UNIVERSITY OF CAMBRIDGE

LAING O'ROURKE CENTRE *for* CONSTRUCTION ENGINEERING *and* TECHNOLOGY

Transforming Construction

Review 2020-2023

Our vision and mission

Vision

Our vision is to improve the quality of life for all in an equitable and sustainable way.

Mission

The Laing O'Rourke Centre for Construction Engineering and Technology aims to drive transformation in the construction industry by focusing on Education and Skills, Research and Innovation and Policy and Thought leadership.

The Centre was launched in 2010 with industry partner Laing O'Rourke to fulfil a shared vision of transforming the construction industry through innovation, education and technology.

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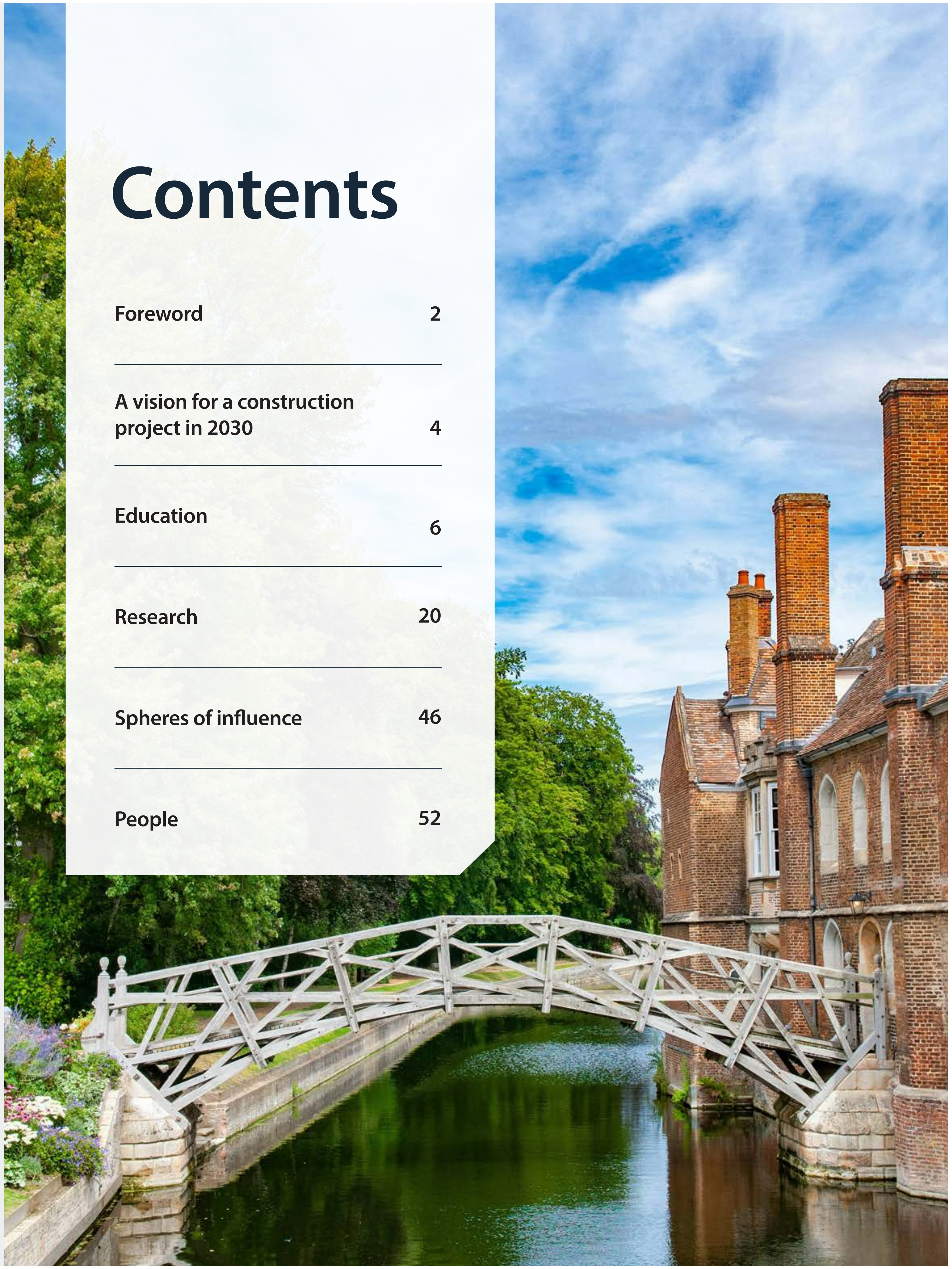

Professor Campbell Middleton
Centre Director

Foreword

A constructive engagement between academia, industry and policymakers is critical to providing informed, evidence-based, world-class policy and guidance. Such engagement clears the way for research to have a real impact on the construction industry and society.

The Laing O'Rourke Centre is catalysing change and has a measurable impact on the industry through (i) educating and upskilling future construction leaders, (ii) undertaking applied research in close partnership with stakeholders, and (iii) generating an evidence base and thought leadership to underpin and support the implementation of new policies, processes and methods in the construction sector.

Over the last three years, we have started work on some new strands of exciting research that have attracted much attention and support. I invite you to read this update to learn more about our progress and the impact our work is having on addressing the industry's major challenges.

The Centre's research strategy focuses on three main desired outcomes: (i) sustainable infrastructure, including net zero carbon, (ii) improving productivity, and (iii) increasing the social value delivered by construction projects in the built environment.

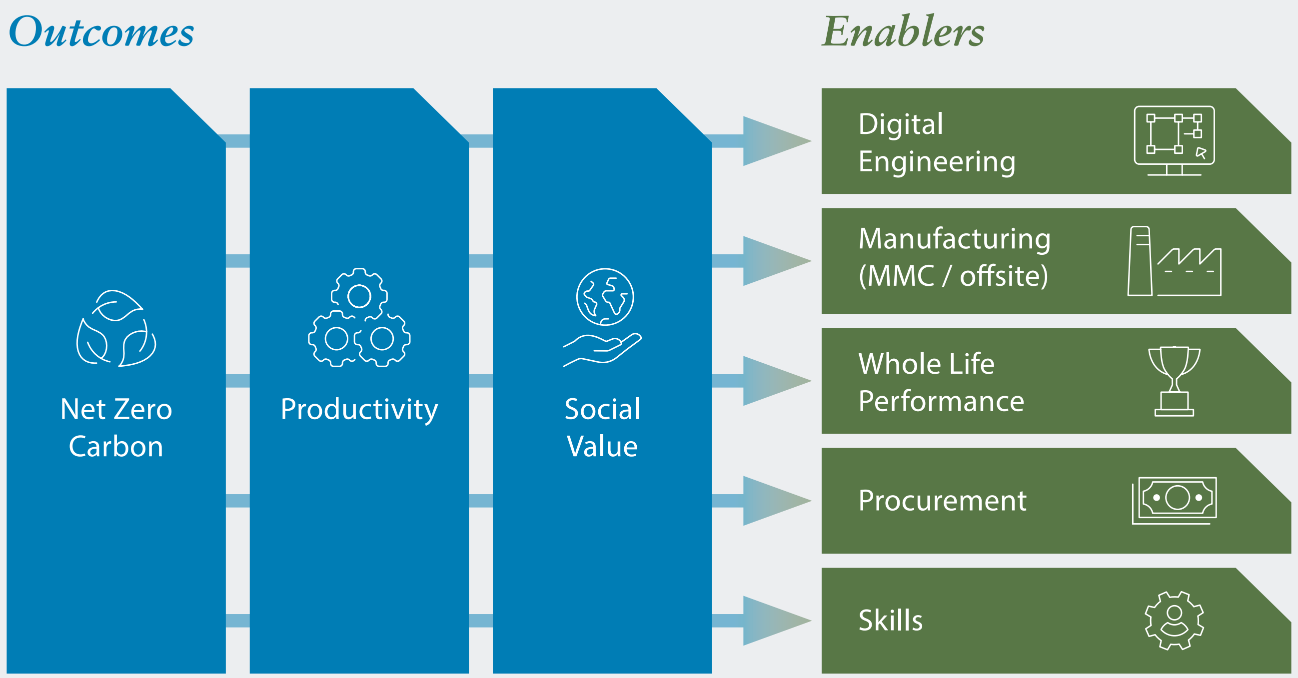

Figure 1: Laing O'Rourke Centre research strategy.

These outcomes will be enabled by greater adoption of digital engineering, modern methods of construction (MMC), a focus on whole-life performance, new procurement models and upskilling of the workforce.

We are actively pursuing research in each of these areas.

Work on wellbeing brought together key industry players in a first dialogue chaired by Dame Professor Carol Black with the aim of reducing the unacceptably high rates of suicide in the construction sector. Our research will help find solutions for improving mental health and wellbeing and enhancing other aspects of social value.

A new strand on productivity demonstrates the importance of having an evidence base to determine what is happening on-site and how productivity improvements can be made. Over the last three years, we have worked with several companies that are now part of the data gathering and analysis activities required to generate metrics for the industry. The findings so far offer valuable insights to planners and project managers, empowering them to make informed interventions and drive improvements in on-site productivity.

Current research in digital underground construction will leverage next-generation digital technologies to revolutionise how underground infrastructure is delivered. This will play a vital role in addressing the increasing demand for infrastructure development while minimising disruption to surface activities and optimising land use.

The work we are conducting on sustainability investigates how to support rapid, low-threshold, high-impact reductions in the use of key materials like cement and steel, which account for approximately 15% of global emissions. The research outcomes help identify opportunities to reduce the built environment's impact whilst reducing expenditure on high-cost and high-carbon-intensity materials.

Skills are a fundamental enabler of transformation, and as technologies evolve, the workforce will need to be upskilled to maximise the potential of improvements offered by new tools and technologies, leading to new ways of working. Our skills work comprises several elements:

- The Laing O'Rourke Centre was invited to join a Construction Leadership Council (CLC) Skills Working Group to deliver research on the skills that will be required by the industry to deliver net zero in 2050 and that will support the industry's adoption of digital technology and modern methods of construction.
- The Centre won a major EU and EPSRC grant to train researchers to deliver world-class research through the Digital Future Roads initiative. Our researchers are working on digital engineering aspects of road transport in collaboration with many industry partners to develop a connected physical and digital road infrastructure system. The outcomes of this research will be transferable and aim to deliver resilient roads that measure and monitor their own performance over time.
- I am delighted to report that both our new students and also those who have completed our world-leading Construction Engineering Masters (CEM) degree programme are implementing their learning in the workplace, bringing direct benefits to their employers and responding to the needs and realities of the industry. In the last three years, 86 industry professionals from 42 companies and 15 countries have joined the CEM programme, building valuable networks of highflyers who will implement innovative technologies and methods to achieve the Centre's overall strategic objectives.
- In addition, we are broadening our impact by expanding the CEM and our executive education and alumni programmes and introducing alternative short-course educational initiatives to provide the skills our industry leaders require to deliver change.

Over the last three years, we have started work on some new strands of exciting research.

The targeted nature of our Centre's strategy will enable us to generate the evidence and tools required to challenge the status quo and provide the skills and knowledge needed to improve procurement and productivity, reduce carbon, improve wellbeing and mental health, and increase the social value generated by our industry.

I invite you to learn more about how the Laing O'Rourke Centre is shaping the future of construction through research, education and thought leadership. We start by sharing a vision of what a construction project might look like in 2030.

Professor Campbell Middleton
Centre Director

Dr Brian Sheil
Laing O'Rourke
Associate Professor
in Construction Engineering

A vision for a construction project in 2030

In this piece, we envision a construction project in the year 2030 to stimulate new thinking, debate, and research directions.

Our project vision unites people, processes, and technologies across four distinct paired dimensions: digital, physical, onsite, and offsite. Certainty in delivery, achieving the trajectory required for net zero carbon, heightened productivity, and increased social value will converge to mark a new era for construction. We identify below the three key areas that underpin this transformative change.

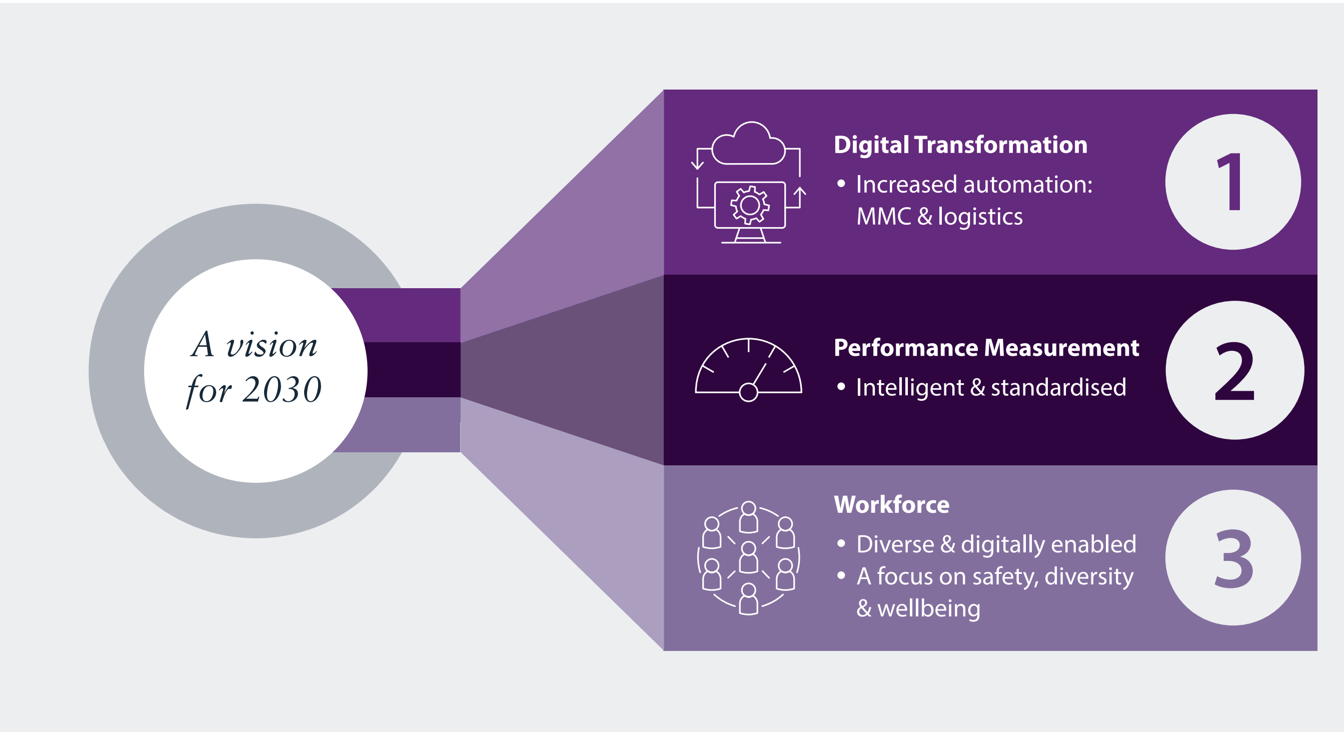

Figure 2: Three possible enablers of transformative change by 2030.

Digital transformation

From a digital perspective, the deployment of digital twin technology is central to our 2030 vision. This advanced technology allows the creation of a replica image of the physical world in the digital realm, combining both semantic and geometric information. Leveraging data science, actionable insights can be extracted from these digital twins, empowering intelligent decision-making that drives project success. Turning to the physical processes, we expect to see innovative materials and lifecycle processes. With a determination to achieve net zero carbon targets and minimise the industry's impact on climate change, innovative solutions will span the entirety of a project's lifecycle.

Our vision for processes involves automated logistics seamlessly facilitating the movement of materials, equipment, and supplies. Traditional construction elements will be replaced with cutting-edge practices, exemplified by the goal of implementing real-time monitoring through connected autonomous plants. Early progress in modern methods of construction (MMC) will evolve further, culminating in significantly increased automation by 2030 (e.g. fully automated offsite production, semi-automated on-site assembly). Digital twin-led practices and Internet of Things support will drive this automation, closely tied to the establishment of a flexible and reconfigurable kit of parts catalogue.

Performance measurement

As 2030 approaches, intelligent construction project performance measurement will become a reality, enabled by mature data capture technologies and exchange standards. The foundational element involves the establishment of consistent and universally accepted performance metrics, notably in relation to time, cost and quality, ranging from overarching project evaluation to granular task-specific assessments. Subsequently, the integration of cutting-edge tools such as sensors, cameras, and laser scanners for automated data collection is poised to foster seamless and continuous information acquisition.

By 2030, we envisage real-time data interpretation that transcends conventional graphical representations, enabling immediate contextual insights that, in turn, empower informed decision-making and strategic planning. Furthermore, the iterative cycle of automated improvement actions ensures that insights gleaned are promptly translated into tangible enhancements. This cycle culminates with comprehensive reviews at both team and business levels, fostering a culture of continuous learning and adaptive refinement.

As technologies advance, the workforce will undergo upskilling to harness the potential of new tools and methodologies.

Skilled workforce

The role of skilled individuals is also pivotal to our transformational vision. As technologies advance, the workforce will undergo upskilling to harness the potential of new tools and methodologies. Emerging roles include generative designers proficient in AI-driven optimal designs, sensor system integrators adept at consolidating data flows, and net zero evaluators merging environmental evaluation with construction planning. The industry will need to take proactive steps to nurture these talents, offering personalised career development paths and leveraging programs like the Construction Engineering Masters program to equip current and future leaders for success. We also see safety practices being integrated into every aspect of a construction project, ensuring the well-being of all members. In parallel, a culture of diversity and well-being takes root, fostering an inclusive construction environment. Promoting diversity, prioritising well-being, including mental health support, and nurturing a sense of shared responsibility and empowerment will be central to future workforce recruitment and retention.

Recognising the seismic changes brought about by these advancements, we anticipate organisational shifts. Traditional reporting systems and decision-making structures are poised to evolve, ensuring alignment with the new ways of working and the expertise of the transformed workforce. By 2030, we expect to see a construction industry that not only embraces innovation but thrives on it, setting new standards and achieving unparalleled project outcomes.

Education

The Centre focuses on educating and inspiring current and emerging leaders and innovators, equipping them to influence the industry and implement research outputs that deliver value to society.

Dr Gavin Davies
Course Director, Construction Engineering Masters

Future skills and future leaders

At the heart of our education work is the Construction Engineering Masters, the CEM. The CEM is a part-time Masters programme aimed at equipping future industry leaders with the knowledge, skills, inquisitiveness and inspiration to lead and deliver a meaningful change and positive transformation of the sector.

The CEM programme combines academic rigour with practical application and features face-to-face residential teaching weeks. The direct access to real challenges facing organisations and the wider industry provides ideal inspiration to students for their research. The CEM enables students to trial new ideas and evaluate them effectively in an evidence-based way to address and provide recommendations and solutions for real-life challenges.

> *"This course gives me the confidence that we have access to the leading future thinking in our industry."*
>
> **Mike McNicholas**
> Managing Director at AtkinsRéalis (CEM student sponsor)

89%

CEM student overall satisfaction based on the 2022 Postgraduate Teaching Experience Survey (national survey including all Cambridge University postgraduate courses).

>180

Over 180 leaders across the construction industry have participated in the CEM programme.

90%

of students from the first five cohorts have been promoted since starting the course.

66%

of students who graduated in the last four years have been promoted since starting the course.

Research into action

One recent graduate of the CEM programme studied the use of digital models during the construction phase of projects. His research highlighted substantial potential efficiencies that could be achieved by taking a design digital model and adapting it for the specific needs of the construction and assembly phase of the project. The background research and pilot project undertaken as part of the CEM dissertation studies were so successful that the student was able to implement a refined version of their methodology widely within their organisation, leading to cost efficiencies and reduced re-work. Please read the project overview and outcomes on pages 16 and 17.

Diversity

Students on the CEM are drawn from organisations across the construction industry, including designers, contractors, clients, professional advisers, construction lawyers, technology companies and others. Since 2020, a further 86 industry professionals from 42 different companies and 15 countries have joined the programme, bringing the total number of participants since the course started to 254.

This blend of disciplines and backgrounds generates a wealth of views and perspectives that are shared peer-to-peer, challenged and explored in an encouraging and supportive environment. The diversity of perspectives gives rise to opportunities for free-thinking and creative thought leadership that can benefit the sector and society more widely.

Topics covered in their dissertation projects include embodied carbon and net zero, design for manufacture and assembly, digitalisation, artificial intelligence, procurement, organisational structures, risk management and skills.

Dr Gavin Davies

Course Director, Construction Engineering Masters

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Career progression

Looking through the CEM cohorts back to the first students who started the programme in 2011, we see that around 90% of students from the first five cohorts have been promoted since starting the course. Of those who graduated in the last four years, two-thirds have been promoted since starting the course, suggesting that the course positively influences its students' career progression.

The talent and diversity of the CEM students offer great hope for the future of the industry. By refining the skills and helping to focus the passion of these students, the CEM can continue to be a force for good in the construction industry.

The following pages explore different perspectives of the impact of the Construction Engineering Masters programme on participants, sponsors and for the construction sector.

"The CEM makes you look outside the boundaries of your day-to-day pressures and gives you the skills and competencies to challenge the status quo, along with a network of like-minded people who want to improve and positively impact the industry."

Andrew Ernest

CEM cohort 07

Strategic Bidding Director at Kier Construction

Net Zero Carbon

Whole Life Performance

Jimmy Barratt-Thorne
CEM cohort 11
Technical Director at WSP

CEM dissertation: Transformation response to net zero

What is the challenge?

Bridges are particularly carbon-intensive elements of infrastructure, being formed primarily from concrete and steel, which are the two most carbon-intensive materials, accounting for 15% of global emissions combined. There is a particular need to reduce the embodied carbon of these structures since these are upfront emissions, and we are in a critical period of change.

The current literature on carbon in bridges shows much variance in their carbon efficiency, partly attributable to the substructure, particularly at the lower span range where the abutments and foundations contain a greater share of the carbon total. However, there is a current gap in the literature as there is not a breakdown to understand how significant this is. Furthermore, the significant variance in carbon conversion factors raises uncertainty around whether making decisions based on previously developed solutions remains valid in differing geographies or points in time.

Figure 3: A45 Whilton Brook Bridge as constructed.

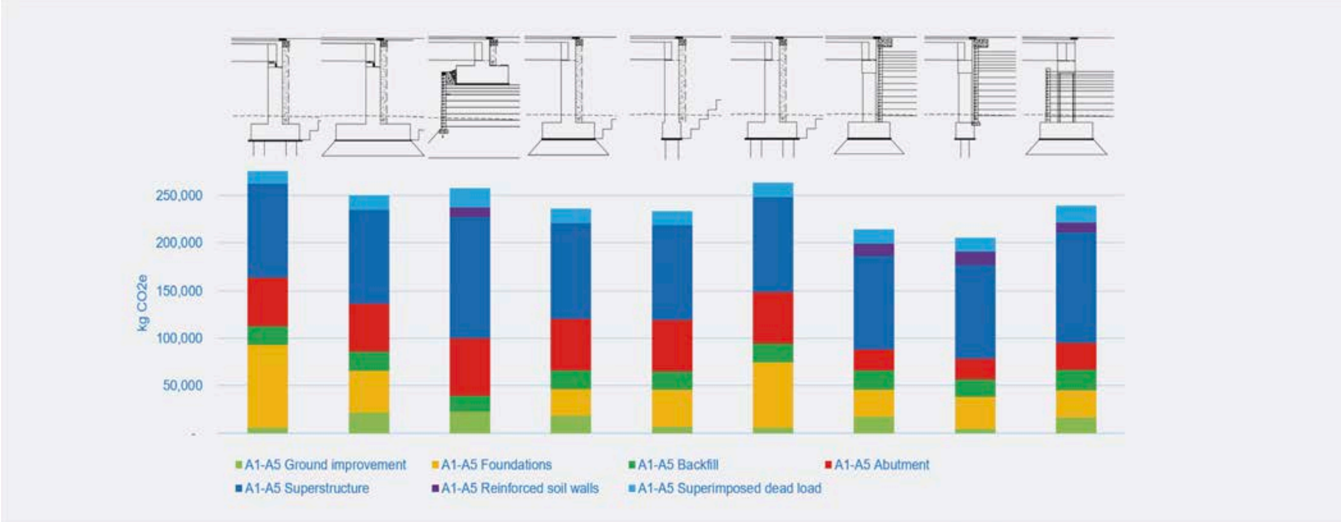


Figure 4: Results for nine substructure forms, including superstructure.

The research project

This research explored how do different forms of substructure affect the embodied carbon of a bridge. Using a case study based on a real structure constructed in 2018, nine alternative forms of substructure were developed in line with best practices from PD6694 and then evaluated their embodied carbon using an in-house carbon calculator based on the Institution of Civil Engineers (ICE) materials database. Only the substructures were changed, with the span length and abutment height kept constant.

These options were then put through a sensitivity analysis to understand whether the results obtained are limited to the single structure considered in its single geography at the time of construction or whether the results are more generalisable.

What is the outcome?

The outcome showed that for this bridge, the substructure can make up a share of between 40% and 55% of the bridge total, even when excluding wing walls, which haven't been considered in this study. The most preferable form was the use of reinforced soil behind individual columns, with a foundation comprising a single row of piles. This optimal solution contained 50% of the embodied carbon compared to the least favourable.

The sensitivity analysis showed that the carbon conversion factors used can make a significant difference to the absolute total carbon in a structure by a factor of five. However, when considering various scenarios of upper and lower bound factors on concrete, steel reinforcement, and aggregates, the hierarchy of which option remains lowest in carbon generally remains true, and the selection of a preferable option is fairly insensitive to the carbon conversion factors. This supports current around using global factors at early design stages when decisions are made.

It was only when considering a locally available source of low-carbon aggregates for ground improvement that the spread foundation became more favourable than a single-row foundation, despite the spread foundation containing less concrete and reinforcement, the carbon associated with the ground improvement results in the single pile row being preferable in most instances.

Other behaviours and trends observed are that the two-piled row foundation is the most carbon-intensive and that the integral frame solution is more efficient than the semi-integral counterpart. Despite the enhanced earth pressures on the abutment, the benefit from the framing action makes a saving in the foundation requirements. All options have also been evaluated for cost, and a strong correlation has been shown, equating carbon saving with cost saving and, thus, a further incentive for material efficiency in design.

By highlighting how different forms of substructure affect the embodied carbon of a bridge, this research is helping equip designers with knowledge in this area, enabling them to make better-informed decisions and helping to move away from practice as usual and designers 'sticking with what they know', but also highlighting how a poor decision at concept stage can lock in both carbon and cost inefficiency.

Professor Peter Guthrie
CEM Fellow and
Director of Studies

CEM dissertation impact: A Director of Studies perspective

The perceived wisdom on offsite manufacture for elements of buildings is that this will be more environmentally friendly, cheaper and of a higher quality.

A CEM student used the opportunity of their Masters research to take a case study and directly compare prefabricated bathroom pods with what would have been done in traditional construction.

The findings were surprising and instructive. The quality of the finished pods was excellent and reduced the need for specialist trade skills on site. There are clear benefits for workers who are employed at factories rather than being forced to move from one construction site to another. The design decisions for the bathroom pods had to be made earlier in the process than for a traditional form of construction, but wastage was reduced as control of materials was more effective in a factory setting. The potential downside of being unable to change the detailed design of the pods demands greater certainty in the design at an early stage. There was no benefit in terms of greenhouse gas emissions for a number of reasons. The critical condition of the bathroom pods was when in transit, and the pods had to be strong enough to withstand being moved from one factory to another and finally to the site for installation. Each pod was made progressively at three different factories, thereby increasing the transport emissions. The pods, being structurally independent, required special casting in the floors of the building to allow for the pod floors to be flush with the finished floor level.

Lessons learned from the exercise included that the emissions associated with offsite manufacture need to be more fully integrated into the project formulation so that claims for reduced greenhouse gas emissions for offsite manufacture can be justified.

Productivity | Digital Engineering | Skills

Herman Ferreira
CEM cohort 09

Additional text by Dr Gavin Davies, CEM Course Director

CEM dissertation: Impact to the sponsoring company

Construction projects are required to address sustainability issues more comprehensively than ever. At the same time, poor construction productivity is a major hindrance to delivering these sustainability goals.

New technological developments in digital information systems can provide novel solutions to improve productivity and so there is a real imperative that these are evaluated and adopted quickly, where they generate measurable value. The idea of Digital Twin Construction (DTC) is to fully utilise digital design and construction information as an integral part of the construction process. The contention of this research was that the DTC approach has the potential to proactively shift the industry to more productive and sustainable project delivery.

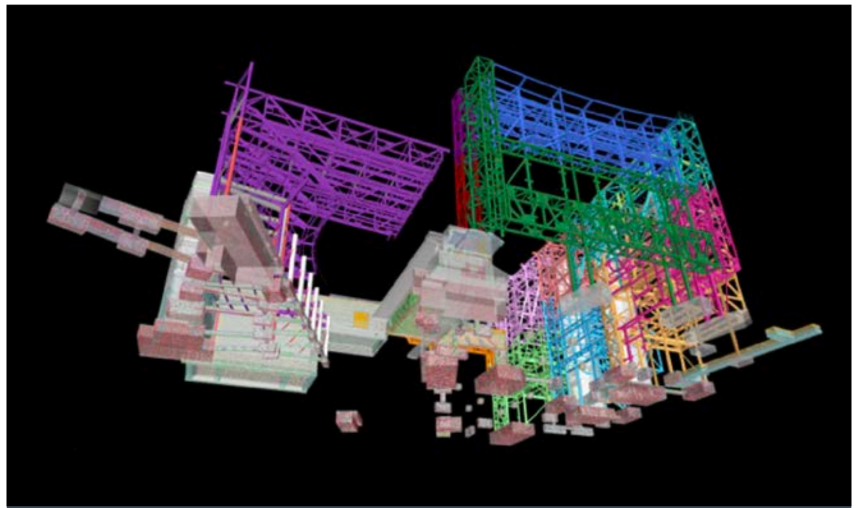


Figure 5: The completed Design-Build which shows the fully 3D detailed reinforced concrete works.

A conceptual analysis of Digital Twin Construction

Digital Twin Construction as a concept is new and exciting and is arguably the first attempt to provide a considered and inclusive framework for digital twin information systems for application within the construction process. A conceptual analysis of Digital Twin Construction was used to investigate whether this data-centric approach to project delivery can bring value now or whether such value creation remains an aspiration for the future.

Evidence gathered from this research indicated that value could be generated in the short term if contractors invest in three key areas:

1.

Initiating a radically different approach to Building Information Modeling (BIM). In contrast to current industry practice, this research suggests that the contractor can generate value by producing full construction detail building information models, even from scratch if necessary, during the project delivery phase. Designer-authored models were found to lack the data structures (called schema) and geometric detail to allow digital models to be enriched with site-collected data which in turn can be used to generate value during construction.

2.

Collecting key productivity output data by extending data collection from existing sensors already used by industry. Increasing the frequency of sensor data collection establishes a near "real-time" connection between the virtual and physical construction sites.

3.

Integrating key labour productivity input data already collected on-site using smartphones. By integrating this input data with measured output data and BIM, it is possible to identify opportunities to improve productivity by creating a closed-loop productivity digital nervous system on the project.

The findings from the dissertation highlighted the substantial potential efficiencies that could be achieved by taking a digital design model and either adapting it or regenerating it completely for the specific needs of the construction and assembly phase of the project.

Impact and benefit of the research dissertation to the industry sponsor

Based on the research findings and recommendations of this research, Laing O'Rourke has initiated a full-scale Digital Twin Construction trial implementing a refined version of the research methodology. Early results show that this has led to cost efficiencies and reduced re-work.

Grace Newey: "The CEM has been one of the most fulfilling experiences of my life"

Grace Newey is a digital transformation specialist at AtkinsRéalis and part of Cohort 11 of the Construction Engineering Masters (CEM). Throughout her tenure, she has actively promoted innovation and positive change, with a focus on digital transformation.

Grace recently completed her CEM dissertation viva and hopes to graduate this summer. She describes the experience as a significant source of personal and professional growth and an important step forward in her career. The programme has equipped her with the necessary skills and instilled the confidence to challenge the status quo, envision her impact on the industry, and strategise her path to success.

Grace Newey.

What do you love the most about working in this industry?

The varied experiences and exciting projects. There are always loads of problems that need innovative solutions, which allows me to blend my soft skills with more technical expertise. Working on projects where you feel like making a difference to society, whether transport, mobility or critical infrastructure, can be really rewarding.

What do you feel is the role of the CEM for the industry, and how can it positively impact the construction industry?

Though many exciting things are happening within our industry, there is also much room for growth and improvement. The CEM provides a unique opportunity to gain insight into the state of the art and what the future might hold while also offering a stark look at our current situation and the lessons we can learn. Most importantly, it shows us students how we can make a positive impact. The blend of technical, operational, and strategic content equips us to take on more responsibility and elicit better outcomes, fostering a sense of empowerment and hope for the future of our industry.

You have juggled work and study for two years. How did you manage it, and why was it worth it?

The key to balancing work and studies is to be honest with yourself and the support network around you. This network should include personal, professional, and academic support. It is important to stick to your plans and, if required, be willing to ask for help, whether it's someone marking up your work or just listening to your plans over a coffee. The worst way to tackle this is to feel like you're drowning alone. Remember, nothing is a lost cause unless you suppress and ignore it. Reflecting on the discipline and dedication you mustered and seeing your contributions as an outcome is incredibly rewarding.

Based on your experience in education, what is unique about the CEM compared to other programmes?

The CEM is set up to give students a well-rounded view of the construction sector. The content is varied with presenters from every corner of academia (including Judge Business School), as well as some of the industry's best current leaders and influencers, sharing their experiences of the industry, how they have contributed to change, and what their legacy will leave for us students to take forward. I haven't encountered another construction-specific course that provides you with all the operational knowledge you would get from an executive business qualification but with an industry-specific lens. I genuinely believe selecting a course like the CEM would be tenfold more valuable than a generic leadership qualification for people within our sector.

How do you feel the CEM degree has impacted your career and how you do your job?

I have two stand-out outcomes from the course when considering my career. The first is the ability to refine my public speaking style. I have always enjoyed presenting, but through the duration of the course, whether that be from individuals who have presented and inspired me, getting involved with debating at the Cambridge Union, or through the presentation coaching we have received directly, I feel confident stepping up in front of a large audience and talking passionately about my work. I also greatly value the networking I have been able to do with the presenters during our coffee breaks, panel discussions and Q&A sessions, and my fellow cohort members. The students in this course have some of the most interesting experiences in our industry, and it has totally opened my eyes to different perspectives. I feel connected to them for life after this experience and hope that this connection will allow us to collaborate and support each other with our missions well into the future!

> *"The blend of technical, operational, and strategic content equips us to take on more responsibility and elicit better outcomes, fostering a sense of empowerment and hope for the future of our industry".*
>
> **Grace Newey**

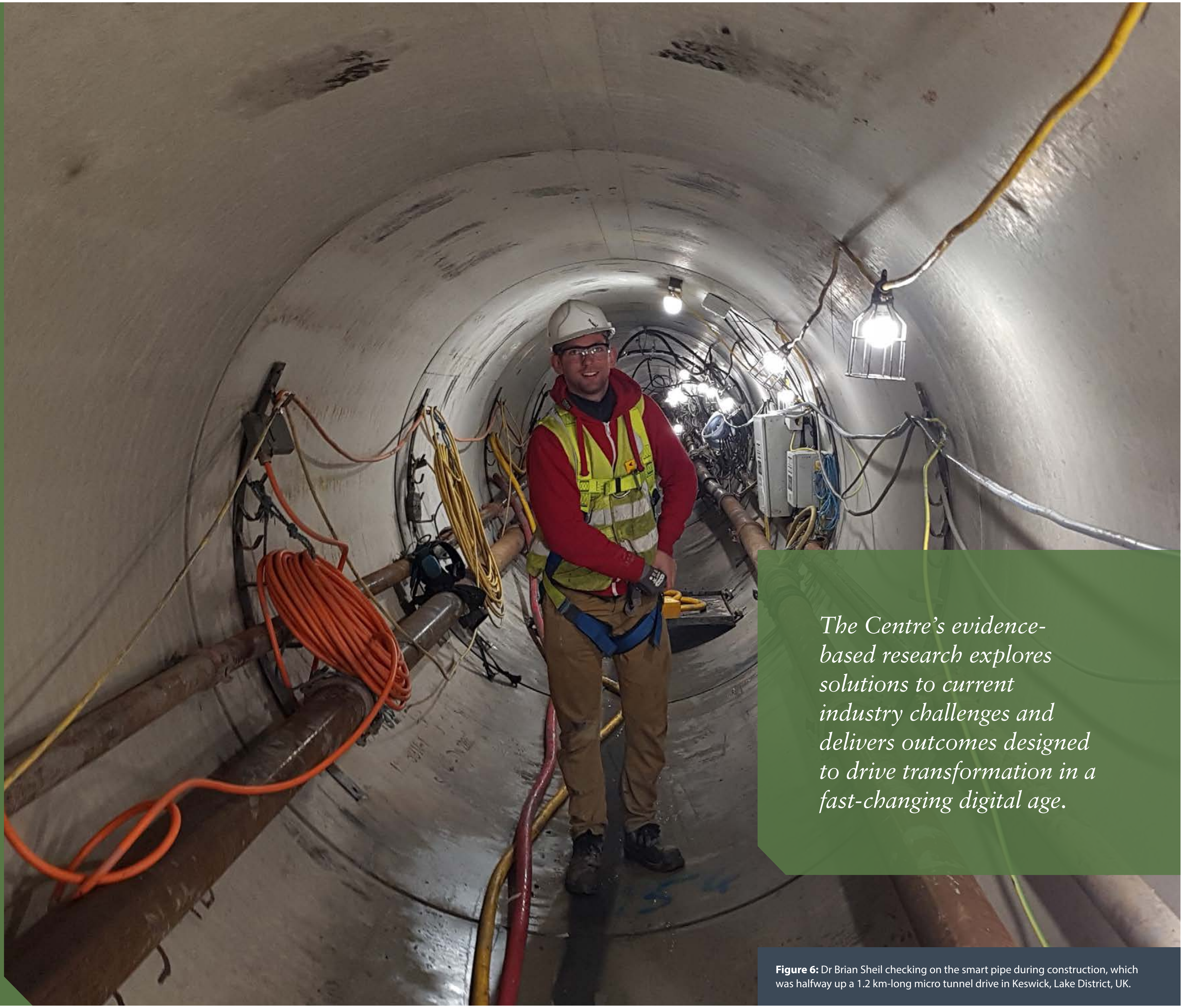
Do you feel different about the industry after completing the course?

The course has made me reflect on what impact I want to make on the industry and how I can do this. This is what now motivates me to want to obtain a senior role within my organisation so that I can make influential decisions and better shape our industry's future.

Do you think that CEM students' companies benefit from employees going through this programme?

Absolutely! For any company with ambitious people, this course is a great way to inspire and motivate them to want to make their mark and help drive you forward in a competitive landscape. As a construction engineering company, if you aren't sending your best people through this programme, then you're missing out!

Research



The Centre's evidence-based research explores solutions to current industry challenges and delivers outcomes designed to drive transformation in a fast-changing digital age.

Figure 6: Dr Brian Sheil checking on the smart pipe during construction, which was halfway up a 1.2 km-long micro tunnel drive in Keswick, Lake District, UK.

Dr Danny Murguia
Senior Research Associate

Revolutionising construction using performance data

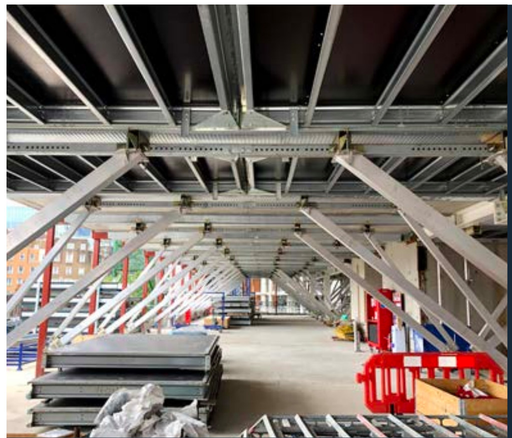


Figure 7: Our research includes a detailed evaluation of several building projects that are trialling modern methods of manufacturing using innovative platform building systems (PDfMA).

Benefits to industry

- A Performance Measurement Framework was developed and tested using real data from major UK construction projects.
- The Performance Measurement Framework can support the establishment of project performance evidence in a consistent way within and between organisations.
- The knowledge of current performance can provide enhanced insights into what is going on in the field, identify process waste, and lead to interventions to dramatically improve programmes, efficiency, and carbon utilisation.
- Project performance data can be used as a basis to set national and international benchmarks for both building and infrastructure projects.

Measuring performance: one of the greatest challenges faced by the construction sector

It is well known that the construction industry has struggled to measure performance improvement despite the increased adoption of Building Information Modelling (BIM) and off-site construction. The CIRIA C792 report *"Methodology for quantifying the benefits of off-site construction"* (Jansen van Vuuren and Middleton, 2020) has been the first major attempt to investigate the benefits of off-site construction. However, the report revealed that performance data is inconsistent within and between construction organisations, and/or data is simply unavailable. As such, there is little clarity on the boundaries of the data needed for meaningful collection and analysis. Therefore, there is a need to clarify *what*, *how* and *why* to measure project performance. This foundational work will set a basis for any meaningful micro and macro performance assessment efforts.

The project

A multidisciplinary group of researchers at the Laing O'Rourke Centre are working closely with industry partners aiming to develop new and improved methods for measuring the performance of major building and infrastructure projects.
The objectives of this project are:

- Develop a Performance Measurement Framework with appropriate indicators for defining outcomes and value.
- Develop a Digital Dashboard to visualise data and support enhanced insights and timely decision-making.
- Develop a Digital Twin Construction ecosystem for collecting, interpreting, and visualising construction data.
- Use large construction datasets to set up industry benchmarks, identify patterns in data and simulate and predict future scenarios.

Figure 8: A site visit to one of the projects under study. From left to right: Asitha Rathnayake, Dr Danny Murguia, Neil Pennell from Landsec, Prof Campbell Middleton, Dr Vladimir Vilde, Tercia Jansen van Vuuren and Josh Harding, previously at Sir Robert McAlpine.

1.

Building upon the Construction Industry Research and Information Association (CIRIA) C792 report, **Stage 1** of the project is foundational work to determine *what* and *how* to measure overall performance and achieve consensus on the boundaries of data collection. Construction data (e.g., assembly, labour, waste, etc.) from four major developments in London are being examined to find out the available data, the level of granularity, and the performance indicators that can be evaluated. The triangulation of multiple data sources, interviews with key project participants, and several workshops helped define a multi-level Performance Measurement Framework at the project, work package and activity levels. The current work focuses on performance indicators with a view on installation variability, construction workflows and the identification of process waste. This stage also involves the development of a digital dashboard through several cycles of iteration and industry engagement and draws from real-time data to visualise performance.

2.

Stage 2 of the project involves conducting a macro assessment by engaging a larger number of clients and contractors to establish evidence-based project performance of various building and infrastructure projects. The team is working closely with the Construction Productivity Taskforce, a group of major clients and contractors working on improving productivity in the UK construction sector, to implement the performance and productivity framework, collect productivity data from several demonstrator projects, use metrics to improve decision-making and set up industry benchmarks.

3.

Stage 3 of the project will develop a Digital Twin Construction ecosystem for project performance measurement by leveraging automated and semi-automated methods for collecting and interpreting construction data. Computer Vision techniques, sensor data, and digital records can be used to simultaneously collect and model inputs (e.g., material delivery, labour, and equipment) and outputs (e.g., installation, embodied carbon, and waste). Digital data streams and appropriate metrics can provide stakeholders with new information and insights to identify *"process waste"* and enhance responsiveness to address the challenges of project performance in terms of productivity, programme, cost, and sustainability.

Transformational performance can only be achieved when decision-makers understand what is happening in the field, evaluate performance against benchmarks, and formulate strategies to radically transform their operations.

From performance data to decisions

The availability of a consistent set of performance data within and between organisations can be a valuable enabler for the identification of areas for performance improvement, as well as national and international benchmarking. Despite the fact that many progress monitoring technologies have been deployed in the industry, transformational performance can only be achieved when decision-makers understand what is happening in the field, evaluate performance against benchmarks, and formulate strategies to radically transform their operations. The use of digital technologies will not be meaningful until data is collected and performance is measured consistently to support project success.

Early outcomes and impact

This project is supporting and working closely with the Construction Productivity Taskforce. The work is being presented to multiple key stakeholders, including developers, consultants, and Tier 1 and Tier 2 contractors, and has driven further engagement from the industry to trial the new methods on new live projects. The early results have identified two key metrics that simultaneously measure the speed of construction operations and the efficiency of labour utilisation. Moreover, the data has been presented using flowlines to visualise process waste and identify areas for improvement. The research team has provided feedback to the Taskforce's guide entitled *Measuring Construction Site Productivity: A Seven-step Framework for Success*, based on the preliminary findings. The work has been presented at academic conferences such as the CIB W78 conference in Melbourne, Australia in June 2022 and the 31st Annual Conference of the International Group for Lean Construction in Lille, France in June 2023.

Digital Twin Construction platform

As illustrated in figure 9, the Digital Twin Construction platform will collect, integrate, and interpret data from live construction projects to provide timely information to project managers and corporate decision-makers in terms of productivity, schedule and cost. To do this, we are working closely with industry partners to determine the value-adding performance metrics and data needed for improved decision-making. This includes:

- Developing a data architecture including labour, deliveries, installation, crane usage, weather, among others.
- Developing a digital ecosystem to capture data consistently across projects.
- Developing a "Performance and Productivity" dashboard to visualise performance and understand variability.
- Conducting data analytics to determine cause-effect relationships and implement change on factors that influence performance.
- Benchmarking of best practices across projects.
- Using actual performance data to simulate and optimise programmes and cost, and thus, de-risk project management.
- Using machine learning and artificial intelligence to convert performance data into actionable insights.

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Figure 9: The Digital Twin Construction platform will collect, integrate, and interpret data from live construction projects to provide timely information to project managers and corporate decision-makers in terms of productivity, schedule, and cost.

Net Zero Carbon | Digital Engineering | Whole Life Performance

Dr Brian Sheil
Laing O'Rourke
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Leaner and greener: next-generation underground infrastructure

Figure 10: Large-diameter caisson for an underground stormwater pumping station at Anchorsholme park, Blackpool, UK.

Benefits to industry

- **Quantify:** accurate estimation of carbon emissions is essential to improve the delivery of underground utility infrastructure.
- **Improve:** the research enables existing design methods to be updated to eliminate over-conservatism, excessive material use and related emissions.
- **Innovate:** we propose new construction methods and design methods, enabling further reduction in material use and emissions.

Background

Buried infrastructure offers the most, if not the only, viable solution to meet growing infrastructure demands in urban environments whilst minimising environmental impacts. Two construction methods set to play a key role are microtunneling (MT) and open shafts. MT is an increasingly popular method of installing buried utility tunnels for clean water and wastewater applications. In MT, soil excavation is undertaken by a tunnel boring machine, typically commencing in a launch shaft and terminating in a reception shaft. The shafts are commonly constructed as open-dug caissons, which are installed by constructing the shaft at ground level before allowing the entire structure to sink under self-weight whilst excavating inside to control the lowering of the shaft.

The Problems

1.

No studies prior to this project have calculated carbon emissions related to MT considering on-site activities and material production.

2.

Design methods for sinking open-dug caissons, a key component of many MT projects, remain rudimentary, leading to over-conservatism and excessive material use. One of the main drivers when designing the shafts is the skin friction on the outside of the shaft during sinking, hence the mass of concrete required to ensure the shaft sinks under self-weight. There is currently no universally accepted theory for the calculation of skin friction during sinking of shafts.

3.

Analogously to Problem 2, skin friction on the outside of the shaft after construction, in resistance to flotation, is also a key design driver. Once again, there is no universally accepted theory for calculating skin friction resisting shaft flotation. In practice, resistance to flotation commonly relies solely on the self-weight of the shaft, once again leading to excess materials and embodied carbon.

Figure 11: Instrumented 'Smart Pipe' being installed in the longest micro-tunnel drive completed in the UK to date (~1.2km, Keswick, UK).

The Laing O'Rourke Centre Solution

Working in conjunction with industry, a large database of MT projects has been curated. A bespoke workflow has been developed to calculate carbon emissions and identify carbon-intensive construction stages and activities.

> *We propose new construction and design methods, enabling further reduction in material use and emissions.*

Whilst the analysis showed emissions of both the tunnels and shafts to be significant, consultation with industry partners concluded there was greater scope for reducing material use and hence emissions resulting from shafts. The research is focused on improving the understanding of skin friction on shafts through small-scale laboratory modelling. Using bespoke apparatus, a series of experiments is being carried out to work towards developing a universal method for calculating skin friction on open-dug caisson shafts during sinking. Following this testing phase, a second phase, focusing on quantifying skin friction in resistance to the flotation of shafts, will be undertaken. Early outcomes from this work have been disseminated in the form of a journal publication for additional take-up by the academic community.

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Tercia Jansen Van Vuuren
Research Associate

Understanding the landscape of decarbonising construction

Benefits to industry

- Understanding the breadth of topics under the umbrella of decarbonisation.
- Guidance on key issues and challenges to be addressed.
- Identify relevant initiatives or resources that can support action.

The challenge

The UK has a legally binding requirement to achieve net zero by 2050, with an interim target to reduce emissions by 78% by 2035 compared to 1990 levels. The built environment is a significant contributor to these national Greenhouse Gas (GHG) emissions, both from the provision of infrastructure and services required for the development of society (new-build and retrofit), as well as from the ongoing energy to heat and power buildings and infrastructure.

Whilst the last few years have seen a significant increase in consideration of carbon emissions across the construction sector, the broad spectrum of stakeholders and range of types of projects and activities that comprise the industry, together with the long history of reliance on traditional methods with carbon-intense materials such as concrete and steel, makes construction a particularly complex sector to decarbonise.

All this activity, together with the broad range of avenues for addressing decarbonisation of construction, can be overwhelming and it can be challenging to understand the landscape of the topic and then know what action to take. This creates uncertainty about how each stakeholder can drive change within their own sphere of influence and what will be complementary and working in synergy to drive the industry towards the changes necessary for a low-carbon society. This results in inconsistency in actions and targets by organisations in the sector and a lack of holistic system thinking that could potentially result in incompatibility or unintended consequences.

Capitalising on existing knowledge

The next decade is the most critical for achieving reductions, which means we need to be capitalising on what we already know, focusing on the technology we already have to inform actions to take today. However, the complexity of the challenge and the overwhelming amount of information available can be bewildering. Consequently, individuals and organisations can spend considerable time and expense unnecessarily repeating the work of others and not capitalising on existing knowledge or lessons learnt. It is important to ensure that we are able to identify key sources of knowledge, drawing on the expertise already developed and driving industry forward to collectively reach the net zero target.

Removing barriers

Through upskilling the sector and building on the collective action already underway, we can use our influence to address our own areas of impact within the landscape of decarbonising construction. It will clarify to decision-makers and individuals working at all levels and stakeholders of the built environment what action they need to take within their own organisations/projects to ensure we can reduce carbon at the rate needed.

The work on mapping the landscape of decarbonising construction has taken a three-pronged approach in seeking to provide clarity on the subject:

1. Mapping topics and themes: this mindmap provides an overview of the different ways that reducing carbon emissions is being addressed across the full spectrum of the built environment. This highlights the work happening in many different fields, which can seem quite narrow and unrelated, and shows how these fit together holistically to address all the aspects that need to be decarbonised (from embodied, to operational, to organisations etc.).

2. Academic research across the University of Cambridge: using the themes and topics identified, this map provides a visual and interactive way of investigating the different research centres and academics across the University who are engaged with research that in some way seeks to contribute to reducing emissions in the built environment.

3. Landscape map of industry: this extends the mapping exercise to the wider construction industry and provides an overview of activities, initiatives, task forces, resources etc. The map acts as a 'gateway' and directs users to organisations or information that may be useful in their understanding of decarbonising construction.

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Net Zero Carbon

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Improving thermal comfort: Modelling the airflow above a heated surface

Benefits to industry

- Greater predictive capability of temperature distribution within rooms.

How does the airflow behave above a heated surface?

We are all familiar with the fact that hot air rises and, conversely, cold air sinks. However, whilst the general principles are well understood, there is not a full description of the airflow that develops above a horizontal heated surface or, equivalently, below a cooled surface. This is because the flow is highly complex, with near-horizontal flow close to the surface, which turns to form a vertical flow structure known as a plume. Additionally, at the scales we are interested in, the flow is turbulent, which complicates any mathematical analysis. The different flow features and the turbulent nature of the flow are visible in the accompanying image, which shows an instantaneous flow visualisation of a plume.

Cold draughts and thermal comfort

Building occupants want to be comfortable, which means that we, as engineers, need to be able to predict the temperature distribution within a room. Whether the air in a room is stratified, i.e. warmer near the ceiling and cooler near the floor, or all at the same temperature, depends on the distribution of heated and cooled surfaces and the plumes of air that they generate. However, until this work, it was impossible to model the behaviour of the plumes rising and falling from the surfaces because there was no description of the airflow close to the surface.

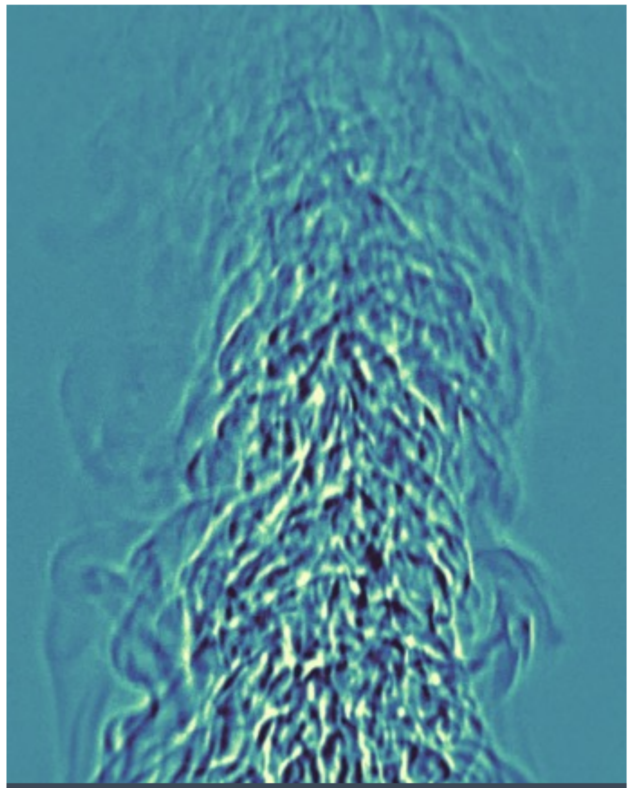

Figure 12: A false-colour shadowgraph of a plume of air above a heated plate.

Mathematical modelling and flow visualisation

We developed a theoretical fluid dynamical model to describe the near-surface flow and used it to estimate source conditions that could be used with existing models of plumes. This gave us predictions for the plume shape and temperature distribution. To test the model, we conducted shadowgraph experiments to visualise the flow shape as well as making temperature measurements. The measured data showed excellent agreement with the model.

New predictive capability

Armed with our model, engineers will be able to better predict the temperature distribution in rooms, enabling greater thermal comfort for the occupants. The model also applies to plumes of cold air descending from passive-chilled beams and so should aid in the design of such systems. This, in turn, should save considerable energy, carbon and money by using smaller, targeted heating and cooling systems to achieve thermal comfort.

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Manufacturing

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De-carbonising precast modular concrete – visualising variation in embodied carbon density

Many sustainability projects focus on novel material or technological solutions to achieve improvement targets. This results in sustainability being an expensive and high-threshold activity.

In conjunction with the Centre for Industrial Sustainability and Laing O'Rourke, a procedure to visualise variation in the carbon intensity of existing products has been developed to pinpoint variance in current practice and guide carbon reductions resulting from design choices.

Strategically prioritising existing best practice offers a zero-technological-threshold avenue to identify existing opportunities to reduce the impact of the built environment whilst reducing expenditure on high-cost and high carbon intensity materials like cement and steel.

Our challenge is to help Laing O'Rourke accelerate its decarbonisation programme, expanding on material and technological approaches to create a systems-level guide to decarbonisation.

One of the potential benefits of off-site construction is the higher control and repeatability which is possible in a factory environment. The potential to capture and analyse data from years of production all under one roof offers the opportunity to spot trends in practice beyond any individual site, with a continuous reporting system and a full optic on both supply chain and waste management decisions.

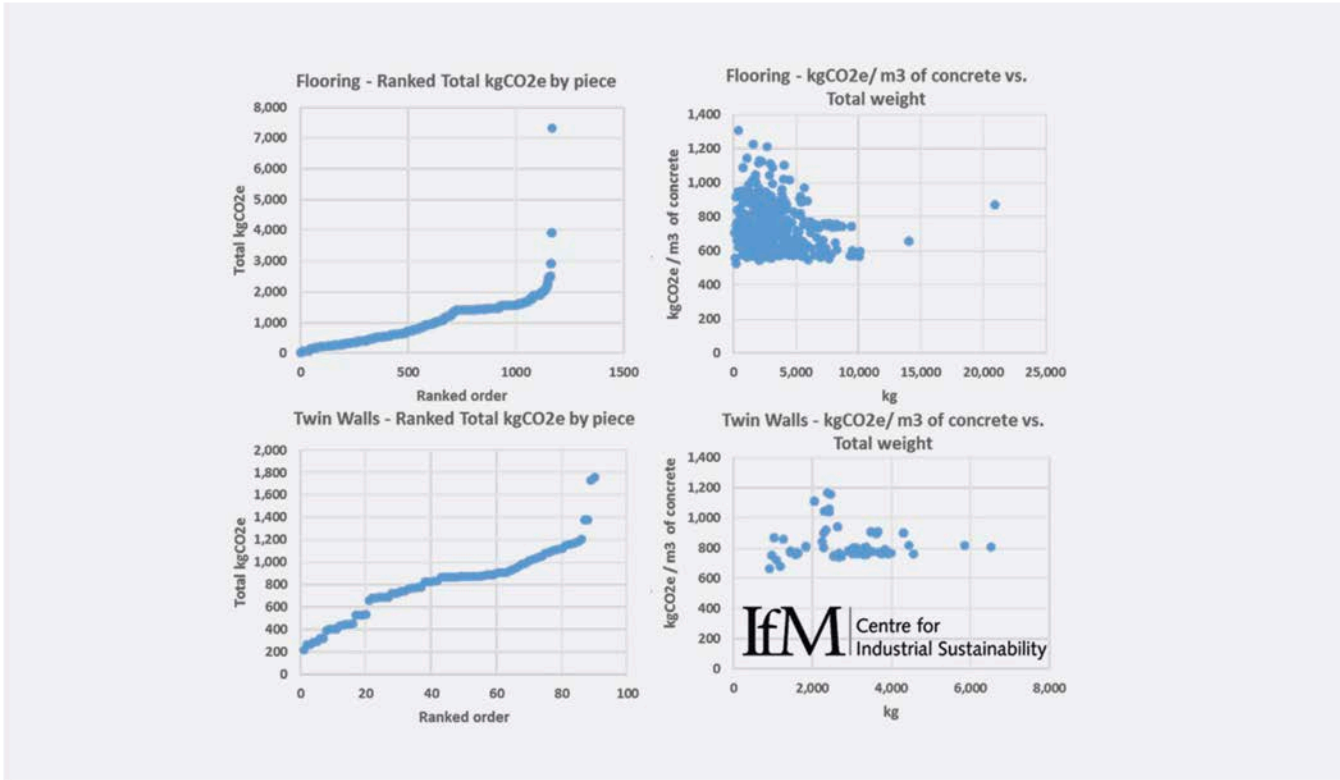

Figure 13: As part of assessing the scope for improvement within current practice, one year of product data was assessed by product category, and the embodied carbon density was ranked by weight. This allowed targeted insights into the causes of variation in embodied carbon density between similar size products within a given product class.

We have taken a year of production data from Laing O'Rourke's Centre of Excellence for Modern Construction and used this to develop a framework to visualise variation in embodied carbon density within their existing product portfolio.

This visualisation tool has identified that within individual product categories, there exists >100% variation in the embodied carbon density for products within a similar weight range. The extent of this variation exceeds what was expected based on load-bearing or use-case requirements and has shortlisted opportunities to drive improvement by comparing best- and worst-in-class.

This work has successfully demonstrated considerable existing scope for reducing the carbon intensity of parts of the UK building sector. The next chapter of this collaboration in 2024 has been funded through the Industrial Energy Transformation Fund, in collaboration with the Centre for Industrial Sustainability in the Institute for Manufacturing, and the Advanced Manufacturing Research Centre at the University of Sheffield.

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Productivity | Digital Engineering | Whole Life Performance

Maciej Trzeciak
Former PhD student

Real-time 3D reconstruction of construction sites using hand-held scanner

Figure 14: Maciej Trzeciak testing on-site.

Benefits to industry

The benefit of using hand-held scanners over static/terrestrial scanners is:

- The decreased effort put into the scanning and processing the collected scans. Since the device is mobile, the user can easily enter less accessible places and collect data faster.
- In addition, reconstructing construction sites in real-time has the advantage of instant feedback reported to the user, who can then take corrective measures on the spot. This reduces the risk of re-surveying, which static scanners are often subject to and significantly decreases the time needed to create geometric replicas of construction sites.

Importance of resolution and accuracy

Despite decreasing the effort put into scanning, hand-held scanners suffer from low resolution and low accuracy compared to the workflows based on static scanners and land surveying equipment.

The problems with resolution result in the inability to recognise important details/features in scans, such as corners and edges, and combined with low scan density, it impacts how faithfully a scanned construction site is represented. This problem is significant because many popular use cases in construction, such as progress quality assurance, detection of concrete planeness deviation or scan-to-BIM, cannot be accommodated directly on point clouds by hand-held scanners. Instead, inspectors and contractors resort to other measures, translating into higher costs.

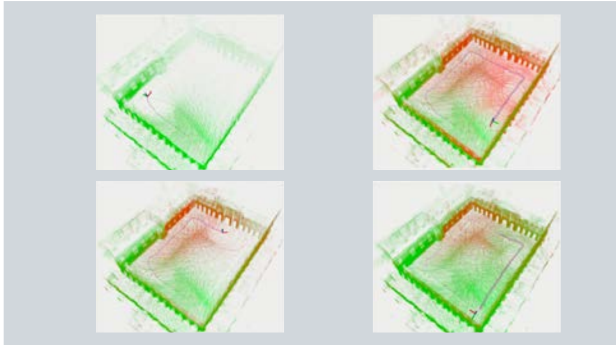

Figure 15: Progressively-built point cloud in real-time with overlaid uncertainty. Green indicates high point cloud correctness while red stands for predictions for a relatively higher spatial error.

The problems with the accuracy of scans result from the underlying technology mobile scanners utilise, called SLAM (Simultaneous Localisation and Mapping). SLAM introduces drift into scans, skewing point clouds and thus, increasing their spatial error. Therefore, it is not uncommon for a mix of static and mobile scanners on construction sites depending on the requirements of use cases at hand. Research into this problem can unlock engineering surveying or high-accuracy measured building surveys, which are some of the use cases currently unresearched by state-of-practice hand-held scanners.

Bringing spatial AI to hand-held scanners

A prototypic scanner consisting of a Velodyne VLP-16 lidar, a standard-lens colour and near-infra-red cameras was built and proposed two methods for improving resolution and accuracy.

The first method targets the resolution problem and utilises recent advances in spatial AI to predict dense feature maps in images and use them as additional constraints in a better geometric understanding of the scanned scene.

The second method, in turn, focuses on accuracy. The method reconstructs the scanned scene in real time and predicts the regions of a potentially high spatial error with a high confidence level. The user can then revisit these parts of the scene, which adds additional constraints on the underlying probabilistic graphical model, thus reducing the drift and increasing the confidence in the correctness of these regions.

Promising results

The experiments show that the first method outperforms the current indoor scanners, such as Google Tango and the top general mobile reconstruction method called LOAM (Lidar Odometry And Mapping), with around a 67% and 91% reduction in the noise of reconstructed flat surfaces for indoor and outdoor scenes respectively, without any post-processing of the point cloud. Also, our point clouds more reliably represent the reconstructed scene by preserving more detail, especially indoors. In addition, point clouds produced by our approach are at least six times denser than those by LOAM. All these factors directly influence the resolution of point clouds by mobile scanners.

Our system can help the construction industry reduce the effort (time and money) generally put into scanning construction sites.

Results on the second method show that the areas predicted with a relatively high spatial error indeed suffer from it, while areas with relatively higher correctness predicted do have a smaller spatial error in reality. Our system can help the construction industry to reduce the effort (time and money) generally put into scanning construction sites. Since the user is aware of the regions of potentially high spatial error during scanning, they can take corrective actions on-the-fly, and not after the data collection and processing have been completed. This, in turn, might eliminate the potential risk of re-scanning.

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Former PhD student

Social Value

Dr Olivia Remes
Research Associate

Tackling wellbeing, mental health, and social value in construction with a focus on reducing suicide risk

Challenge

- Men in construction have a three times higher likelihood of dying by suicide compared to the (male) UK national average.
- High stress, loneliness, and anxiety are some of the key issues experienced by this group.
- Reasons for poor mental health in construction include working in a high-pressure environment (and away from home), dealing with financial pressures and facing job instability.

Why is this important?

Every two days, a life in construction is lost to suicide. We need to do something about this. Companies and their staff, communities, and societies stand to gain when people's overall wellbeing and mental health improve. Return on investment studies has clearly shown the positive impact that workplace mental health interventions have. If we want to make a difference in mental health, we must identify and implement best practices. As the saying goes, there is no health without mental health.

Research we are undertaking

We are: 1) conducting research and collaborating with construction companies across the UK, and 2) creating a community of interest of stakeholders coming from industry and academia, and we are guided by the voices of those with lived experience. The aim is to bring awareness to the mental health issues experienced in construction and implement best practices. Our valued collaborators include Kate Goodger, Head of Human Innovation and Performance at Laing O'Rourke; Silvana Martin, Wellbeing Leader at Laing O'Rourke; Andrew Ernest, Director of Framework Strategy at Kier and Fiona Ward, Group Occupational Health Manager at Costain.

University of Cambridge Wellbeing in Construction Forum

A Construction Forum was held in May 2023 in which we discussed key issues related to wellbeing, mental health and social value in construction. Professor Campbell Middleton opened the event and highlighted the staggering statistics on suicide that underpin the work we do. Following this, Dame Carol Black, past Principal at Newnham College, University of Cambridge and former UK Government National Director for Health and Work, provided an overview of mental health in construction – the gaps and opportunities, and landmark research that has been conducted on work and health.

Our research vision was outlined and then Catherine Tilley, Lecturer in Business Ethics and Sustainability and Impact Director at King's College London, talked about wellbeing of factory workers. Finally, Alex Morris, Senior Civil Structural Engineer and Associate at Arup, shared his knowledge and insights on inclusion and diversity – which is of key importance to organisations and society.

When people feel included, this has a positive influence on wellbeing. This event kick started a number of follow on activities. including discussing action steps for our next in-person event.

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Whole Life Performance

Digital Engineering

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Setting up the UK's first truly smart bridges for Network Rail

In this project, the researchers from the Laing O'Rourke Centre for Construction Engineering and Technology and Cambridge Centre for Smart Infrastructure and Construction (CSIC) have instrumented two railway bridges with fibre optic sensors during their construction stage in an effort to build the UK's first truly smart bridges.

The main objective is to demonstrate the capability of the sensing system and data analytics integrated with the digital twins to improve asset management capability while reducing costs. Unlike current practice, which largely relies on periodic visual and tactile inspections that only provide qualitative results, data provided by bridge instrumentation and fed into smart asset management systems (digital twins) can provide quantitative information for bridge assessment and help Network Rail better maintain its assets. This enables a more accurate assessment of bridge condition, enabling condition-based maintenance planning and reducing or eliminating unnecessary time-based interventions and maintenance while simultaneously identifying deteriorated assets before they reach their serviceability limit. In addition, costs are saved, and safety is improved by reducing the need for inspectors and operatives to work trackside. Continuous monitoring targets limited maintenance budgets by prioritising assets and moving away from time-based maintenance and inspection schedules to need-based schedules.

The data analysed by the digital twin provides a level of information that previously was not possible to obtain. For instance, the researcher empowered the digital twin models with advanced algorithms that can predict accurate axle weights of passing trains from the deformations measured by the sensing system, which enables realistic simulation of the site conditions and determination of stress formation everywhere on the bridge. Such a system provides a more reliable approach to condition assessment, enables more effective asset maintenance interventions, and develops deterioration models for the assets. Information provided by the asset management system about the volume and weight of the trains using the bridge is also relevant to other bridges on the same section of the track allowing bridge-specific-loading models to more accurately assess the load-carrying capacity of these bridges (in addition to the monitored asset). This facilitates a more accurate condition assessment of a broader range of assets. This will optimise necessary maintenance while reducing or eliminating unnecessary bridge repairs or replacement – reducing costs and reducing disruption to train journeys.

Figure 16: Instrumented self-sensing railway bridge in the UK.

Costs are saved, and safety is improved by reducing the need for inspectors and operatives to work trackside.

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Whole Life Performance

Dr Kasun Kariyawasam
Former PhD student

A breakthrough in vibration-based bridge scour monitoring

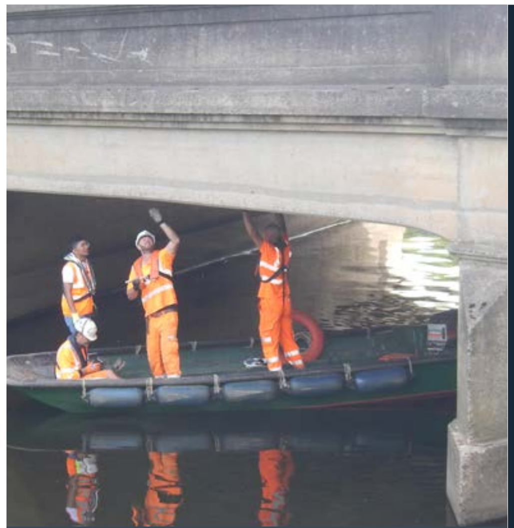


Figure 17: Sensors installed during the field trial.

Benefits to industry

- A sensing technique that utilises two novel vibration-based scour monitoring indicators: modal amplitudes and spectral density, in addition to the traditional indicator, natural frequency.
- Capability of detecting both the presence and the locations of bridge scour.
- Supported by experimental evidence from a field study, numerical modelling simulation and a first-of-a-kind geotechnical centrifuge testing programme.
- Ability to monitor scour at bridge foundations using sensors mounted on the bridge deck and piers above the water level, ensuring easy installation and reliable operation.

Challenges in scour monitoring

Scour, the gradual erosion of soil around bridge foundations due to rapid water flow is the leading cause of bridge failures worldwide. A reliable technique to monitor scour could potentially guide a timely repair and, in turn, mitigate the risk of future scour-induced bridge failure. Currently, there are various, mostly underwater, techniques employed by bridge managers to monitor scour, ranging from diving inspections to autonomous underwater vehicles; however, none have gained wide acceptance.
A particular disadvantage of underwater monitoring techniques is that the equipment underwater is relatively difficult to install and prone to damage from fast-flowing water and debris.

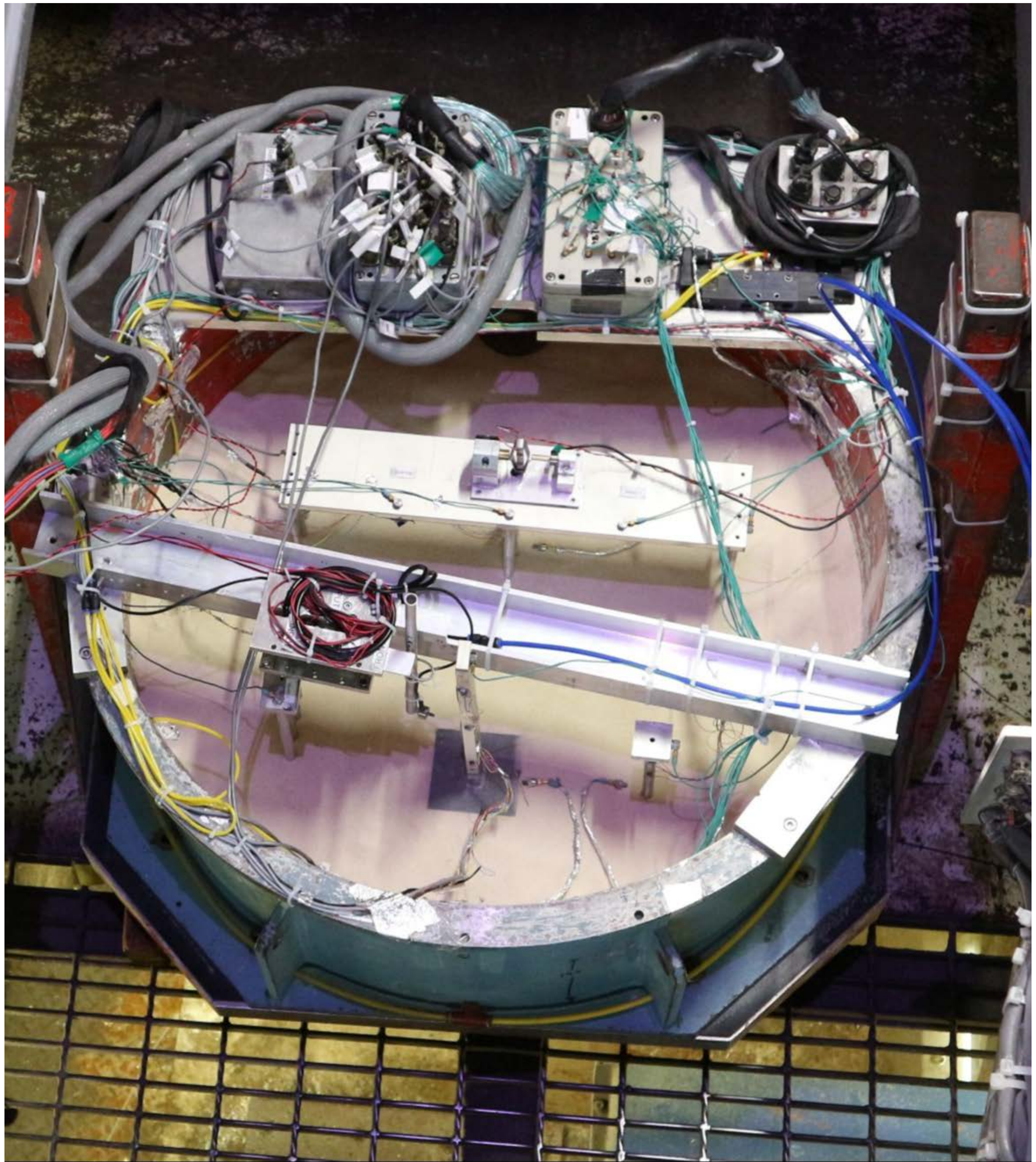
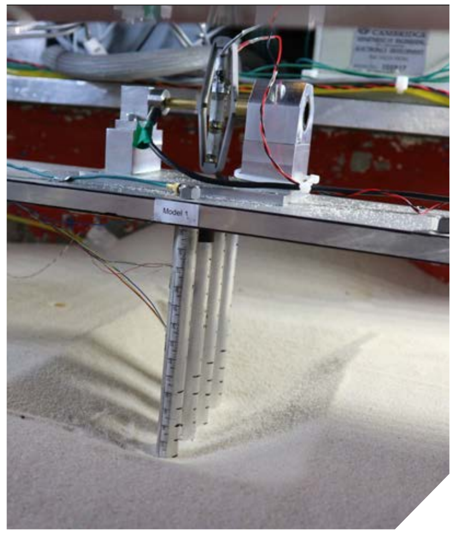


Figure 18: The model setup inside the Geotechnical Centrifuge.

Productivity | Digital Engineering | Manufacturing

This research project at the Laing O'Rourke Centre proposed a novel vibration-based scour monitoring technique based on a combination of three vibration parameters.



Vibration-based scour monitoring

An alternative solution is using vibration-based methods to monitor scour indirectly by detecting changes in dynamic modal parameters (e.g. natural frequency) through sensors mounted on the bridge deck or piers above the water level. There has been extensive research into the use of vibration-based monitoring methods to identify other causes of failure, such as cracking and deterioration in bridge superstructures; however, this has proven to be ineffective in practice, as the expected sensitivities in modal parameters were only single-digit percentages and therefore insufficient to overcome environmental and operational sensitivity.

A three-parameter vibration-based scour monitoring technique

This research project at the Laing O'Rourke Centre proposed a novel vibration-based scour monitoring technique based on a combination of three vibration parameters: spectral density, mode shape and natural frequency. The technique was investigated using first-of-a-kind experiments and numerical modelling simulations on various types of bridges and forms of scour.

Experimental Programme

A field trial was carried out on a full-scale bridge with pre-existing scour (see Figure 19), which was monitored for ambient vibrations throughout a repair process involving controlled scour backfilling, i.e. "scour in reverse". The effect of this scour backfilling was captured by measuring changes in two of these parameters, mode shape and spectral density, derived from the ambient vibrations. The mode shapes, in particular, showed the potential to localise the presence of scour to a specific pier.

A centrifuge model testing programme was developed to study all three vibration parameters in a controlled environment. The tests considered small-scale models representing three full-scale bridges with different bridge deck and foundation configurations (i.e. integral/ simply supported decks and shallow/deep foundations) and two forms of scour (i.e. local/ global). The observed results of these small-scale centrifuge models were used to calibrate numerical models of full-scale bridges representative of these centrifuge models. Numerical simulation techniques were also developed to simulate the experimentally observed effects of local and global scour.

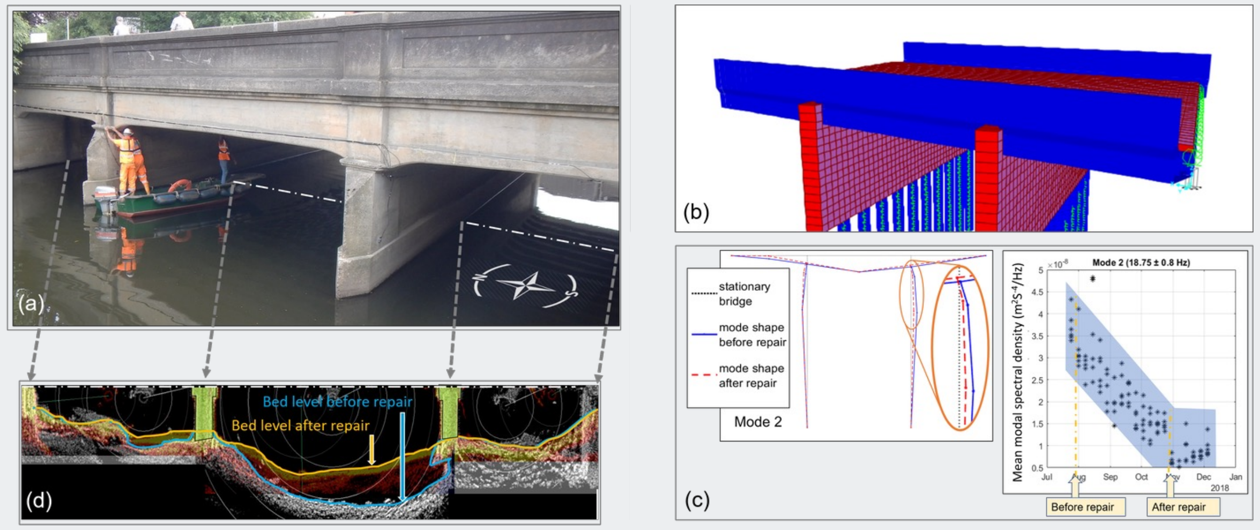


Figure 19: The field trial at a bridge with pre-existing scours (clockwise from top left): (a) Deploying accelerometers, (b) FE model, (c) Experimental data of mode shapes and modal spectral density indicating scour depth change and (d) River bed profile from BridgeCat sonar scanner.

Potential impact

The experimental programme and the associated numerical modelling found that vibration-based methods have broad applicability for bridges, although only some parameters exhibited sufficient sensitivity to be viable as a monitoring technique in certain types of bridges. For example, the centrifuge bridge models with a shallow foundation did not show a significant change in natural frequency or mode shapes, but they did show a considerable change in modal spectral density. This research demonstrated that a vibration-based scour monitoring technique, examining the combined effect of natural frequency, mode shape and spectral density parameters, holds substantial potential to measure and even localise the change of scour depths at bridge foundations.

The findings were presented at the International Workshop on Structural Health Monitoring (IWSHM) conference at Stanford University and the International Conference on Smart Infrastructure and Construction (ICSIC) conference at Cambridge University and published in the Journal of Civil Structural Health Monitoring. The research gained attention in New Civil Engineer magazine, The Engineer magazine and American Society of Civil Engineers (ASCE) Smart Brief, and was nominated for Collaborate to Innovate Awards 2020 as well as for Digital Initiative of the Year at the British Construction Industry Awards 2020.

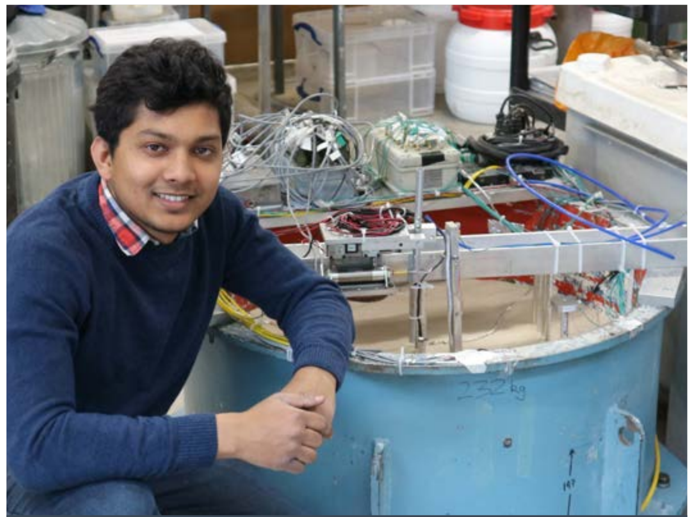


Figure 20: Dr Kasun Kariyawasam with the Centrifuge Model.

Dr Kasun Kariyawasam
Former PhD student

Net Zero Carbon | Whole Life Performance | Skills

Jason Qianchen Sun
Former PhD student

Foundation integrity assessment using a risk-based thermal approach

Benefits to industry

- Develop an innovative method for foundation assessment using concrete thermal data.
- Popularise the pile thermal integrity testing technique in the UK industry.
- Design and generalise the risk-based foundation assessment framework.
- Standardise the testing method and data interpretation strategy with the UK's leading piling industry.

Assessing the quality of foundation piles

The need for larger and deeper foundations to support taller buildings, structures with large spans, and buildings in poor ground conditions is increasing. Although pile installation equipment and machinery continue to be developed, there are still challenges for the construction industry to overcome, including determining the as-built quality of foundation piles. This is a crucial task that needs to be established immediately following the construction stage. It assesses whether the pile foundations are constructed according to the design and, if verified, opens up the possibility for future pile reuse with better as-built records.

What is the challenge?

Traditional pile integrity testing techniques only provide data to assess a limited part of the concrete between and around access tubes and results that are very difficult to interpret. Some techniques even pose safety risks for operators. After pile installation, anomalies such as voids, soil intrusions or shaft collapse are very challenging to detect. The presence of these anomalies could result in structural instability or severe durability issues.

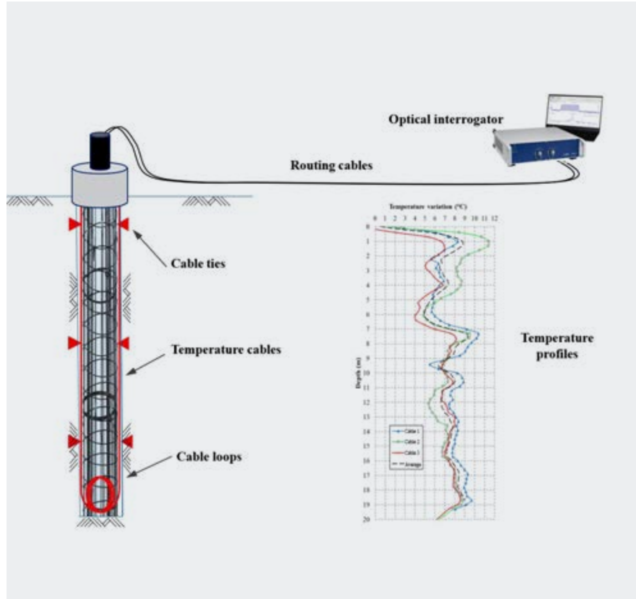


Figure 21: Pile instrumentation with distributed fibre optic sensors.

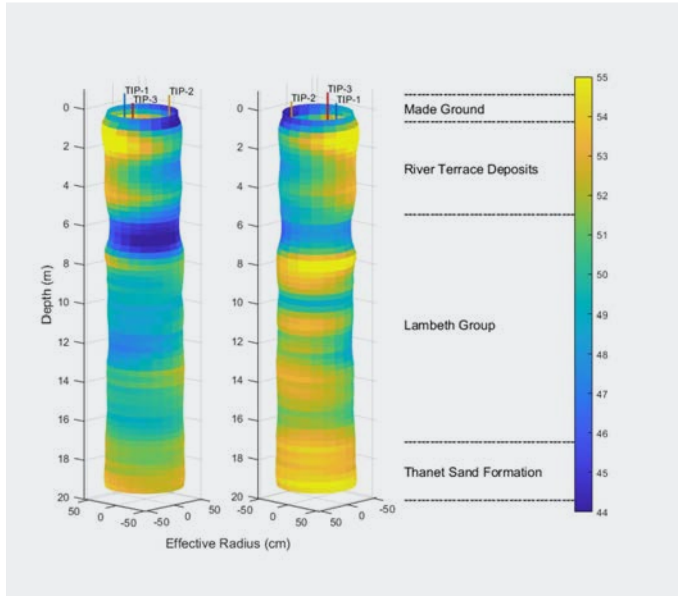


Figure 22: Pile quality assessment.

Thermal integrity testing and early outcomes

Thermal integrity testing, a new integrity assessment method, has been put into use in foundation construction. This technique measures temperature changes and thermal profiles of concrete during curing. Heat generation and dissipation of early-age concrete are determined by the concrete mix, the ground conditions and the shape of the concrete structure. If defects exist inside the concrete body, they will appear as local temperature variations compared to the expected heat generated during curing. However, the industry practice of data collection uses a string of point sensors, and data interpretation is primarily based on experience.

Consequently, the data obtained is not sufficiently comprehensive to cover the entire pile. Anomaly detection through direct analysis of temperature profiles is indicative or suggestive, and temperature signatures are usually similar, and numerous causes are not easily isolated. The core principle/theme of this currently used technique – collecting detailed temperature measurements along the pile during the hydration process – is promising, but a more reliable and effective foundation evaluation approach is required.

The research team have designed a novel sensing instrumentation strategy. Distributed fibre optic sensing can capture thousands of data points along one single fibre. The optimal sensing layout and detailed instrumentation requirement have been proposed. In addition, a risk-based interpretation framework for thermal integrity testing data has been developed. The framework follows an investigative staged process to establish and assess anomalies in the problematic regions along the pile employing the combined use of detailed finite element (FE) simulations, the actual temperature data from field testing and optimisation algorithms. At each stage, more details can be revealed about the defects being investigated, including location, size and shape. This staged process enables practitioners to follow a risk-based approach and decide whether or not to pursue subsequent stages of construction depending on the results they get at the end of each stage.

The team will continue working with industrial partners on more field trials to verify the detectability in different field conditions. Researchers expect this thermal integrity approach will become a standard quality control approach in the industry within a few years. In the meantime, a software prototype for thermal integrity testing data analysis is under development for use by industry practitioners.

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Spheres of influence

Our research activities are inextricably linked to thought leadership, as they provide the evidence base to inform discussion, policy decisions and industry practice.

Centre staff and researchers help to shape policy through membership of and contribution to government and industry advisory panels, committees, summits and workshops, including:

- HS2 Design Panel
- Bridge Owners Forum
- Transport Research and Innovation Board (TRIB) Infrastructure Working Group UK
- Highways England "Developing our vision for 2050 Strategy Workshop"
- International Association for Automation and Robotics in Construction (IAARC)
- International Society for Structural Health Monitoring of Intelligent Infrastructure (ISHMII)
- Cambridge Robotics and Autonomous Systems Team, UK RAS Network, EPSRC
- Transportation Research Board (TRB), US National Research Council (NRC) of the National Academies
- European Council for Computing in Construction
- Construction Leadership Council Sub-Working Group: Skills for a Modernised Industry
- City Bridge Foundation Board
- Construction Productivity Taskforce

The Centre continues to accelerate its impact and influence in the construction sector by delivering transformative change through education, research and innovation, thought leadership and shaping policy to provide economic, social and environmental benefits to society.

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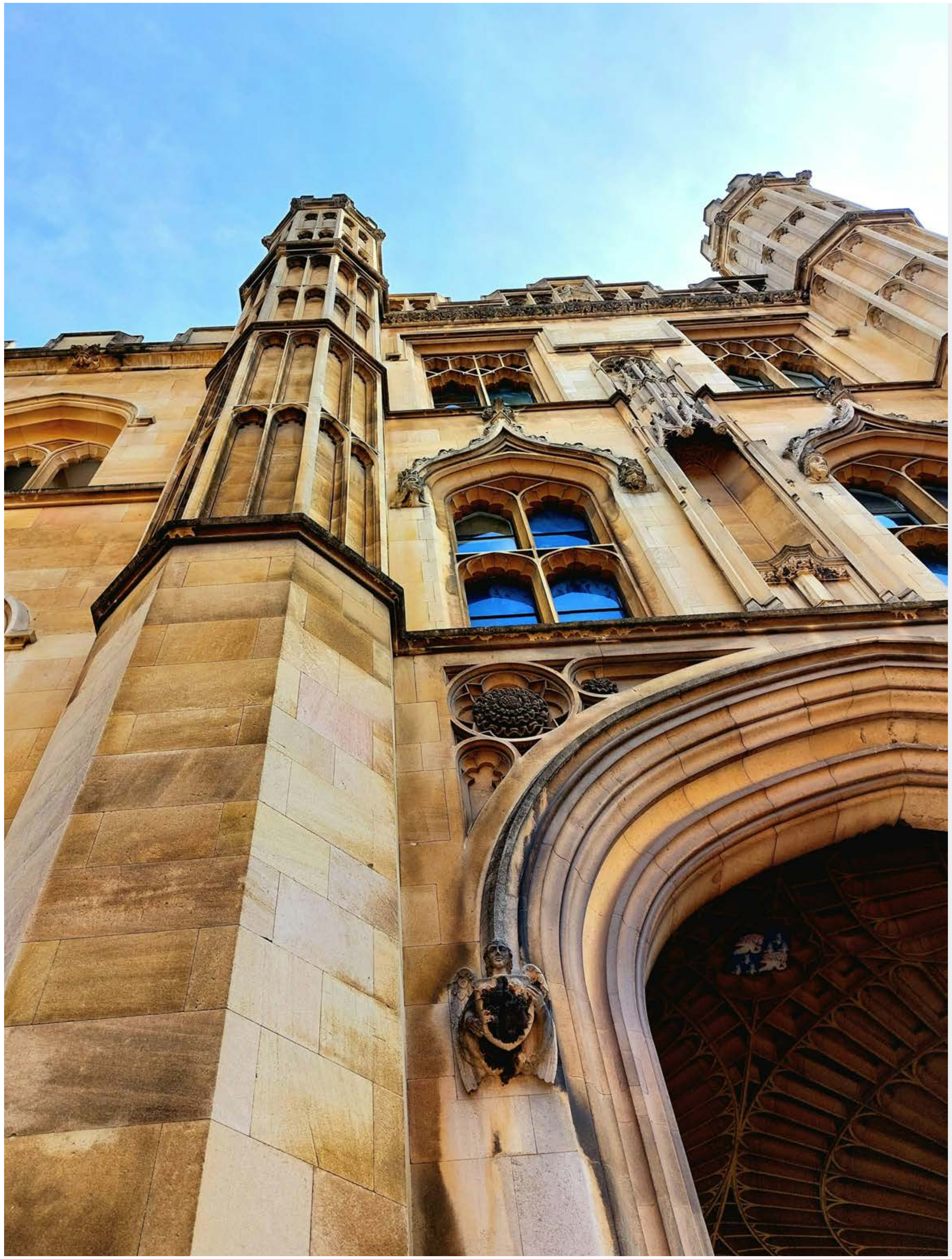

Excellence

We proudly present a selection of awards and prizes that recognise research excellence to:

2020

Dr Kasun Kariyawasam, Professor Campbell Middleton and Paul Fidler were nominated for the "British Construction Industry Award" 2020.

Professor Ioannis Brilakis and Dr Mahendrini Ariyachandra received the "ISARC 2020 Best Paper Award" for paper *Digital Twinning of Railway Overhead Line Equipment from Airborne LiDAR Data*.

2021

Construction Engineering Masters (CEM) student Sheryn Gillin was awarded the 2021 "Cambridge-McKinsey Risk Prize" for the best submission on risk management.

CEM student Dr Claire Bennett received the "Top 50 Women in Engineering 2021 Award" from The Women's Engineering Society (WES).

2022

Dr Brian Sheil received the "Young Researcher Award 2022" from the Civil Engineering Research Association of Ireland.

Professor Ioannis Brilakis received the "Scherer Award" from the European Council for Computing in Construction, Brussels.

Professor Ioannis Brilakis received the "Thorpe Medal" for his paper *Digital Technologies Can Enhance Climate Resilience of Critical Infrastructure* from the European Council for Computing in Construction, Brussels.

2023

Dr Brian Sheil won the Institution of Civil Engineers (ICE) prestigious "Crampton Prize" for his paper *Monitoring the construction of a large-diameter caisson in sand*.

Dr Brian Sheil received the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) Europe "Bright Spark Lecture Award".

Professor Campbell Middleton and Asitha Rathnayake received the "ASCE Editor's Choice Award" for their paper *Systematic Review of the Literature on Construction Productivity*.

Dr Brian Sheil's research group won the "Data Sciences & AI-Enabled Solutions" prize at the COP28 UN climate summit's Prototypes for Humanity initiative.

Laing O'Rourke Centre for Construction Engineering and Technology

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Professor Campbell Middleton | Laing O'Rourke Professor of Construction Engineering and Centre Director

Professor Ioannis Brilakis | Laing O'Rourke Professor of Civil and Information Engineering

Dr Gavin Davies | Associate Teaching Professor and Construction Engineering Masters Course Director

Dr Brian Sheil | Laing O'Rourke Associate Professor in Construction Engineering

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