics and composite material science to monitor a wide range of structures.

The highlights of this year's activities in fibre optic sensing are:

- performance monitoring of retaining walls at Crossrail's Pudding Mill Lane, Limmo Shaft, Stepney Green and Paddington Station sites
- monitoring of a very deep diaphragm wall at the Abbey Mills Shaft for Thames Water (winner of the 2013 Fleming Award)
- assessment of National Grid's tunnel lining behaviour during tunnel construction by embedding optical fibre in the precast concrete lining segments
- monitoring of masonry structures at London Bridge Station to observe the movements during extensive piling work below
- 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; a major new London embassy; and a site in Houston, US 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
- monitoring of the 100-year-old Post Office railway tunnel during construction of Crossrail's tunnels immediately below

Looking ahead

- we are currently developing a new low cost miniature fibre optic analyser in collaboration with UCL and Aeroflex
- we are developing cheap fibre optic sensing cables and connectors with several industry partners
- new field deployment projects are starting, including tunnels at CERN and piles at the Victoria and Albert Museum
- we are starting a new research project to develop a system to measure strains for dynamic problems, such as traffic-induced vibration on bridges
- we are targeting all our developments for practical use in civil engineering and the construction industry
- CSIC is hosting its first international conference in June 2014 to disseminate our fibre optic sensing work as well as to provide opportunities for academics and practitioners to share their experiences

Computer vision

CSIC's innovative computer vision tools aim to replace current visual inspection to detect and monitor anomalies such as cracks, spalling and staining of concrete in construction and maintenance work.

Our computer vision tools transform image sets from varying and unknown coordinate systems into one single coordinate system. This will provide inspectors with automatic tools to combine large numbers of pictures into a single, high-quality, wide-angle composite view.

Subsequent images can be compared to the past history and used for change detection to identify anomalies such as water leakage and crack development.

We are also developing another computer vision system called Digital Image Correlation (DIC), which evaluates the movements of an objective from multiple images taken at different times using fixed cameras. This system is considered to be complementary to conventional theodolite surveying systems and can be effective when targets are difficult to install or when a site requires large numbers of multiple 'moving' locations for monitoring.

The highlights of this year's field activities in computer vision are:

- we have trialled a new computer vision system at National Grid's new power tunnels in London in collaboration with Toshiba Cambridge Research Laboratory.

  This work was presented at the 13th IAPR Conference on Machine Vision Applications in Kyoto, Japan and won the best paper award
- digital image correlation techniques were used to monitor the movement of the Post Office railway tunnel during construction of Crossrail's tunnels immediately below

Digital Photogrammetry and deployment of WSN system in the 100-year-old Post Office railway tunnel

"This technology has the potential to transform the way in which we monitor the structural integrity of our tunnel network and potentially removes the risks associated with inspection persons entering the cable tunnels."

Mark Farmer, Project Engineer, National Grid

Looking ahead

- we are developing change detection software, which identifies the regions of changes between multiple images of the same scene taken at different times
- the computer vision software tools will be integrated to robotics for semi-automated image capturing
- field trials at London Underground sites, London Bridge Station and CERN are planned

Wireless Sensor Network and Micro Electro Mechanical Systems

Future monitoring systems will undoubtedly comprise Wireless Sensor Networks (WSN) as part of the 'internet of things' and will be designed around the capabilities of autonomous nodes. Each node in the network will integrate specific sensing capabilities with communication, data processing and power supply. The use of wireless sensor technology has significant potential benefits for infrastructure monitoring, allowing a rapid deployment due to elimination of cabling. Combined with low power Micro Electro Mechanical Systems (MEMS) sensors, there is an opportunity for substantial overall cost savings for large scale monitoring.

WSN (Wireless Sensor Network)

CSIC's challenges have been to establish a methodology that:

- is robust
- works in confined space conditions with intensive construction activities
- ensures that the system (both sensor and communication) is calibrated properly on site
- the data is reported in the way that clients can use effectively to make decisions

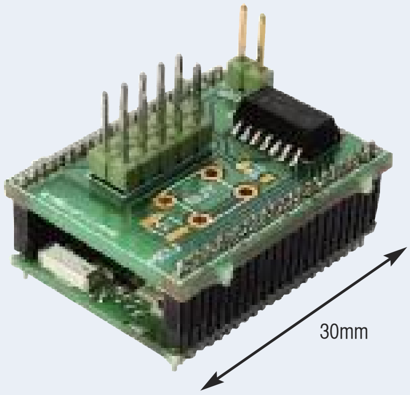
Our R&D development in WSN includes open source WSN software and hardware for civil engineering monitoring, a network diagnostic tool and a 'BIM friendly' WSN planning and maintenance tool.

The highlights of this year's field activities in WSN are:

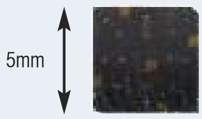
- we deployed a portable WSN system that was attached to temporary timber tunnel linings at London Underground's Victoria and Tottenham Court Road Stations. The objective was to measure the load applied to the timbers during and after tunnel construction so that the size and thickness of the timber can be optimised for safe construction
- we installed a large scale WSN system in the 100-year-old Post Office railway tunnel to measure its movement during construction of a large diameter platform tunnel underneath it as part of Crossrail's project
- a WSN system was installed at Crossrail's Paddington Station site to monitor the movement of retaining walls during excavation
- CSIC PhD student Heba Bevan developed an ultra-low power 'UtterBerry' WSN mote which received recognition at the 2013 IET Innovation Awards.

Looking ahead

- we are working with its industry partners to develop a WSN guidance document to be published in 2015
- more field deployments are planned at several London Underground stations and for the London Bridge Station upgrade project



Wireless sensor network mote



MEMS strain sensor designed with its own unique 'compass' of sensing elements to sense strain from different directions

Ultra low power 'UtterBerry' wireless sensor mote

MEMS (Micro Electro Mechanical Systems) technology:

CSIC's WSN system is integrated with sensors – many of these are based on MEMS technology.

About MEMS:
MEMS are 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.

We envisage an integrated MEMS WSN system offering a solution to monitor and control physical and chemical parameters in many civil infrastructure applications.

MEMS sensors offer major advantages over conventional monitoring systems:

- smaller size
- lower power consumption
- value for money due to mass production
- extended performance and lifetime

Looking ahead

- we are developing a low power MEMS-based strain sensor which has a strain resolution of at least 20 nanostrain
- we are developing a 1 cm^3 package comprising low-noise multi-axis resonant MEMS strain gauges (and a temperature sensor) co-integrated with low-power interface circuits that provide digital output
- the circuits will be optimised to target an average power dissipation of less than 100 microW to enable the future integration of energy harvesting technologies
- a prototype MEMS circuit integrated device is expected to be available for testing in mid-2014

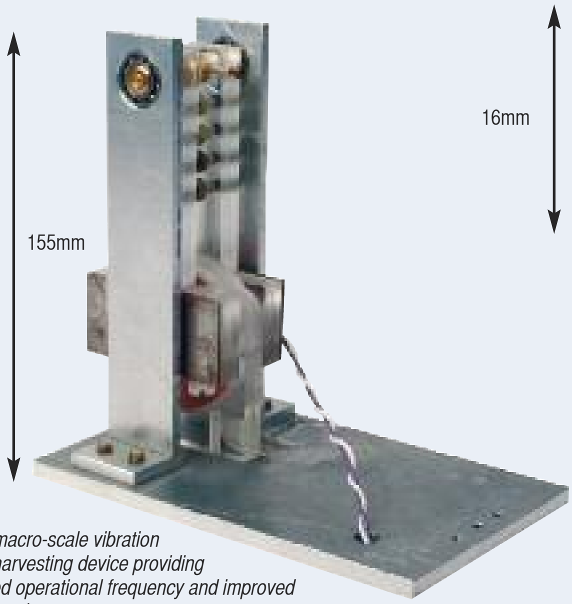
Energy harvesting technology

This is a key enabler for the development of a range of WSN-based structural health monitoring solutions where the use of batteries or mains power is either impractical or adds significant cost.

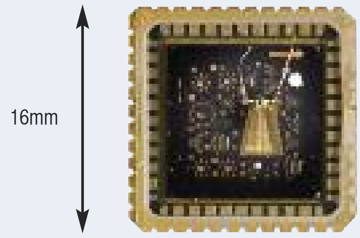
Energy harvesting solutions can enhance battery lifetime or potentially eliminate their use completely. They will cut cost by minimising the requirement for repeated manual intervention

CSIC has developed an innovative vibration-based energy harvesting device at macro- and MEMS- scales. This device is based on parametric resonance with the following benefits:

- it provides the potential for an increase in harvested power density
- It enables a wider frequency band of operation compared with similar devices excited by direct resonance
- CSIC and Cambridge Enterprise have filed a patent on this unique technology



CSIC's macro-scale vibration energy harvesting device providing enhanced operational frequency and improved power density



MEMS-scale energy harvester on a silicon chip

Looking ahead
CSIC is currently developing second generation prototypes for parametrically excited vibration energy harvesters, expected to be ready for commercialisation in 2015

"Energy harvesting has been attracting serious research and development attention over recent years. Increasing the harvested power will expand the potential implementation into real industrial remote sensing applications."

Steve Riches, Business Development, GE Aviation Systems, Newmarket

Way forward

We believe that working with teams of infrastructure owners, consultants and contractors is the key to introducing innovation into the construction and infrastructure industry quickly.

All parties need to understand the advantages and limitations of the technologies and work together to overcome issues arising from the technology level, regulations and the site environment.

Our main mission is to pass this knowledge to the construction and infrastructure industry through field demonstrations, training courses and guidance document publication, so that the industry as a whole can be recognised as an innovation leader.

Many of our CSIC industry partners believe in this and we have started to see more infrastructure owners and consultants specifying the use of new sensor technologies in their design and construction activities.

We will continue to develop new sensor technologies, at the same time being committed to delivering practical solutions to the industry so that everyone can use them.

The Technology Team

Fibre optics
Professor Kenichi Soga
Dr Mohammed Elshafie
Professor Robert Mair
Dr Cedric Kechavarzi
Dr Loizos Pelecanos
Peter Knott

Fibre optics analyser
Professor Kenichi Soga
Dr Jize Yan
Dr Xiaomin Xu

Wireless Sensor Network
Professor Kenichi Soga
Dr Cecilia Mascolo
Professor Campbell Middleton
Dr Jize Yan
Dr Xiaomin Xu
Dr Sarfaz Nawaz
Paul Fidler
David Rodenas Herraiz
Dr Christos Efstratiou

Computer Vision
Professor Kenichi Soga
Professor Roberto Cipolla
Dr Ankur Handa

MEMS/Vibration Energy Harvesting
Dr Ashwin Seshia
Professor Kenichi Soga
Dr Cuong Do
Yu Jia

Case study

Transforming construction: implementing a large scale monitoring scheme to measure structural performance and associated ground movements of a deep shaft

Attaching fibre optic cable on a diaphragm wall reinforcement cage

Installation of reinforcement cage with fibre optic cables

Deep circular diaphragm wall shaft – monitored with fibre optic instrumentation

Location

Abbey Mills Shaft F, Stratford, East London (Thames Water Lee Tunnel project)

Working with

Thames Water along with AECOM, MVB JV, CH2M Hill, Bachy Soletanche and Underground Professional Services

Challenges

- to ascertain accurate ground movements around a deep excavation
- to reduce costs by improved understanding of structural performance

Project details

- one of the largest and deepest shafts ever constructed in London
- 72m deep; 30m diameter
- forms an integral part of the Lee Tunnel and Thames Tideway Tunnel projects
- CSIC asked by Thames Water to deploy fibre optic strain sensors in the major circular shaft excavation at Abbey Mills
- we monitored deformation in the retaining walls and adjacent ground during shaft excavation
- we instrumented three diaphragm wall panels with fibre optics to monitor both bending strain (in the vertical direction) and hoop strain (horizontal direction)

Achievements

- fibre optic sensors successfully installed in three 84m deep diaphragm walls – minimal disruption to construction process
- first use of fibre optics as a measure of hoop strain (and hence hoop stress)
- new and detailed understanding of performance of 72m deep shaft showing that separate segments of the wall act as a solid wall with isotropic stiffness in hoop direction
- surface settlements were extremely small, particularly during excavation: < 2mm (vs. empirical predictions of 40mm)

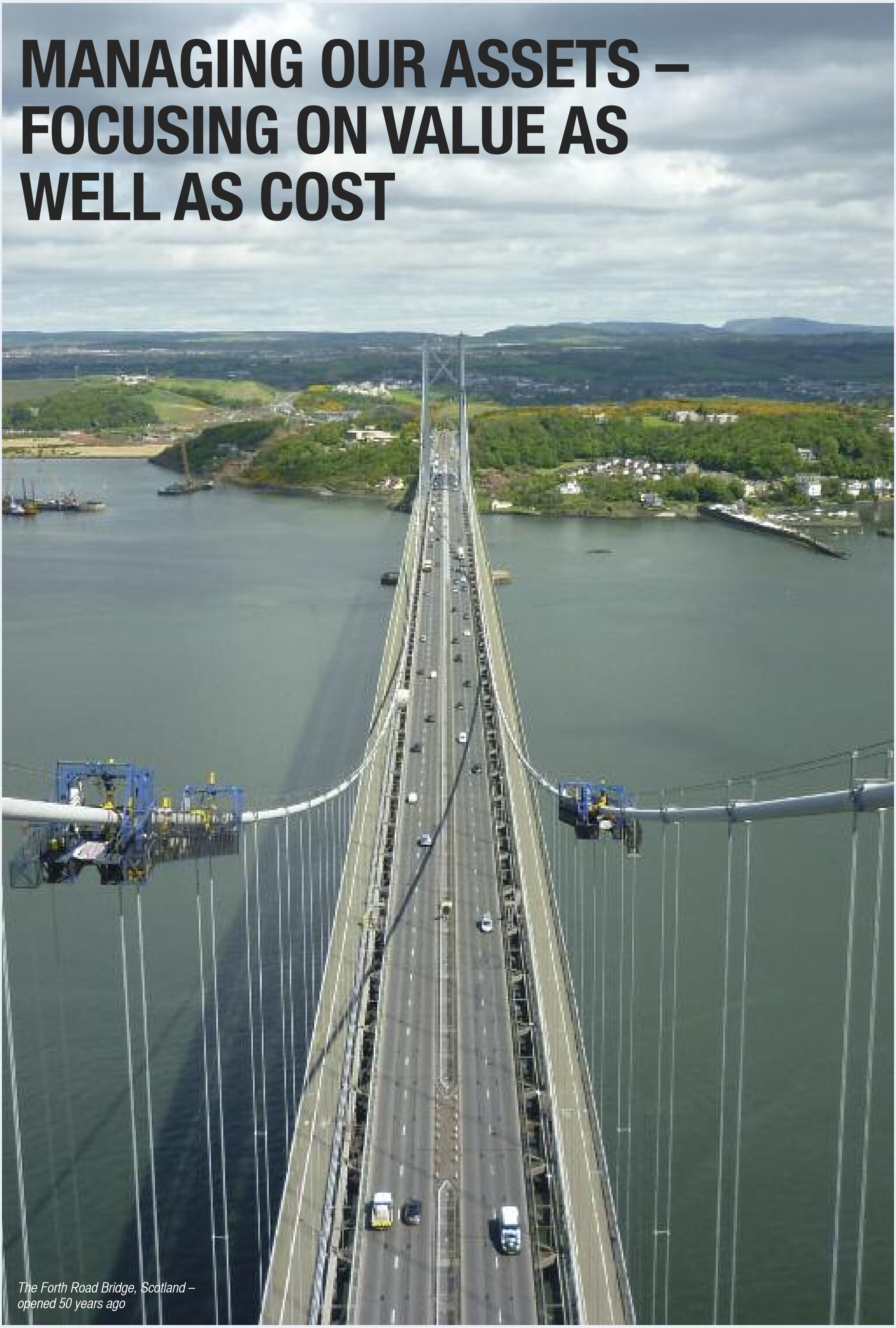
Transformative benefits to the construction industry

- an estimated cost saving of at least £10 million in risk mitigation for future Thames Water construction projects
- minimal disruption to construction process: as fibre optic sensors successfully installed in three 84m deep diaphragm walls
- innovative design for future work: improved understanding of structural behaviour and improved understanding and confidence in fundamental behaviour of the shafts and associated ground movements enabling innovation in design
- award winning: winner of 2013 Cementation Skanska's Fleming Award – one of the top prizes recognising excellence in geotechnical engineering
- pioneering research: provided data and evidence for future deep shaft design and construction – with particular use for the forthcoming Thames Tideway Tunnel project involving 18 further deep shaft excavations in built up areas

"Thames Water's approach has been changed by this successful result; it will apply the method to all future major shaft excavations. The confirmation of the design models that will be realised by this work will give greater confidence and fewer objections by third party structure owners and operators thus reducing the level of institutional objection during the planning process."

John Greenwood, Tideway Tunnels

MANAGING OUR ASSETS – FOCUSING ON VALUE AS WELL AS COST



The Forth Road Bridge, Scotland – opened 50 years ago

Professor Duncan McFarlane
Co-Investigator CSIC,
Professor of Industrial Information Engineering,
University of Cambridge

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

Sustaining economic growth and meeting the challenges of the future necessitates huge investment to develop and maintain UK infrastructure. It has been predicted that approximately £40-50 billion per annum investment is required until 2030 to extend the existing asset life as well as invest in new infrastructure to cope with future demands.

Given the current economic climate and the cost of building new infrastructure, it becomes extremely important to find a balance between investment in new projects and the upkeep of existing infrastructure.

We aim to address the challenge of managing the current ageing infrastructure by determining the type, the level and the timing of investment required so our assets can meet current and future demand.

We are doing this by devising a number of informative, value-based, predictive tools which will inform and enable asset owners to make appropriate decisions to maintain and even enhance the value of their asset. We believe this is vital, as budget and resource capabilities are constrained.

Current best practice methodologies available for infrastructure asset management focus on economic factors with less attention given to social and environmental factors. They minimise the whole life cost of an asset. This does not guarantee best value.

The case for using sensing and data analysis to enable smarter, proactive asset decision-making:

- being proactive not reactive: maintenance, inspection and refurbishment programmes across a portfolio of infrastructure assets focusing on condition and preventive maintenance programmes need to be developed
- decisions must result in the best value for money
- it is essential to capture and analyse the right data at the right time for asset management decisions to be effective

CSIC is developing sensing and data analysis models which will provide an excellent platform for providing data to enable smarter and proactive asset decisions.

"The Underground has recently made good progress in developing methods for treating condition issues such as seepages in our tunnels. To achieve best value in future, our challenge is now to select the most beneficial of these techniques for each situation. The ideal treatment in a station may be quite different to that in a running tunnel or an equipment room. CSIC's asset management tool offers an opportunity to assess systematically what we should value in each case and guide the decision making accordingly."

Dr Keith Bowers
London Underground's
Profession Head for
Tunnel Engineering

CSIC's Value Mapping Tool

The asset management team at CSIC is developing state of the art methodologies and tools to help infrastructure managers develop asset management plans that can ensure that the asset in question will continue to provide the best value for money.

CSIC's Value Mapping Tool will identify:

- the key stakeholders of the assets. For example, asset owners, maintenance contractor and the end users
- their needs and requirements from the asset
- how these requirements are fulfilled by effective maintenance policies adopted through the asset life cycle
- it will facilitate easy visualisation of key value elements such as the dependencies between type of intervention and the condition of the asset, and the impact on the cost, risk and performance of the asset
- it will identify intervention options available to asset managers to manage or control the value

The Value Mapping Tool's benefits:

- it will help asset managers devise maintenance policies by taking into account the various possibilities and evaluate the best value. The decision maker will be able to choose between cheaper but frequent short-term repairs and expensive but long-term refurbishments, and will be able to balance the cost, risk and performance in a systematic way
- it will be supported by mathematical modelling techniques to determine through-life costs, risks and performance of the assets
- this will help the asset management programme to maximise the value to the various stakeholders at the best possible minimum cost
- this approach assists asset managers to think systematically about the different ways by which the asset value can be managed, and also will highlight the important pieces of information that are necessary to manage the asset

Information Management: CSIC's Information Requirement Tool

A key challenge in infrastructure asset management is the need for proper information management.

The problem:
The wide variety of infrastructural assets spread over a large geographical area coupled with fact that there are various stakeholders with different requirements pose significant challenges for information management.

CSIC's information requirement tool will help infrastructure companies to understand the through-life information requirements for decision making. Its key benefit is understanding the business and decision making processes and eliciting the information requirements to support them.

This tool will help organisations identify the key information that is actually needed to support the decisions, minimising information overload.

Information Future Proofing Tool

The lifetime of an infrastructure asset is typically more than 25 years, and in most cases, assets last more than 100 years. Asset related information must be available to decision-makers over a long period of time – something which becomes challenging given the obsolescence caused by the ever shortening lifecycle of information technologies.

CSIC's Information Future Proofing Tool will:

- help asset intensive infrastructure companies to develop strategies to futureproof information
- examine the technological and organisational aspects for information future proofing
- help decision makers in choosing the right technologies and data formats
- help decision makers collect data and ensure it is available in the long term

Looking ahead
The CSIC asset management work is well under way, with the initial tool developments completed. We are in the process of evaluating the tool's practical applications through a series of case studies with the industry. For example, we are working with London Underground examining how to optimise the maintenance of both running and platform tunnels in the Bakerloo Line and with Surrey County Council to optimise replacement timings for highway protection barriers.

In order to promote industrial adoption of our tools and transform the way infrastructure assets are managed in the UK, we will publish guidance documents for through-life asset management. We will also be working closely with our partners and the wider industry through the HM Treasury Infrastructure UK, Client Working Group to pilot and deploy the tools and methodologies, and to share best-practices and pave the way for truly smart infrastructure management.

The Asset Management Team
Professor Duncan McFarlane
Dr Ajith Parlikad
Dr Phil Catton
Dr Tariq Masood
Dr Raj Srinavasan
Dr Rachel Cuthbert

Case study

Transforming asset management: developing maintenance planning tools for metro tunnels based on systematic evaluation of value to the end user

CSIC researchers with engineers from Tubelines surveying the tunnel geometry, feeding into London Underground's overall maintenance strategies

Location
Euston Station, London

Working with
London Underground

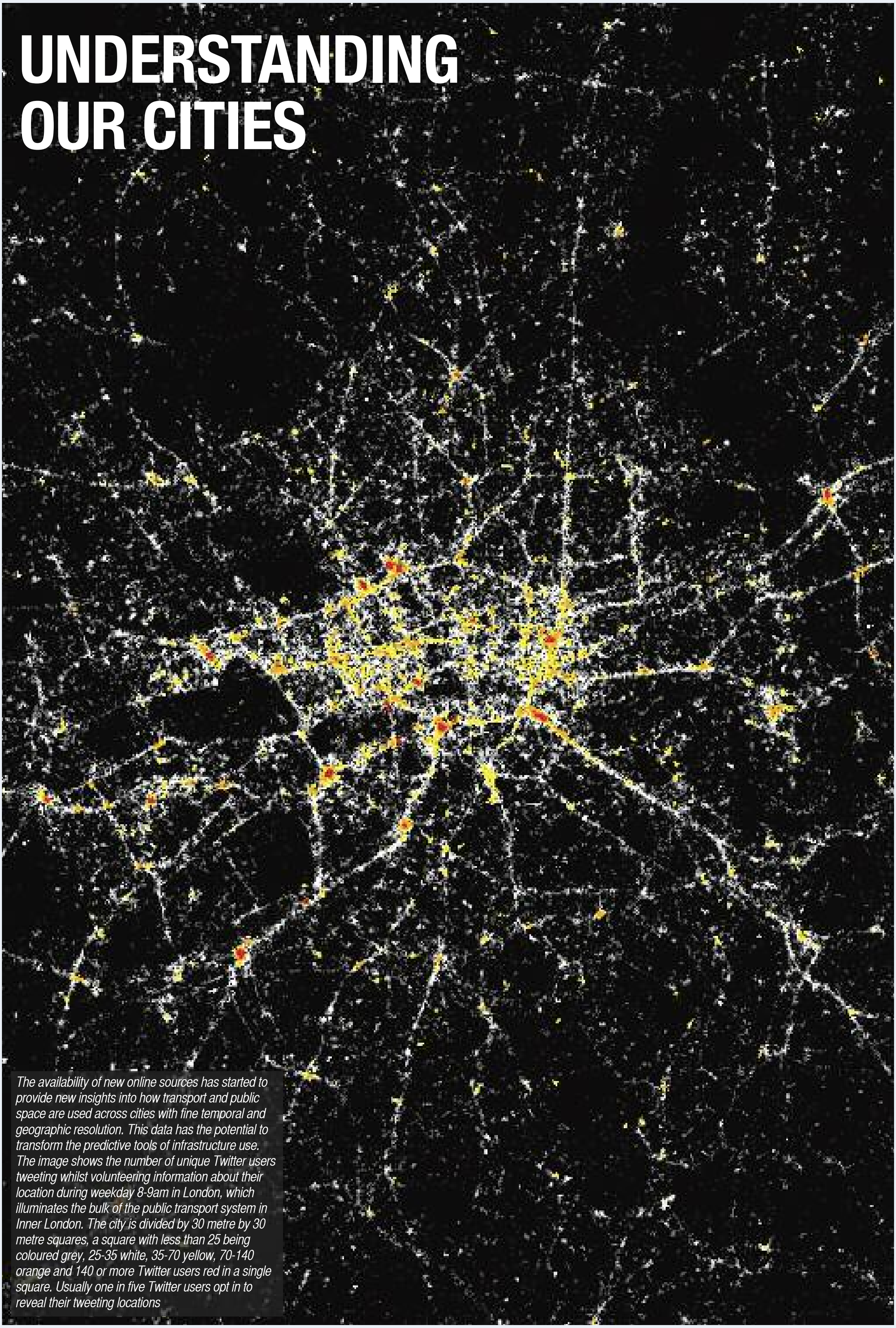
Challenges
- railway tunnels are reliable structures with relatively low maintenance requirements but some problems do occur and can be challenging to treat
- ground water seepage is the most common concern in many underground railway systems. This can be a particular issue in older tunnels not built to modern waterproofing standards
- uncontrolled seepage can result in a variety of condition problems including: corrosion of track and structures, disruption to signalling and other electrical systems and general deterioration of surfaces. If untreated these issues can lead to reliability issues and a poor ambiance in public areas
- the precise location of seepages can be hard to predict so maintenance to correct specific instances is often reactive in nature. This can make effective maintenance planning difficult

Project Details
- seepages have occurred in several areas on the London Underground tunnel network. Signficant maintenance effort is required to prevent these issues affecting the reliability of the service
- London Underground has invested in trials of materials and methods to treat these issues. These have established a palate of remedial solutions together with published guidance on the design and implementation of grouting to control individual seepages
- the logical next step is to develop a model to select a treatment approach taking account of what the railway values in different locations. For example, the right treatment for a running tunnel may not be same as for a public area where appearance is important. The project will aim to develop a tool to assist in this process by approaching these decisions from the perspective of client values
- it is anticipated that this value based approach may have applicability to both individual decisions and overall strategic planning of maintenance

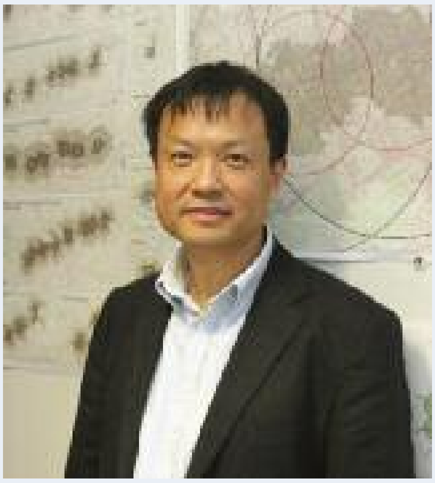
Achievements
- the study will examine what the client values by assessing the specific impacts of water seepage at various points in the tunnels
- it will also aim to provide London Underground with an effective maintenance policy tool that can maximise the tangible value provided by maintenance within budget constraints

Anticipated transformative benefits to London Underground
- the study will aim to provide a tool which enables London Underground to assess possible maintenance strategies in terms of tangible measures of value to the organisation. These will not be limited to cost concerns but will also incorporate other potential value drivers such as reliability and ambiance
- it is expected that application of the tool will improve the ability to make good investment decisions and so achieve maximum value benefits from a given level of investment
- the model will also provide an additional tool to help in making the right maintenance and inspection choices for specific situations

UNDERSTANDING OUR CITIES



The availability of new online sources has started to provide new insights into how transport and public space are used across cities with fine temporal and geographic resolution. This data has the potential to transform the predictive tools of infrastructure use. The image shows the number of unique Twitter users tweeting whilst volunteering information about their location during weekday 8-9am in London, which illuminates the bulk of the public transport system in Inner London. The city is divided by 30 metre by 30 metre squares, a square with less than 25 being coloured grey, 25-35 white, 35-70 yellow, 70-140 orange and 140 or more Twitter users red in a single square. Usually one in five Twitter users opt in to reveal their tweeting locations



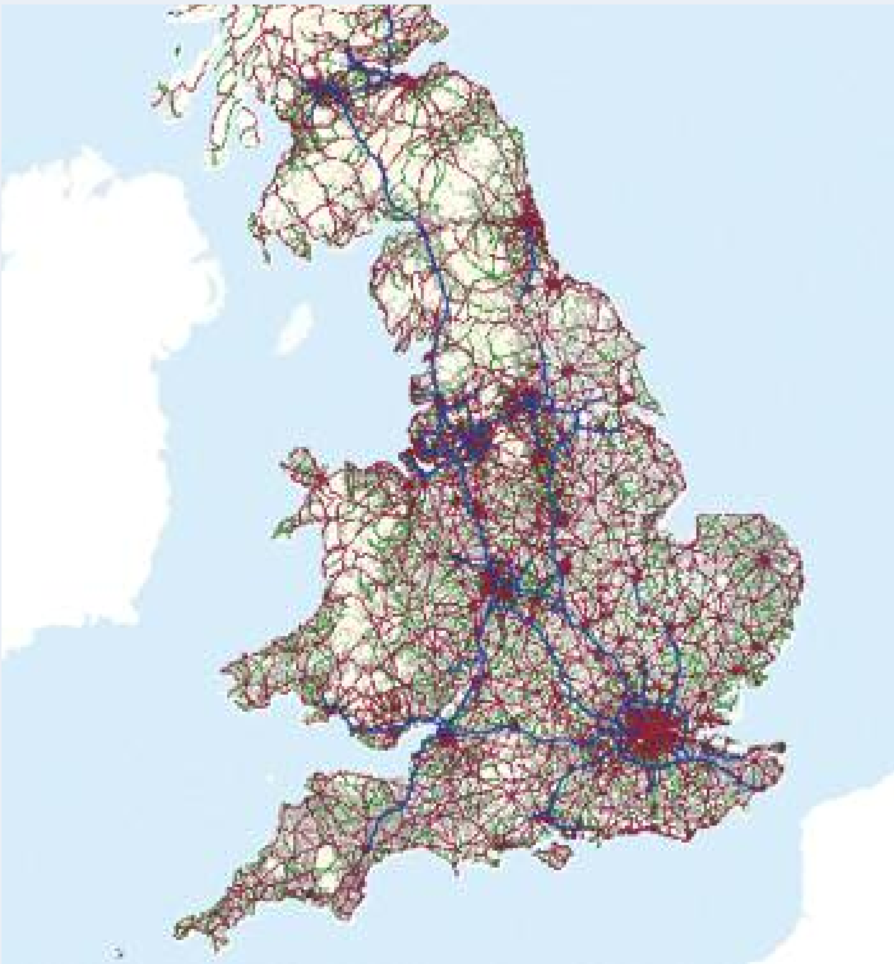
Dr Ying Jin
Co-investigator CSIC,
Lecturer,
Department of Architecture,
University of Cambridge

Cities represent the highest concentration of infrastructure and building assets. Intricate webs of individual and collective decisions are made about their construction, adaptation and use, which has a direct bearing on how cities function and defines the physical and virtual environments in which we live and work.

CSIC has developed new analytical tools through in-depth case studies of good practice to reveal how the decisions and their interactions form economically productive and environmentally attractive places to live and work.

The findings of this project serve a practical purpose:
- to inform the planning of specific cities and infrastructure projects through new quantification of benefits and costs
- to shed light on the ethos and code of conduct for creating a fair, green, resource-efficient and productive urban environment, through working with the Standards Agencies in the UK and worldwide

Our new analytical tools focus on transport, urban development and urban regeneration initiatives from the local to the national scale.



The road network of Britain – the adaptive zoning method is capable of retaining the local traffic details when analysing traffic through the national network

National scale: fast simulation algorithm that retains local details

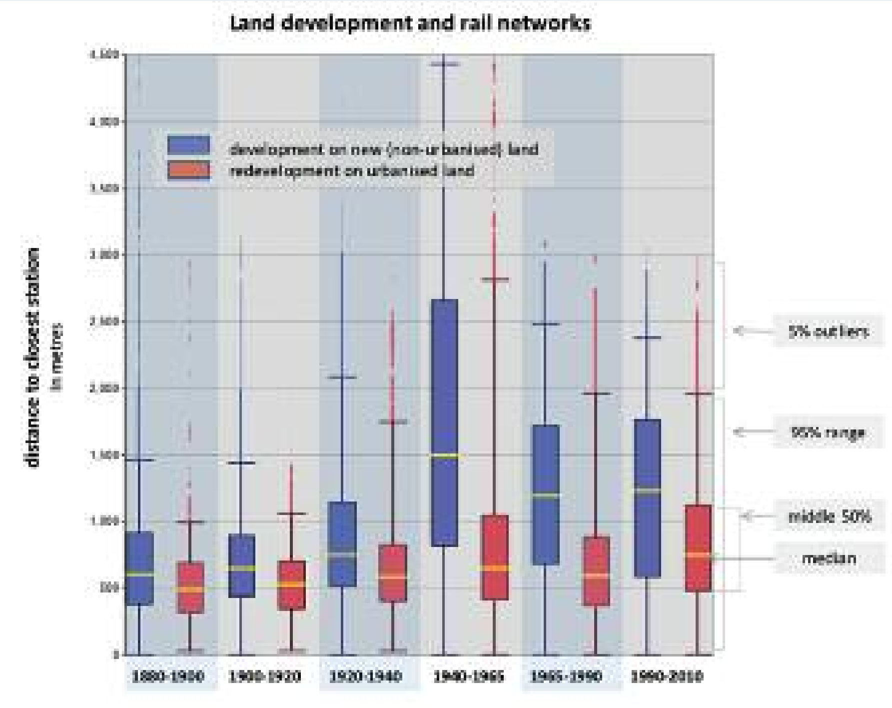
We have incorporated rigorous economic theories into 'adaptive zoning', a highly efficient computer modelling algorithm which we created as a product of earlier research work.

The firm economic grounding of the algorithm now allows quantification of costs and benefits of investment and regulatory decisions to inform decision-making, with the following advantages:
- it is capable of modelling travel demand and road traffic at national scale
- it retains high levels of relevant local details for each origin and destination assessed
- new advances cut the computer model run time by up to 10 times whilst improving the precision of model results

Benefits and application:
The algorithm can be used by central government agencies in assessing national level infrastructure and development plans such as the strategic road and rail networks. It can also be used by local authorities in testing alternative solutions to unblock local bottlenecks which are used simultaneously by local and inter-regional traffic.

City scale: the impact of infrastructure on urban development and redevelopment: evidence from London's history

We have developed new ways of examining historic data to uncover and quantify the evolution of urban land use, transport investment and regulatory measures.



Land areas developed in relation to rail and underground stations in West London 1880-2010

We have developed a detailed database of land use and transport changes in an area of 200 square km between Heathrow Airport and Holland Park in West London from the 1870s to 2011. This has enabled us to analyse the evolution of different types of land use, roads, intersections, rail lines and stations, tube lines and stations, and provide the evidence to calibrate robust forecasting models for new infrastructure and development plans.

The data series provides completely new evidence on how infrastructure and construction prompted every kind of development over time. A meta-analysis of the land use and transport models has resulted in an up-to-date and comprehensive assessment of the performance of the predictive models. Together they underpin the development of new models that are better able to quantify the economic and wider impacts of urban infrastructure interventions.

The evidence and the new models will enable major infrastructure scheme promoters to examine and prioritise investment options under the new Infrastructure Planning Framework.

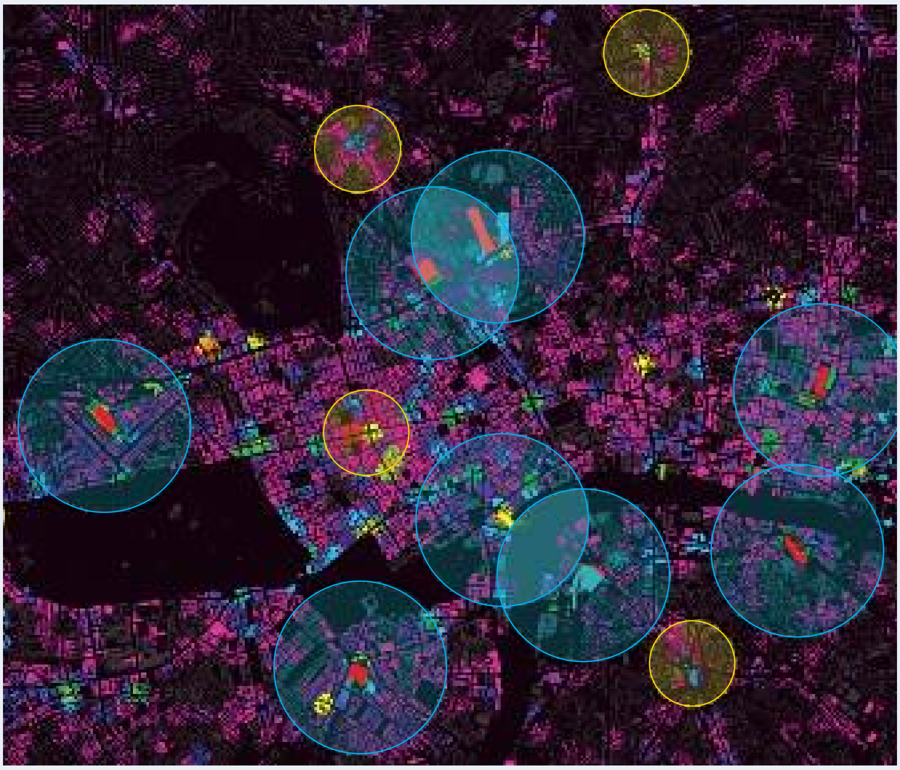
Findings:

- analysis shows how development spread from rail or tube stations in West London from 1880-2010
- the late 19th century development shows that the most effective service catchment of a rail/tube station is within an 800m radius; this has not changed for pedestrians today
- the most recent period from 1990 to 2010 shows a steady increase in the distances to stations, with the median distance from new development reaching 1200m and redevelopment 750m

This system-wide picture tells a different story from recent successes in central London rail hubs and indicates that there is a real challenge in redeveloping the surrounds of stations across the city. Without addressing this challenge, current and future rail investment will be unable to achieve the full economic and environmental benefits.

Crowd-sensing and crowd-sourcing: transforming the way we monitor infrastructure use

We have recently started this new project focusing on crowd-sensing and crowd-sourcing. We use open social media data, such as Twitter and Foursquare, and new urban sensors in collaboration with infrastructure developers.



Social media data from Foursquare.com showing the number of occasions when its users categorise their activities under 'Transport' during December 2013 to February 2014 across London. Tube and rail stations that featured most are highlighted with half mile catchments for rail and quarter mile ones for Tube stations. They are (from left to right) Paddington, Victoria, Camden Town, Oxford Circus, Euston, King's Cross-St Pancras, Charring Cross, Waterloo, Highbury Islington, Elephant and Castle, London Bridge and Liverpool Street.The data represents a new, emerging dimension to our knowledge of transport demand and urban land use

At London Bridge Station we are collaborating with Network Rail and Costain to test multiple pedestrian flow monitoring techniques for preventing undesirable crowding conditions inside the station – these will establish patterns of pedestrian distribution for providing effective services in and around the station.

A unique feature of the CSIC smart data work is that we build on our own extensive knowledge/library of UK cities and their demographic, socio-economic, land use and transport data.

Intended applications and benefits

Our aim is to develop new smart data methods which will:

- make it significantly easier, cheaper and more practical to monitor infrastructure use at or near real time
- work in tandem with existing data sources to optimize the coverage, precision and corroboration of model predictions
- inform short-term operational decisions (such as pedestrian flows at main stations) as well as medium to long-term planning

Working with BSI and Smart Cities Advisory Group

During the past year we have been working with the British Standards Institution (BSI) and the Smart Cities Advisory Group. We have been feeding our new research directly into the development of a novel, over-arching level of BSI standards for smart cities. The aim is to develop cities that effectively integrate the physical, digital and human worlds to deliver a sustainable, prosperous and inclusive future for its citizens[1].These standards aim to:

- understand current gaps in the knowledge of infrastructure development practice in particularly challenging locations, such as around rail and metro stations
- contribute to the development of new urban development and infrastructure planning standards
- be useful to city leaders
- distil current good practices into a set of consistent and repeatable patterns so leaders can develop, agree and deliver smart city strategies that can transform their cities' ability to meet future challenges and deliver policy aspirations

Looking ahead
With support from BSI, our Industry Partners and government agencies, we are aiming to deliver new case studies and modelling in the coming year. Additionally, we will incorporate new methods to account for the inherent uncertainties in complex infrastructure projects and background urban trends, so that flexible options and adaptive processes can become part of our recommendations for developing new standards and urban infrastructure plans.

[1] British Standards Institution (BSI), Draft Consultation Document for Publicly Available Specification (PAS) 181 on the Smart Cities Framework, January 2014.

Project site scale: developing new standards through good practice

Our focus here has been to learn from good practice in integrating urban infrastructure surrounding main urban rail and underground stations at specific sites.

We are undertaking case studies including:

- King's Cross Central redevelopment
- Crossrail station pedestrian catchments – particularly at Tottenham Court Road
- London Bridge Station's surrounding redevelopment initiatives

Benefits:

- Through the case studies we monitor how improved infrastructure and design at these sites reap social as well as economic benefits
- the work has highlighted the importance of assimilating good practice into guidance and new standards for smart cities
- we intend to use these studies to examine what has worked and distil good practice to inform new policy initiatives across UK cities

© GMJ for the King's Cross Central Limited Partnership

Artist's impression of the intended transformation of the Coal Drops Yard at King's Cross Central, currently under construction

"BSI is actively contributing to the creation of international standards for smart cities. We have closely engaged with CSIC in doing so, collaborating as an end user of their research."

Dan Palmer, Head of Market Development, BSI

Way forward

We believe that working with a team of infrastructure owners, consultants and contractors is the key to introduce innovation into the construction and infrastructure industry quickly.

At the city scale, our mission is to provide robust scientific evidence for planning:

- infrastructure projects by scheme promoters
- urban development policies by national and city governments
- smart city standards by BSI and ISO

In doing so we will advance the knowledge on smart data, infrastructure use monitoring, and the interactions between urban development and infrastructure. The key focus will be on challenging urban locations such as regeneration around public transport hubs, where the knowledge of good practice and predictive capability is currently least developed.

The Smart Cities Team
Professor Kenichi Soga
Professor Marcial Echenique
Dr Ying Jin
Dr Kiril Stanilov
Dr Claudio Martani
Ian Williams
Vassilis Zachariadis
Steve Denman

Case study

The transformation of a historic urban quarter

View from Pancras Square to King's Cross and St Pancras Stations. Up to 30,000 people are expected to live and work in the King's Cross Central Development by 2016

Location
King's Cross-St Pancras Station area, London.

Working with
British Standards Institution (BSI), Argent, Allies & Morrison, Chapman Taylor

Context
- London has been facing intense growth pressures unseen since the mid 19th century. This is likely to continue to 2030 and beyond
- at King's Cross-St Pancras, new and upgraded rail infrastructure creates an ideal environment for urban growth. However, historic legacy and complex urban fabric have foiled many attempts to regenerate the area
- public and private investments since the 2000s have reshaped the area and transformed it into one of the fastest growing urban quarters and a popular destination. By 2016, up to 30,000 people will be living, working and studying at King's Cross Central

Challenges
- to establish what general lessons could be learnt from the success to inform the approach to planning and infrastructure development for this challenging type of urban regeneration
- to ascertain how the general lessons learned can be translated into appropriate codes of conduct and standards of urban development that will be useful in the UK and internationally

Project details
- the King's Cross experience is being analysed as a key case study for the BSI smart city standards and strategies for redevelopment and regeneration around rail stations
- the project is analysed throughout its development against the history of difficult challenges of regenerating the area, from the early stages of its current masterplan, through the uncertain periods of the dot-com bust, world financial crisis to the current London property boom

Achievements
- CSIC has actively engaged with DfT, Network Rail, Argent (the Developer), Allies and Morrison (the Masterplanner) and Chapman Taylor (the Retail Designer), and are continuing to discuss the case study with other stakeholders to build up a complete picture of how the regeneration have been planned and implemented
- the case study benefits from a historic perspective from the 1870s, which we have built up using similar data to our West London study
- the case study has helped to establish a new simulation model for regeneration, which incorporates the uncertainties arising from the background trends and interactions among components of infrastructure and building property development

Transformative benefits to the infrastructure and construction industries
- opportunities to develop property and change consumer behaviour: as immediate surroundings of the rail/metro services improve through investment
- powerful regeneration catalyst: as the pedestrian catchment is transformed.
- economic, social and environmental benefits from rail investment: careful planning and management have enabled regeneration of a challenging area
- study recommendations will contribute to plans and actions for other sites, particularly in the surrounds of 25 national hubs, 66 regional interchanges and 275 key feeder stations

Transforming cities
King's Cross is one of three major case studies CSIC is working on to inform a new type of over-arching BSI standards for cities.

DEVELOPING RELATIONSHIPS WITH INDUSTRY

Phil Keenan
Business Development Manager, CSIC, University of Cambridge

Working with industry is vital to CSIC and we attach real value to our relationship with our industry partners. Working in partnership with leading organisations in the construction and infrastructure industry enables us to develop cutting edge innovations which are demonstrated in real projects, and which will help to transform infrastructure and construction.

How we work with industry

Our industry partners make time to participate in our project workshops which we hold throughout the year. We use these workshops to gain feedback on the direction our work is taking, and to ensure that the construction industry's needs are being adequately and accurately met. For example, we held a fibre optic sensing workshop, and gained valuable insights into industry strain sensing needs (attendees included, Skanska, Arup, Laing O'Rourke, itmsoil, Strainstall, Costain and Soldata). As a result, CSIC decided to invest in a dynamic strain sensing technology, widening our capabilities, with three demonstration projects planned for 2014, supported by a new research associate.

Our partners also provide us with opportunities to demonstrate our technologies on construction projects and infrastructure deployments which we value greatly. This year, CSIC has worked on many projects with our industry partners, implementing monitoring systems to provide insights into the behaviour of structures and demonstrate the capability of our technologies. These include:

- Crossrail: instrumenting the new Paddington Station box with wireless sensors and fibre optics; instrumenting tunnel segments for the Thames crossing at Woolwich (with Hochtief); and monitoring the Post Office railway tunnel where it is affected by construction of a major platform tunnel at Liverpool Street Station
- National Grid Power Tunnels (with Costain), where our innovative work was shortlisted for the ITA Awards in two categories
- London Bridge Station (with Costain and Network Rail), where we are using fibre optics to understand the behaviour of Victorian masonry arch structures, as well as developing innovative wireless sensor systems for monitoring sound

Field trials are an excellent opportunity for us to demonstrate and deliver robust construction site instrumentation. The knowledge that we gain in the instrumentation of structures often cannot be obtained by conventional means. Without these opportunities many of CSIC's technologies would remain in the laboratory.

Our site work provides CSIC personnel with the opportunity to deliver important new insights into how structures perform and enables them to challenge conventional understanding.

Developing offerings to commercial maturity

Beyond demonstration, we also need to develop our technologies and techniques to the point where industry can deploy them. This involves providing initial installation services while we develop robust solutions and best practice guidance, and then training industry to deliver these services.

We have begun to provide monitoring and analysis services in fibre optic instrumentation of piles for load testing and geothermal pile testing. This year we have carried out pile monitoring at two high profile projects in London, including one at Canary Wharf, and we are working closely with industry partners to deliver services for a number of other projects in the coming year. Next year we will further develop this approach to develop a commercial offering for wider fibre optics applications.

We have also held successful fibre optics awareness training courses, and over the next year we plan to develop our fibre optics training further, so that we can begin to train industry in the practical tasks of both deployment and analysis and interpretation of fibre optic strain data.

Winning awards with our partners

CSIC was delighted to win two awards in collaboration with industry partners this year:

- the Bevis Marks project, with Cementation Skanska, won the 2013 Ground Engineering Sustainability Award
- the Thames Water Lee Tunnel Project-Abbey Mills Shaft won the 2013 Fleming Award, in collaboration with Thames Water and MVB JV, AECOM, CH2M Hill, Bachy Soletanche and Underground Professional Services

In both of these projects, the close collaboration between CSIC and our industry partners was crucial to us being able to deliver the innovations and insights which helped win the awards.

Broadening our reach – welcoming new members, developing new collaborations and disseminating our work

CSIC has welcomed two new industry partners this year:

- Imetrum, which is working with CSIC on projects involving video extensometry and photogrammetry, and
- Geosense, a geotechnical instrumentation company which has been providing conventional instrumentation to back up the measurements CSIC makes with novel technologies

We have also developed valuable relationships with the Royal Institution of Chartered Surveyors (RICS) and its subsidiary, Building Cost Information Service (BCIS), and with CERN and Hochtief, who are providing unique demonstration opportunities for our technologies.

We are in discussion with professional institutions, including the Institution of Civil Engineers (ICE), the Institution of Engineering and Technology (IET) and the Institution of Asset Managers (IAM) regarding how we can broaden the reach of CSIC's work. In particular, we are discussing a CSIC book series with ICE Publishing, which will include:

- best practice guidance for structural health monitoring
- a series of best practice guides for specific technologies, including fibre optics and wireless sensor systems
- asset management guides

Looking ahead to new opportunities

New Capabilities – Dynamic Strain Sensing

Feedback from a successful industry partners meeting for Fibre Optic Strain Sensing confirmed a need to develop CSIC's capabilities in dynamic strain sensing. To address this, CSIC has begun a new programme to develop Dynamic Strain Sensing using both distributed and multipoint (Fibre Bragg Grating – FBG) fibre optic strain sensors. We are particularly interested in being able to measure highly dynamic events. We are partnering with leading users and providers of FBG technologies in the UK, EU and USA to develop this capability, and will be hiring a new research associate to work with our existing team. With our existing industry partners we have already identified a number of potential demonstration sites for this exciting new project.

New industry sectors

CSIC's approaches are applicable to a wide range of industry sectors, and we are taking the opportunity over the next year to develop our outreach in a number of areas, including investment, insurance and reinsurance, where by better understanding of risks during construction and of the condition of infrastructure, a more informed assessment of investment or insurance risk can be made. To support this activity, CSIC is being assisted by Dr Jan Hellings (formerly the London 2012 Olympics Enabling Works Manager) as an advisor to reach out to investment, insurance and reinsurance companies to explain the value of CSIC's developments of sensing technologies and their application to construction and infrastructure risk management.

Horizon 2020 and TSB Funded Research

CSIC is keen to collaborate more broadly in innovation and applied research funding calls. We are already active in this area and are keen to engage with partners to take forward opportunities, for example:

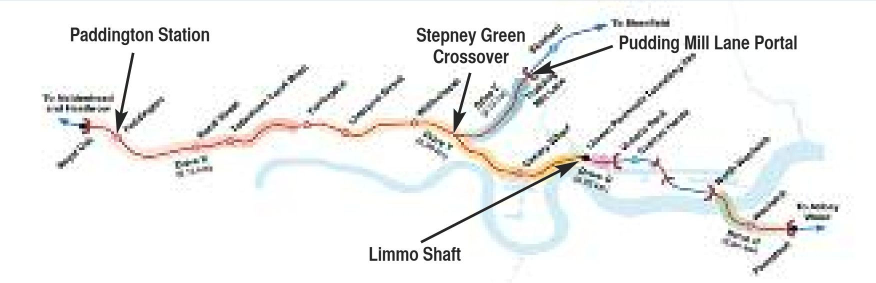
- CSIC is actively investigating opportunities around Horizon 2020 funding, particularly around smarter design, construction and maintenance where our fibre optic strain sensing knowledge and experience can play a part
- CSIC has joined a consortium with OWLC Ltd to submit a proposal to the TSB call in infrastructure for offshore renewables

In summary, engaging with industry partners to implement our latest developments and help our partners to innovate in their own business is core to CSIC's activities. We greatly appreciate the support we have already received from our partners, and look forward to another year of working together to deliver innovation and value to industry.

Fleming Award Winners: Matthew Bellhouse (Bachy Soletanche), Richard Sutherden (AECOM), Tina Schwamb (CSIC), Professor Robert Mair (CSIC) for the work on the Thames Water Lee Tunnel Project

Case study

Transforming construction: innovative fibre optics sensors deployed on a variety of Crossrail sites



CISC fibre optics installations on Crossrail shafts and retaining walls

Location

Paddington Station, Stepney Green Crossover, Pudding Mill Lane, Limmo Shaft.

Working with

Crossrail

Context

- working closely with two Knowledge Transfer Partnership (KTP) Associates (employed by Cambridge University and funded by both Crossrail and TSB) CSIC has led the development and installation of optical fibre and conventional monitoring instrumentation on four major Crossrail sites

Challenges

- to provide new insights into the behaviour of the shaft linings and retaining walls, and adjacent ground movements, during construction
- to develop a robust method for installing fibre optic sensors during construction

Project details

- CSIC has been actively involved on four key sites during construction of Crossrail, principally in the implementation of fibre optic sensing to measure the performance of shafts and deep excavations
- CSIC has successfully installed optical fibre sensors on the diaphragm wall reinforcement cages at the Crossrail sites, with the fibre optic cable being unrolled from drums and fixed to the cage at intervals as it is lowered into the deep trench in the ground
- tunnelling machines were launched from the 40m deep Limmo Shaft
- a novel wireless sensor network has also been installed in the deep excavation for Paddington Station

Achievements

- the monitoring data has provided completely new insights into the behaviour of the shaft lining and ground movements adjacent to the shaft during construction
- the information has highlighted the conservative nature of the design of the shafts and retaining walls – only very small wall strains and deflections were recorded by the fibre optics. The monitoring has also shown much smaller ground movements than predicted
- many lessons have been learned on the complexities of installing fibre optic sensors in diaphragm walls on the Crossrail sites, including the important challenges of working under difficult construction site conditions. Robust installation techniques for achieving reliable measurements have been developed

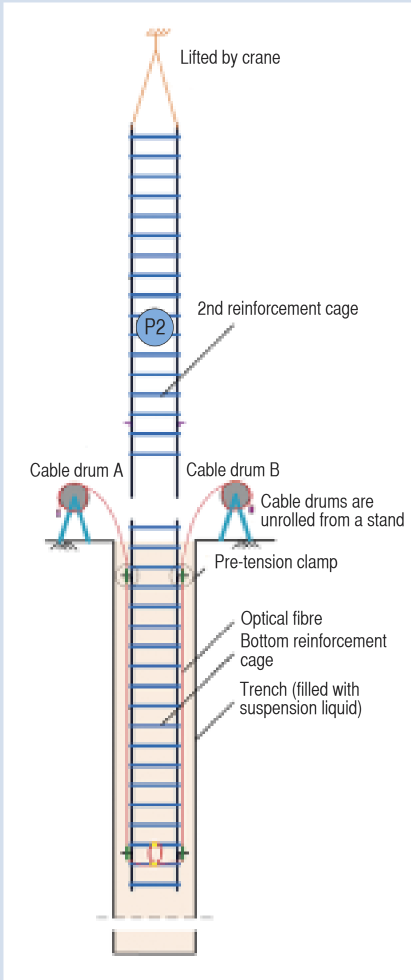
Transformative benefits to the infrastructure and construction industries

- informed decision making: the fibre optics monitoring on these sites has demonstrated that potential economic benefits can be achieved with refined designs. Rationalisation of the design approach for shafts and retaining walls will benefit the wider construction industry
- cost saving: a more efficient design approach should result in reduced amounts of material used and a faster construction process

Going forward

- further plans have been developed by CSIC with Crossrail for monitoring the behaviour of tunnel lining segments in the tunnels to be constructed beneath the River Thames: fibre optic sensors have been installed in the segments when they were cast in the factory
- the behaviour of a sprayed concrete Crossrail platform tunnel during construction of a cross-passage tunnel will also be monitored with fibre optics

Above: installation of reinforcement cage for diaphragm wall with fibre optic sensors attached. Below: diagram showing detail



ENGAGING INDUSTRY THROUGH TRAINING

Industry delegates engage with a lab demonstration during a specialist training course

Dr Cedric Kechavarzi
Training & Knowledge Transfer Manager, CSIC, University of Cambridge

"I am very pleased to be able to support the CSIC teams at work in Cambridge today, while they develop the products and train the teams that will transform the construction processes of tomorrow."

John St Leger, Strainstall

Transferring specialist knowledge and skills is at the heart of CSIC's vision. It is our strategic aim to achieve a step change in the approaches of designers, contractors and clients to the design, construction and use of complex infrastructure.

CSIC's programme of specialist training and development tailored for industry

Over the past year, we have been developing a series of specialist training and development courses which are being rolled out.

October 2013 saw the successful pilot of CSIC's first short course for industry on fibre optic sensing, as described in the associated case study. Other courses have followed.

The programme consists of short courses which impart the very latest information and novel sensing and measurement techniques to enable decision making in the industry.

These one to three-day practical courses aim to:

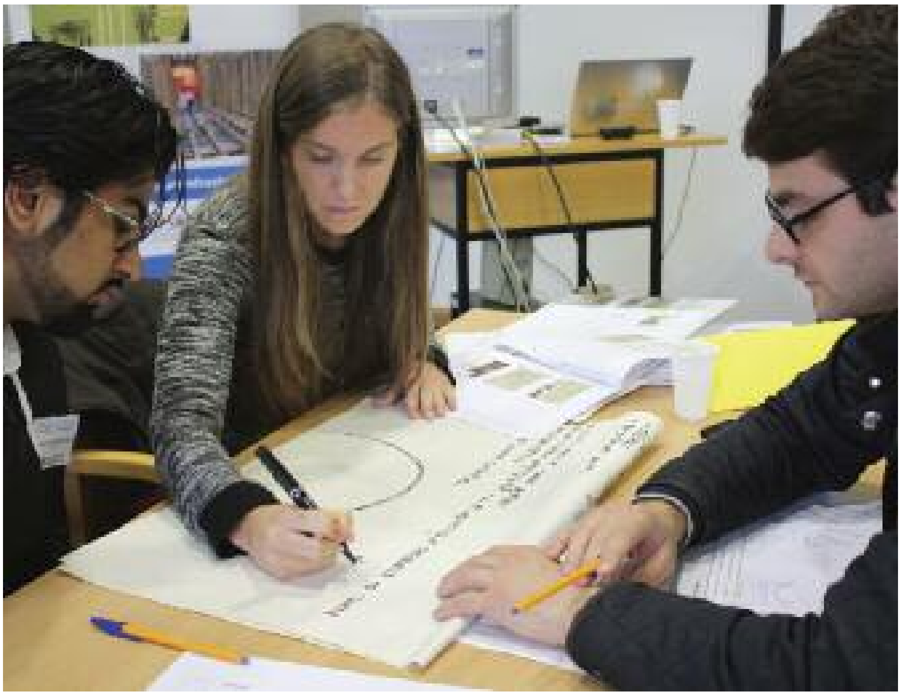
- offer the very latest research outputs and technologies with an advanced level of readiness, having been validated through full-scale field demonstrations
- be hands-on and practical – involving all elements of the construction supply chain, to ensure rapid progress in achieving the intended step change
- promote commercialisation and adoption of new technologies
- reach executive, manager, engineer and technician levels

These courses are led by the University of Cambridge's leading academics and specialists in the fields of civil engineering, asset management and urban infrastructure planning. They are supplemented by regular awareness briefings and workshops with the Centre's industry partners.

Developing internal knowledge transfer

We have also put a great emphasis on developing the capacities of our researchers through internal knowledge transfer and training over the past year:

- in the field of fibre optics, this has included specialised training on newly acquired equipment delivered by external experts in photonics and telecommunication
- an expert group consisting of experienced researchers in fibre optics deployment was formed to oversee the internal transfer of know-how, the efficient adoption of innovation and the retention of knowledge through regular workshops, seminars or supervisions with CSIC staff
- CSIC activities are also being disseminated internally to a wider University audience through fortnightly seminars



Industry delegates get involved with a practical workshop task

Towards best practice: developing guidance documents for industry

CSIC is committed to developing and publishing guidance documents to accompany its technology outputs as an efficient mode of knowledge transfer by making it widely available to industry.

During the past year, we have focused on consolidating the current state of knowledge in optical fibre strain sensing technology and the competence required of those designing, installing and interpreting the output of this type of system.

We have achieved this by working with researchers and technicians involved in more than 30 installations in the field. This has enabled us to identify specific knowledge requirements as well as identify areas in which the technology has required refinement to enable reliable and resilient installation and use.

This knowledge has been encapsulated into a draft Best Practice Guide, the first of its kind for distributed fibre optic strain sensing for geotechnical infrastructure monitoring, which will be published and available to industry next year.

Looking beyond this next year, CSIC's researchers and investigators will be developing training materials to accompany the new technologies being developed by CSIC. These training materials will be used to inform the content of future training and development courses.

Some of this information will also form the basis for new guidance documents. These will be published and made widely available to the construction industry, infrastructure owners and operators, and to the manufacturing, electrical and information sectors.

In summary, it has been an exciting and fruitful year of progress with excellent feedback from all those organisations with which CSIC has engaged. The forthcoming year will build on this progress and see a continued focus on the development of our programme of training, knowledge transfer and dissemination.

Costain engineers and mangers at CSIC's Introduction to Distributed Optical Fibre Strain Sensing for Geotechical Infrastructure Monitoring course

Case study

Engaging with industry

In October 2013, CSIC partnered with Costain to support an initiative to transfer knowledge and embed a new technology that aims to provide a step-change in the way strain is measured in structures, delivering better data and therefore improvements in designs in current Costain construction projects.

The UK's ageing infrastructure requires extensive monitoring and remedial interventions to extend life and prevent catastrophic failures. In addition, 'smart monitoring' has become an important assessment tool for delivering more efficient design and reducing over-specification in new constructions.

Distributed optical fibre strain sensing is a technology that allows continuous strain measurement over an extended distance, with signals being sent along optical fibres attached to or embedded in structures or in the ground. This technology can replace the use of large numbers of point sensors, such as strain gauges.

This form of strain measurement helps improve understanding of the performance of structures during and after construction, and gives insight into the complex soil-structure interaction mechanisms involved, helping to identify localised problem areas.

Fifteen Costain engineers and managers attended a training course entitled Introduction to Distributed Optical Fibre Strain Sensing for Geotechnical Infrastructure Monitoring at CSIC, participating in lectures and workshops to understand and become familiar with the application of the technology and to use this knowledge to exploit market opportunities.

This training course formed part of the first phase of the Centre's aim to increase the UK construction industry's knowledge and understanding of the benefits of distributed strain sensing using fibre optic technology. The course included several case studies where CSIC had delivered knowledge and new insights to construction projects using distributed fibre optic strain sensing.

"This is a great initiative to bring technology from Cambridge's CSIC to our projects, delivering technological innovations to meet and better our client expectations. The training will help us better manage the assets we build throughout their life cycle."

Aalok Sonawala, Business Improvement Manager, Costain

CSIC would like to thank our industry partners

Construction Sector

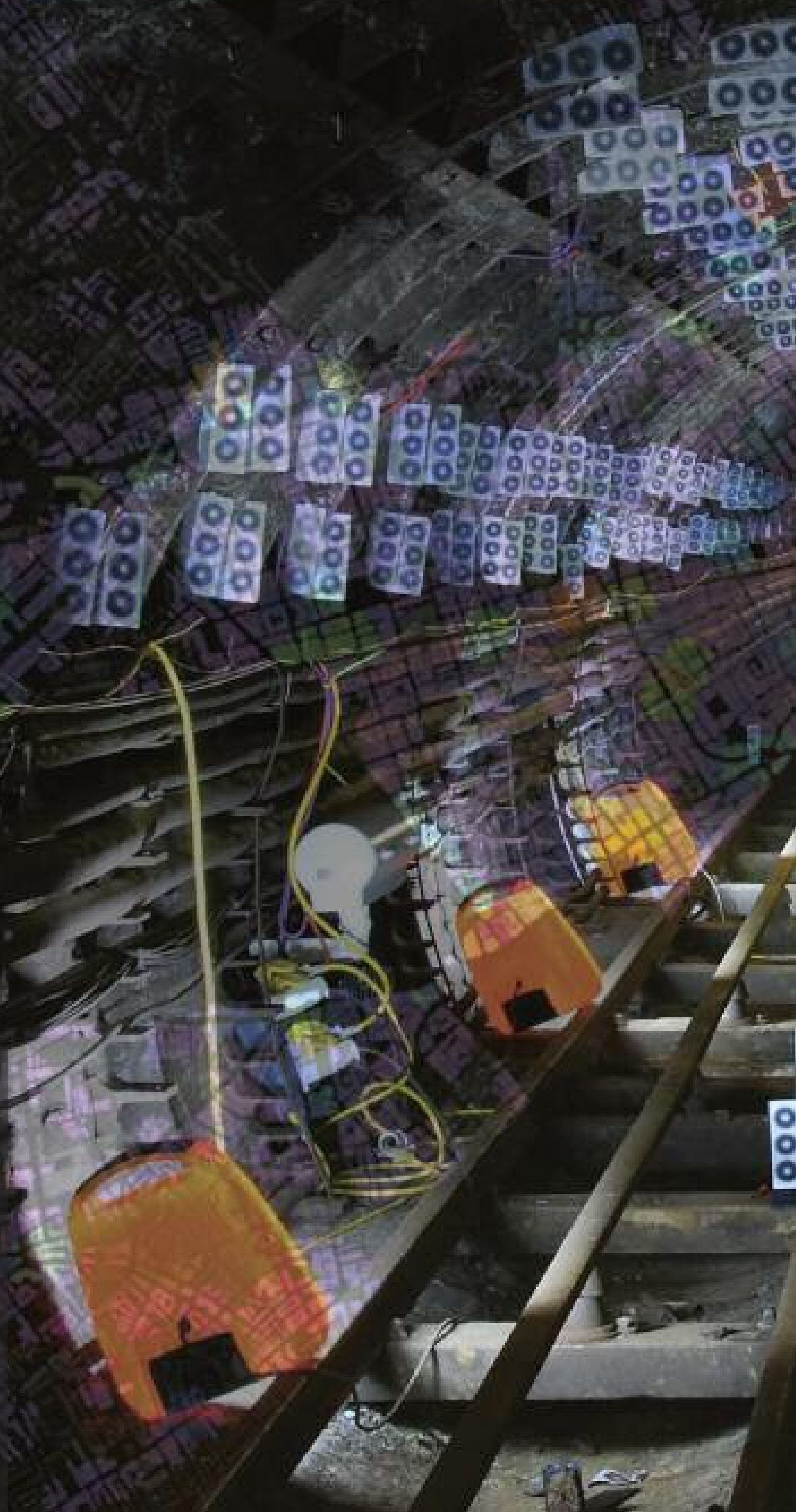
Infrastructure Sector

Technology & Information Sectors

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
and Construction

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



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