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

Smart sustainability

Exploiting data in engineering to mitigate climate change

The 2018 UN Intergovernmental Panel on Climate Change (IPCC) report[1] brings focus to the pressing challenge to keep global warming to a maximum of 1.5ºC. If we ignore this warning the consequences for millions of people around the world will be drought, floods, extreme heat and poverty. Action must be taken to cut carbon pollution by 45 per cent by 2030 and to reach zero emissions by 2050. We have less than 12 years to limit the impacts of climate change – the lifetime of a large infrastructure programme.

> *"The decisions we make today are critical in ensuring a safe and sustainable world for everyone, both now and in the future. This [IPCC] report gives policymakers and practitioners the information they need to make decisions that tackle climate change while considering local context and people's needs. The next few years are probably the most important in our history.*
>
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CSIC Roundtable Discussion Paper
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Institution of Civil Engineers

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Background

In October 2018 the Cambridge Centre for Smart Infrastructure and Construction (CSIC) hosted a roundtable discussion during the Global Engineering Conference (GEC) at the Institution of Civil Engineers (ICE) in London to explore exploiting data as an engineering tool to mitigate climate change. The roundtable included experts from the infrastructure and construction sector, academia, sustainability, finance, insurance, development and policy. Discussions focused on how civil engineers can engage with the challenges of mitigating and responding to climate change, the role of data in mitigating risk and unlocking projects, and the challenges and opportunities of implementing smart infrastructure solutions in a developing world context. This paper summarises discussions at the roundtable, focusing on the role and responsibility of engineers and making the case for exploiting data as an engineering tool to mitigate climate change.

The challenge

The 2018 UN Intergovernmental Panel on Climate Change (IPCC) report[1] brings focus to the pressing challenge to keep global warming to a maximum of 1.5ºC. If we ignore this warning the consequences for millions of people around the world will be drought, floods, extreme heat and poverty. Action must be taken to cut carbon pollution by 45 per cent by 2030 and to reach zero emissions by 2050. We have less than 12 years to limit the impacts of climate change – the lifetime of a large infrastructure programme.

The role and responsibility of the civil engineer in responding to the challenge of climate change

Throughout history civil engineers have been at the forefront of innovation to meet the challenges of their times – from Thomas Telford's roads, bridges and canals that laid the foundations of industrial Britain, to the life-saving system of sewers designed by Joseph Bazalgette, to the current Thames Tideway Tunnel that upgrades London's sewer system to cope with a growing population.

The climate crisis needs urgent action if we are to avoid runaway climate change. Civil engineers have a key role in meeting this challenge by delivering and managing a resilient built environment that requires fewer resources and less carbon for its construction and operation. It is time for engineers to take their seat at the top table in discussions of climate change mitigation and adaptation at policy level, and contribute to a discourse currently dominated by economics, finance and politics. More leadership is needed from the civil engineering community to engage effectively with wider audiences and to demonstrate the value of engineering knowledge and expertise, underpinned by data and information, in meeting the challenges ahead.

Innovation in monitoring, data collection and analysis provides today's engineers with valuable tools to tackle the challenges of climate change by enabling more resource and carbon-efficient design, construction, and operation and maintenance of infrastructure and the built environment. In order to enable engineers to be more effective in responding to climate change several important considerations need to be more prevalent in civil engineering practice.

Key factors for change

Balancing resilience with environmental risk

As civil engineers we strive to understand and assess risks directly associated with the projects we work on, but are often not as familiar with understanding the wider impact at a system level. The ability to balance resilience with environmental risk when estimating and specifying required amounts of materials has become critical. Overdesign of a structure is not a low risk activity when one considers the provenance of construction materials and the environmental impacts associated with their manufacturing and use. This is a balance engineers need to understand to be able to make educated decisions. Time is short to reduce carbon emissions – as an industry we cannot neglect the impact of individual projects on climate change.

Integrating 'green' and 'grey' infrastructure

The integration of natural 'green infrastructure' and human built 'grey infrastructure' is of increased importance in meeting the need for climate resilient solutions. Civil engineers need to be open to implementing a mix of the two when possible and appropriate rather than pursuing purely asset-based solutions. Integrating green and grey infrastructure can help meet the need for lower cost, more resilient, and lower carbon outcomes.[3,4]

Raising the profile of carbon efficiency in design and construction

Engineers are well versed in project safety and the imperative to protect lives; mitigating climate change to protect the future of humanity from environmental catastrophe should also be embedded at this fundamental level. In the UK, government policy brings some focus through the Construction Strategy[5], which has, as one of its goals, an ambition to reduce the whole-life carbon of construction by 50 per cent by 2025. Using data to understand sustainability and carbon efficiency across the entire life cycle of a project from the beginning of the design stage will establish mitigation of climate change as an essential aspect of design and construction to be considered alongside health and safety.

Valuing multi-disciplinary perspectives

The civil engineering community must broaden its understanding and increase its impact by reaching out to different disciplines within the engineering sector and to practitioners from different sectors – chemists and biologists, economists and social scientists – to work collaboratively to create new solutions. Debate and open discussion where multidisciplinary perspectives are heard brings a diversity of skills to address challenges and foster innovation.

Bringing focus to embodied carbon

Good progress has been made on reducing operational carbon but the issue of embodied carbon requires attention and action. Building infrastructure for fast-growing cities in developing countries could release 226 gigatonnes (Gt) of CO_2 by 2050 – more than four times the amount used to build existing developed-world infrastructure[6]. Steel and cement alone account for at least eight per cent of the global CO_2 emissions and with growing economies in China and India the need for new steel and new concrete will continue to rise unless we act now – the UN Global Status Report[7] suggests 230bn m^2 new floor construction between now and 2040. Until we can reformulate the way cement and steel are manufactured these materials will remain carbon intensive. There are new or different composites available with potentially lower embodied carbon but these may also result in a shorter asset life. A whole-life approach must be taken to understand the impact of embodied carbon in order to make informed choices on material selection and quantities.

Resource-efficiency needs to be at the forefront of design and construction. Engineering and construction organisations must become versed in basic material and carbon analysis, and be prepared to ask questions that will uncover new knowledge and a greater depth of understanding. It is time for engineers to be proficient in basic material and carbon analysis and equipped with tools – data, metrics, and heuristics – to fully understand the impact of materials specified, engage in resource efficient design, and avoid waste in construction.

Balancing the demand for short-term cost reductions versus carbon reduction

The criteria by which projects are measured determines outcomes. When the key criterion is lowest cost, that measure will drive decisions and outcomes and strip projects of innovation. Traditional transactional contracting arrangements resulting in low profit margins make carbon-reducing innovation less feasible. Moving away from delivering projects in a transactional manner to new approaches, such as those outlined by Project 13[8], facilitates solutions that take carbon reduction into account. Again, a whole-life approach must be taken in order to identify costs of design innovations at the capital expenditure stage which can be more than made up for through cost saving at the operational phase.

Data as an engineering tool to mitigate climate change

Data can enable better design, more efficient use of resources, reduction in waste, time and cost savings, improved safety and increased infrastructure resilience – all critical factors in reducing carbon emissions from our built environment. The significant reduction in cost of storing, processing and transmitting data in recent years is driving digital transformation across all industries. To date the focus has been on the potential of big data to drive efficiency and profitability of infrastructure and construction. However, there is huge potential for new data and analytics to contribute towards the decarbonisation of the civil engineering sector, and enhance the resilience of infrastructure and the built environment to the impacts of climate change.

Data to optimise performance of new and existing assets

Unlocking the full benefits of data as an engineering tool requires us to identify what information we need from the data we collect, curate it accordingly and make it accessible for future reference. This requires engineers to design for the whole life of an asset, understanding its intended use and collaborating with asset managers at the beginning of the project to anticipate information requirements. This in turn enables a whole-life, value-based decision-making process for asset management, a move to risk-based maintenance, and the futureproofing of our assets in relation to potential impacts of climate change[9].

Data-driven smart infrastructure solutions applied to existing assets enable owners and operators to get more out of what they already have – increasing capacity, efficiency, reliability and resilience – and reducing the need for new builds and associated carbon emissions. Using data as an engineering tool will lead to better-informed, sustainably-grounded decisions to reduce resource use and ensure our assets function long into the future.

Scaling up to an 'urban observatory'

Building on the asset scale to take a systems approach allows scale-up to create an 'urban observatory'[10] where a variety of data is collected from sensors across an urban area to monitor a range of connected factors including air quality, transport flows, water and energy demand. These real-time observations provide long-term understandings that can be related to actions, activities and behaviours across all aspects of a city, from the performance of individual buildings or infrastructures to a 'system of systems' understanding.

The embedded sensor network can be enhanced with other available data – weather radar, air quality measurements, geotagged social media data, as well as data from the natural world. For example, researchers in Newcastle[11] are integrating this wealth of information with flood models enabling predictive simulation, based on real-time analysis and observation of traffic flows, flood impacts and hazards, to offer a better understanding of patterns of disruption through a city as a result of bad weather. This in turn will facilitate both strategic operations and tactical decisions at the city scale during extreme climatic events while providing information that informs the bigger, global picture of long-term, systemic drivers of greenhouse gas emissions and the impacts of climate change, for example, how changes in urban development and form alter the urban heat island.

Data to address criticality and resilience of infrastructure and manage economic risks

Criticality and resilience of infrastructure is increasingly relevant to risk analysis in the insurance industry. The industry has historically referred to past events as part of the process of assessing future risk. This model is becoming less relevant as the frequency of extreme climatic events increases. Currently, the insurance industry lacks a reliable basis to make better risk assessments. There is a pressing need for new parameters for assessing risk to ensure that financial risk can be managed and insurers can continue to deliver insurance contracts on assets threatened by these types of events.

While climate change is a global concern, its effects are not uniform across the world. Local data and local context is essential to risk assessment and investment organisations. Understanding the response of infrastructure through monitoring and data analysis enables informed assessment and management of future risk. Better information systems focused on the whole life of infrastructure are needed to make better assessments of economic consequences resulting from climatic events. Data will deliver information to catalyse innovation in the insurance industry, to assess and underwrite assets that it cannot currently cover.

A better understanding of physical climate risk is also increasingly important to the financial sector. For example, through initiatives like the Federation of Small Businesses (FSB) Task Force on Climate-related Financial Disclosures (TCFD)[12], the finance sector is pursuing information about the physical location and condition of assets and potential changes resulting from climate extremes.

A national framework for data

Only by connecting data from different organisations can we understand system level opportunities and outcomes.

The UK's National Infrastructure Commission (NIC) 2017 report 'Data for the public good'[13] calls for a national framework to enable data to be shared securely between and within infrastructure sectors, enabling benefits of coordination and collaboration across the network of operators, regulators and users to be secured. 'The Gemini Principles'[14] paper, published by the Centre for Digital Built Britain (CDBB) in 2018, addresses key recommendations from the NIC report. A national information management framework for the built environment is recommended to help overcome barriers to the uptake of smart infrastructure solutions emerging from poor curation of data within and between organisations. This was also a recommendation of the infrastructure chapter of the Committee on Climate Change 'UK Climate Change Risk Assessment 2017 Evidence Report'[15]. This will be delivered through DAFNI[16] (Data & Analytics Facility for National Infrastructure), which will become the National Platform to satisfy the computational needs in support of data analysis, infrastructure research and strategic thinking for the UK's long-term planning and investment needs

Using data holistically

Data exists in a variety of different categories, the importance or value of which depends on the user. Engineers focus on asset performance data. Economists pursue usage: what services the infrastructure is delivering, willingness to pay and wider economic benefits of infrastructure provision. The finance sector is interested in costs, bankability, risks and delivery timescales. These different categories of data tend to exist in separate silos.

How can these perspectives be brought together? As engineers we need to understand the evidence needs of each sector. Working collaboratively to secure the right data and communicate information across disciplines and sectors will broaden approaches to planning, delivery and management of infrastructure and construction in a more holistic and sustainable way.

The role of data as an engineering tool in developing countries

The developed world has invested in infrastructure and gained societal, industrial and economic benefits at a cost to the wider global environment. If all urban development to 2050 were to replicate the same traditional approach to infrastructure delivery, then the world would use about 35-60 per cent of the carbon budget available to limit global warming to 2°C [17] – business as usual is clearly not an option. We need sustainable solutions for countries requiring new or improved infrastructure to meet their economic, industrial and societal goals. Of course, these sustainable solutions must also be applied to the developed world and transforming an existing system can be much more challenging.

Data for informed investment in infrastructure

The report by the Infrastructure Transitions Research Consortium (ITRC) and UNOPS, 'Infrastructure, Underpinning Sustainable Development',[18] highlights the central role of infrastructure in achieving the UN's Sustainable Development Goals (SDGs) and in underpinning sustainable development. Organisations that fund projects in countries where there is a legacy of underinvestment in infrastructure and relative immaturity in terms of capacity consider an infrastructure project more viable for investment when it strengthens capacity, among other factors.

Projects focused on achieving the UN's SDGs often face acute challenges of population growth, urbanisation, short political cycles and long-term funding. The goal is to provide benefits of investment in perpetuity. This requires a systems approach to working with local governments to plan, deliver and manage infrastructure throughout its life cycle. This in turn needs infrastructure data to inform decisions on investments – data which is often lacking, making planning difficult and investment decisions harder to justify. Data is key to achieving the goal of informed investment in appropriate and sustainable projects.

Data to enable a whole-life perspective of infrastructure in the developing world

Effective organisations that work in the developing world recognise the imperative of a whole-life perspective and systems approach to planning, delivering and managing infrastructure. Understanding where a country wants to be in future decades enables an organisation to consider risks and hazards, anticipate demand and develop capacity. Once demand is established it is possible to leapfrog technologies from the developed world to plan for a resilient future in an uncertain climate. Using an evidence-based approach to planning infrastructure can support governments to collect the right data and analyse it to make better informed decisions for future infrastructure investment.

Due to limitations associated with political cycles, many engineering projects are driven by pressure to deliver in short time frames, on tight budgets requiring solutions focused on cost reduction at the expense of carbon mitigation measures. However, if we can present decision makers with the right evidence, presented in a form that addresses their needs and makes clear the links to wider policy goals, they are equipped with a fuller picture to determine the most sustainable and appropriate infrastructure solutions for the local context.

Time is short – we must act now

Meeting the challenge of climate change requires cross-sector multidisciplinary engagement, collaboration and action. It needs debate and open discussion where different perspectives are heard, and engagement of a diversity of skills to overcome barriers and foster innovative solutions.

Leadership is needed from the civil engineering community to engage effectively with policy makers and government, and to demonstrate the value of civil engineering knowledge and expertise, underpinned by data and insight to meet the challenges ahead. This requires us to be proactive and strategic in a number of ways:

1) Raise our voices
Civil engineers need to engage in the climate change debate at the top table, promoting the urgency of the challenge, and contributing to the policies developed to address it. We need to highlight the importance of carbon reduction to clients, including government policy and decision makers, and ensure carbon reduction and contribution towards SDGs are used as a criteria in project assessment and delivery. We are aware that we also need 'smart clients' who look for sustainable solutions at the outset before moving into the delivery phase.

2) Engage through enquiry
Enquiry should always be at the heart of engineering. Engineers must endeavour to communicate and debate with technical specialists in other fields in order to understand the broader perspectives of infrastructure projects, and develop systems-thinking approaches.

3) Get the basics right
We should use simple tools and 'rules of thumb' to begin to increase our understanding of how much resource we are using in our construction designs and delivery, and share this transparently. We must reduce (and ultimately eliminate) waste through better process controls and management. We should also think carefully about whether new construction is actually required or whether we can find solutions using existing built assets in order to minimise our use of scarce resources.

4) Use data to calibrate models and inform decision-making
We urgently need to limit carbon emissions and reduce use of limited precious resources in our civil engineering projects. This means using monitoring data, including real-time data, to measure the actual performance of our structures, how they are used, and how they interact with the wider environment over the short and long term, in order to calibrate our engineering models and ultimately change our design codes and guidance to be more efficient in materials use.

5) Understand risk from a broader perspective
Engineers need to think beyond the immediate structural decision making to consider wider impact at a systems level. This means considering longer-term impacts of design decisions, both from a project perspective and more broadly, including the impacts of carbon emissions and potential trade-offs between these[19].

6) Gather data to inform investment in infrastructure
As engineers, we play a vital role in understanding what data is needed to inform decisions around infrastructure investments, and to help gather it – whether this is from metering, demand assessment or structural health monitoring of the existing asset base. We need to lead the way in curating, managing and using the data we generate to ensure that it can be used to inform future decision-making.

7) Present the data that is needed, in the required format
We must learn to understand what information other decision-makers need, and to present it in a way that helps them in their role. This requires us to engage pro-actively with colleagues from other sectors and disciplines, and understand how our insights can help them, and vica versa. It also requires us to consider the ethics and security implications of gathering the data we use.

8) Train engineers to be data literate
Data literacy should be a key part of training for new engineers and continuing professional development for existing engineers. Consideration should be given to data/data analytics being a key competency in chartership, part of accredited degree programmes, and part of civil engineering CPD programmes. We should encourage and support improved development of data skills in schools.

Time is running out. Each and every engineer can make a difference – but we need to speak up, use data and act now.

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