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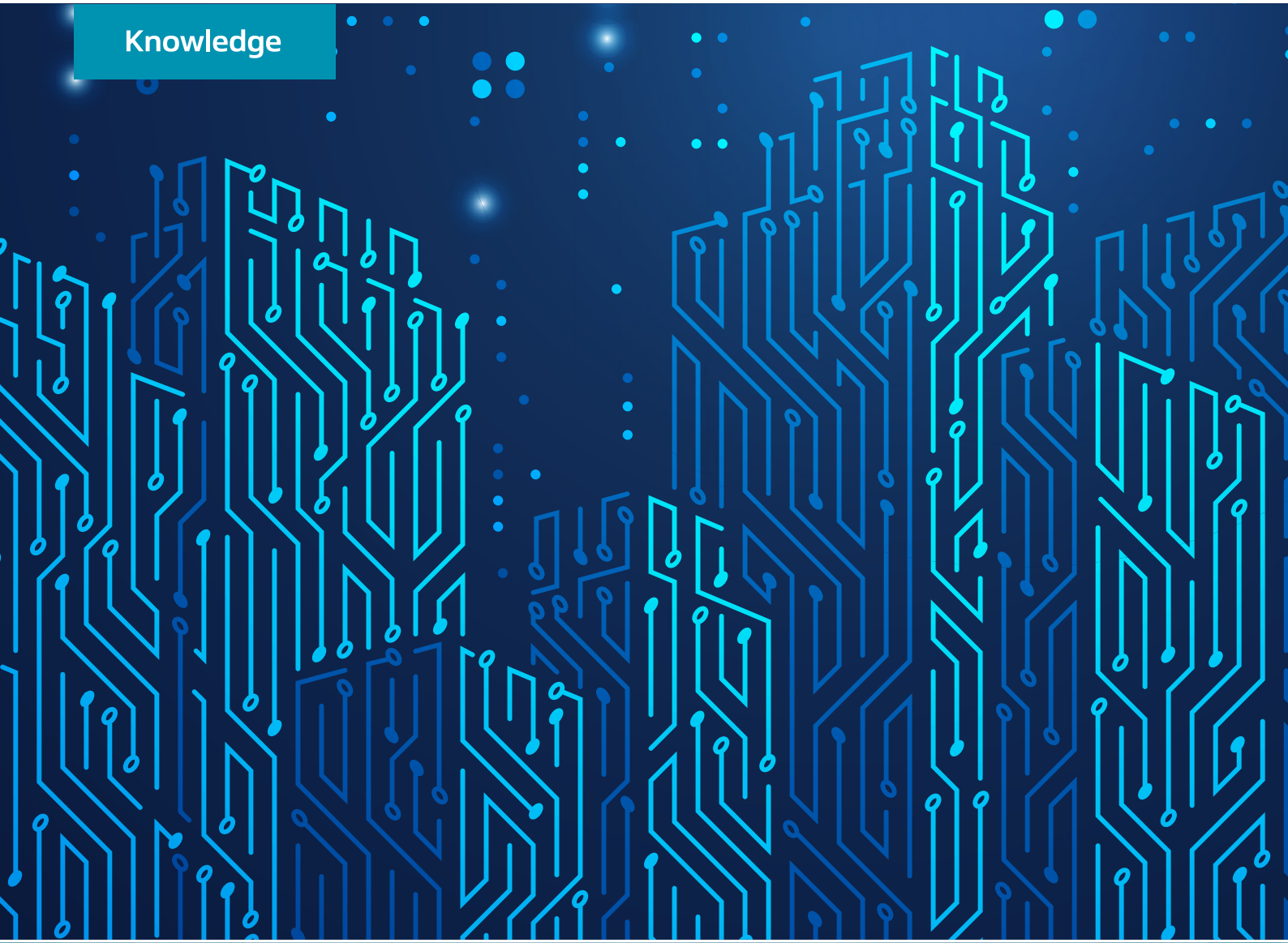
Knowledge



Engineering Rebellion

A study into the future of civil engineering

ice.org.uk

About this report

ICE Council set the question: Who is the civil engineer of the future and how does the ICE adapt to embrace them?

A steering group was set up in early 2020 to debate the possible answers. This report is the culmination of those discussions as well as a public online seminar and a detailed literature review.

Coordination and steering group

ICE appointed Emma-Jane Houghton as chair of the Engineering Rebellion steering group. Emma-Jane then selected steering group members to ensure that all parts of the infrastructure supply chain were represented and that the project had access to expertise in its main lines of enquiry.

Engineering Rebellion steering group members

Emma-Jane Houghton
Independent Chair
Hayley Jackson
2020 ICE President's Future Leader
Andrew Mather
Strategic Sustainability Consulting, Ramboll
Huda Asad
Head of Performance, Infrastructure and Projects Authority
Katherine Bew
Managing Director, PCSG
Dr Sarah Williamson
Civil Programme Director, Laing O'Rourke
Mark Enzer
Chief Technical Officer, Mott MacDonald
Ross Dickie
Project Manager, Heathrow
Brian Downes
Executive Director, Downes Management Consultancy
Michael Florence
Principal Engineer, Cundall
Professor David Richards
Head of School of Engineering, University of Southampton
Brittany Harris
CEO, Qualis Flow
Stephen Thompson
Structural Engineer, Arup, and winner of the James Rennie Medal 2019

Methodology

The steering group oversaw the work of a core team from ICE Knowledge. The core team carried out an extensive literature review (available to download from ICE's website) and engaged in detailed discussion with the steering group and other sector stakeholders. An online Strategy Session (ice.org.uk/eventarchive/ice-strategy-civil-engineer-of-the-future-online), attended by more than 700 people and chaired by ICE President 2019-20 Paul Sheffield, was held to provide wider input.

The outputs from this work were then tested against a range of existing future scenarios to help identify which skill sets and capabilities were likely to be most important in the future.

Foreword

Emma-Jane Houghton
Chair, Engineering Rebellion

The climate crisis, urbanisation, the pandemic and a demand for inclusivity are all accelerating and putting different pressures on the natural and built environment. In response, taxpayers, infrastructure owners and investors are seeking a wider range of outcomes for their money.

Today's civil engineers need to feel they can challenge the collective wisdom of recent decades and explore a much wider range of potential solutions. Faced with increasing complexity, they must think differently, collaborate more widely and master evolving technology to provide sustainable outcomes.

What we think of as civil engineering is also changing. Traditionally, the discipline has been focused on constructing and maintaining structures – but perhaps, at least in the developed world, with its huge stock of infrastructure, the future doesn't have to be about building at all. The future civil engineer may be someone dedicated to investigating what really matters to infrastructure owners and users. The preferred option could be to make interventions into existing infrastructure, using data and technology rather than concrete and steel to meet people's needs. Civil engineers may need to work more closely with different professionals, joining the dots to translate many sorts of inputs into one solution.

This was the context in which we set out to answer the question: who is the future civil engineer and how does ICE adapt to embrace them? When I agreed to chair this initiative, I was clear that I did not want to deliver a traditional report with a set of narrow, deterministic conclusions. It was more important that ICE gave permission for awkward questions to be asked. That was how we could fire up the questioning and creative spirit that has always driven our progress in the past and that we need for debating answers.

The response to framing the challenge in this way has been amazing. I was able to gather a truly diverse group of individuals to explore some different pictures of the future. This early thinking was tested by enthusiastic stakeholders from industry, end users and education. It was a pleasure to road-test ideas in a pilot module for fourth-year students from the University of Bristol – deepening our engagement with academia and the next generation. Later in the process we attracted more than 700 people to a webinar, one of the largest responses ICE has seen, to debate our findings. As the work progressed, it became clear to me that many people were delighted that these questions were being asked. Engineering Rebellion, with its open, questioning approach, spoke to people in a way that other engagement exercises may not.

Out of all this activity, we have identified seven disrupters of the status quo, arising from six big strategic trends. There are huge uncertainties about how these trends will play out and combine – and this uncertainty is something that civil engineers must get better at dealing with. It was certainly a challenge for us, so we took our own medicine and used five scenarios that forced us to think differently about the future professional life of civil engineers and the skills they will most likely need to thrive.

At the end of the report, we plant one final thought: what if we've been asking the wrong questions all along? What if coming up with a single definition of the future engineer in the face of such change is a recipe for inflexibility when what we need is agility? What if society and client needs from infrastructure no longer map to the old professional disciplines? Or if the future is collaboration between people from a more diverse range of backgrounds? In that world, perhaps the priority for ICE is to prepare its members to thrive in the infrastructure team of the future and work out what it has to offer to every member of that team.

Executive summary

Engineering Rebellion was set up to examine who the civil engineer of the future will be and how ICE should adapt to embrace them.

ICE established an Engineering Rebellion steering group that drew on academia, government and all parts of the infrastructure industry. The group oversaw an exhaustive literature review (available from ICE's website) that identified six strategic trends shaping the sector. The trends were used as the basis for detailed engagement with stakeholders and for a module included in the University of Bristol's fourth-year civil engineering course. An online Strategy Session to share thinking and gather feedback was attended by more than 700 people. The output from all of this work was then tested against a set of five scenarios to explore the future skills and capabilities likely to be demanded of future civil engineers.

These strategic trends were: the climate crisis and the UN's Sustainable Development Goals (SDGs); accelerating digital transformation; flatlining productivity; growing complexity; competition for the future workforce and a demand for greater diversity; value replacing volume as the basis for financial reward.

It became clear that these trends were interconnected and interacted with each other. We then identified seven disrupters of the current civil engineering skills profile that were emerging from this process.

Seven disrupters of the civil engineering skills profile

1. Net zero and sustainability benefits will become central to project outcomes.
2. Business models will demand greater collaboration to deliver more value through the asset lifecycle.
3. Diversity – people will need to come into the industry from a much wider set of routes and backgrounds.
4. Digital will create a demand for people with the adaptability needed to understand and work with a wide and rapidly changing set of digital technologies.
5. Productivity will need to improve rapidly. Engineers will need to master the skills and behaviour that will allow innovative practices, techniques and materials to be deployed.
6. Systems thinking will be needed at the project, network and system of systems levels.
7. Upskilling will be constant – civil engineers will need to adopt a proactive attitude to lifelong learning.

Think differently – the civil engineer and the infrastructure team

Engineering Rebellion's main advice to ICE is think differently. As we explored the question, "How should ICE embrace the future civil engineer?" it became clear to us that the institution could benefit from focusing as much on the infrastructure team as the individual. ICE should seek to understand how it will support civil engineers to work more effectively in the multidisciplinary teams that will deliver the work that meets the future needs of society.

ICE should also work with other engineering institutions and non-engineering professions to draw people from more diverse backgrounds into the construction and infrastructure industry.

The institution has an important role in helping the industry to draw on a wider reservoir of talent from different economic sectors, social and cultural backgrounds and age groups, while ensuring everyone working in infrastructure is competent and has the support they need. This means a key question for ICE is how it can offer something of value to every member of the infrastructure team, not just those it will qualify as civil engineers.

Lastly, achieving net zero carbon and the wider SDGs is the moral and technical challenge of this generation. ICE needs to think about what that means for the licence to operate it provides to professionals and how it can better support them to take their key sustainable development competencies to higher levels.

How can ICE offer something of value to every member of the infrastructure team, not just those it will qualify as civil engineers?

Engineering Rebellion

Contents

Find out more: ice.org.uk

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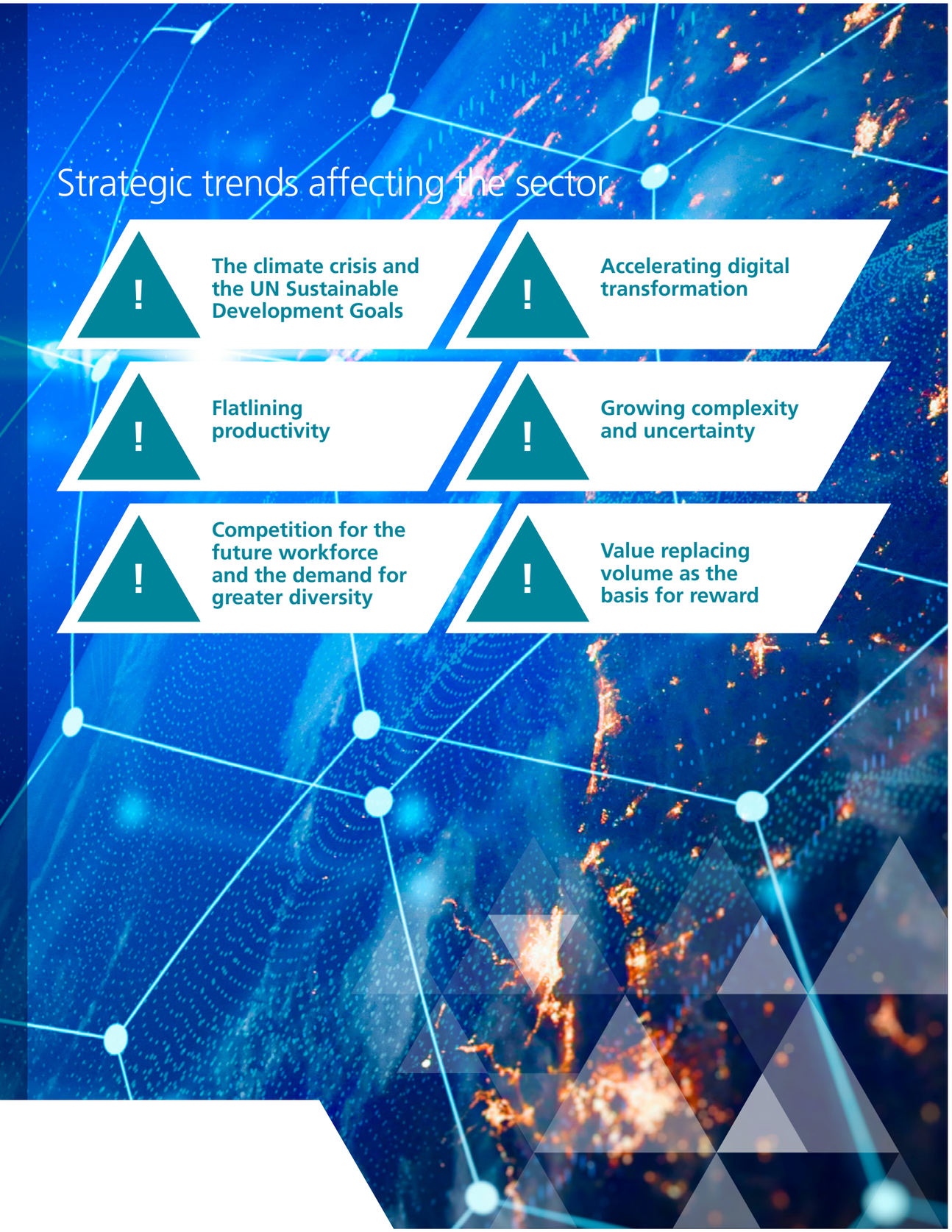


01 Introduction

This study examines who will be the civil engineer of the future and how ICE can adapt to embrace them. Its title, Engineering Rebellion, reflects the fact that answering the question has the potential to be transformative for individual civil engineers, the wider engineering profession, the construction and infrastructure industry, and ICE itself.

Since its formation in 1818, the institution has helped to push forward the knowledge, capability and capacity of the civil engineering profession. In that time, huge strides have been made in our understanding of materials and forces, safety has improved immeasurably and a pathway into the profession has been created for hundreds of thousands of talented people.

Today, however, the profession faces new challenges. Civil engineers work within an industry that is striving to deliver sustainable solutions, exploit technological advances and deal with the existential threat of climate change. In response, we need to capture the questioning, creative spirit that drove those past advances and apply it to the present. Engineering Rebellion therefore set out to assess the economic, political, environmental, social, cultural and technical developments that are changing the construction and infrastructure industry and will shape the work of this and future generations of civil engineers.

The study team carried out a literature review* and tested its assumptions with more than 700 people. Young, old, experienced, early career, ICE members and non-civil engineers have all shared their thoughts with us. This work identified six strategic trends affecting the sector.

1. The climate crisis and the UN Sustainable Development Goals
2. Accelerating digital transformation
3. Flatlining productivity
4. Growing complexity and uncertainty
5. Competition for the future workforce and the demand for greater diversity
6. Value replacing volume as the basis for reward

These strategic trends are explored in Chapter 2, using the following three lenses:

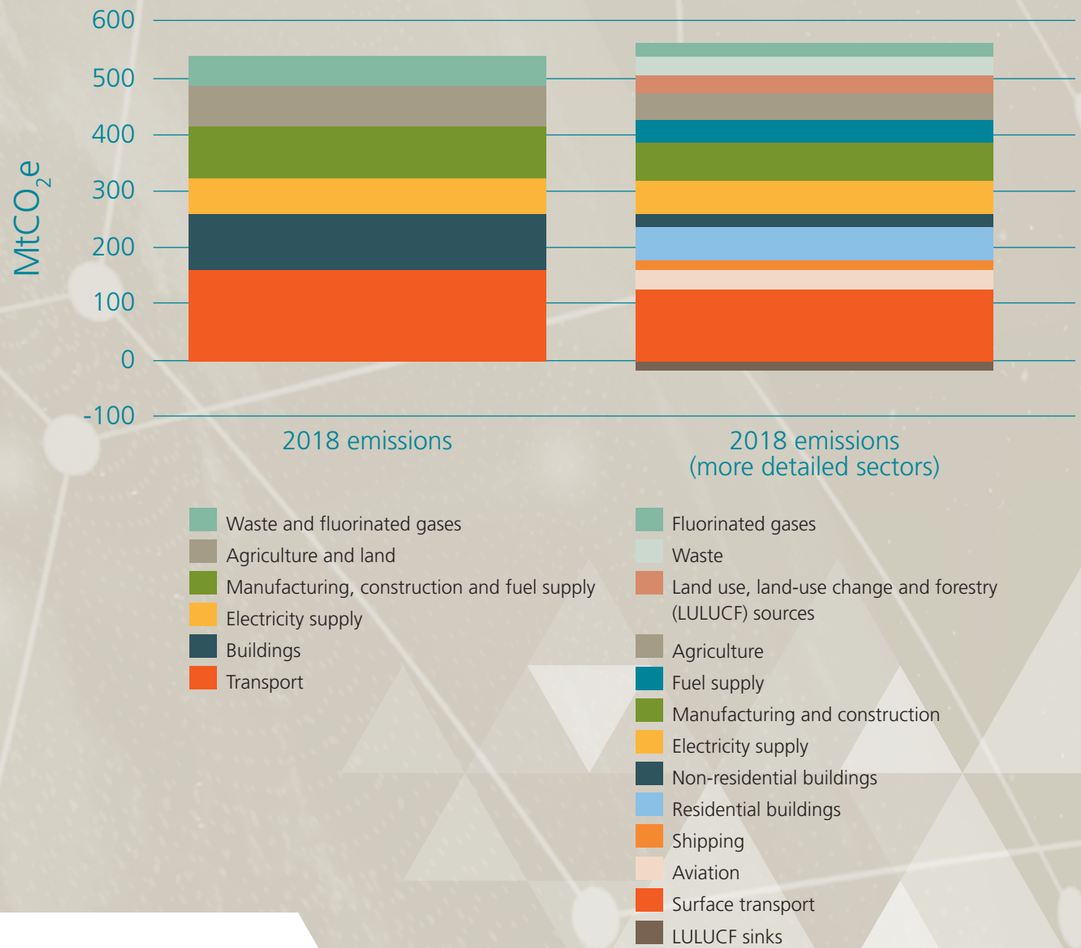
- **Today:** What is the current role and remit of the civil engineer within the construction and infrastructure industry – the ‘As-is’?
- **Changes:** What are the macro factors, technological advancements, trends and changes that are disrupting the ‘As-is’?
- **The future:** What disrupters to the civil engineering skill set and role within the sector arise from these trends? What are the potential implications of these changes for the future civil engineer and the organisations they work for?

We need to capture the questioning, creative spirit that drove the past and apply it to the present

*Engineering Rebellion’s literature review is available to download from ICE’s website

Decarbonisation has become one of the most important drivers for infrastructure owners and operators in the public and private sectors

UK emissions by sector in 2018



Source: Committee for Climate Change (2020), The Sixth Carbon Budget

02 Six strategic trends

1 The climate crisis and the UN Sustainable Development Goals

Future engineers will need to make sustainability benefits a core requirement of their work, not just add-on benefits.

Today Projects are primarily driven by traditional time, cost and quality considerations. While in recent decades health and safety has also become a central concern, civil engineers still incorporate sustainability and net zero benefits as add-ons to these core requirements.

Changes The UK has made a legal commitment to become a net zero economy by 2050. Globally the existential threat posed by the climate crisis has led many nations to make similar commitments. In parallel, public and private sector infrastructure owners and funders are seeking a wider range of social, economic and environmental benefits in line with the 17 UN Sustainable Development Goals (see box, below right).

The future Civil engineers will need to be able to design and deliver projects that support net zero and objectives linked to the UN SDGs, such as enhancing biodiversity or economic levelling up. This will demand changes to all aspects of engineers' work. Civil engineers will also have to rethink what they consider to be an infrastructure project. In developed nations, the role of refurbishment and maintenance will grow. Where new infrastructure is required data, technology and modern methods of construction will open up new options for meeting people's needs at a much lower carbon intensity.

After the net zero pledges from governments globally, decarbonisation has become one of the most important drivers for infrastructure owners and operators in the public and private sectors.

This should not come as a surprise. Analysis in the Climate Change Committee's Sixth Carbon Budget shows that the largest sources of UK emissions – transport, buildings, power, and manufacturing and construction – all fall within the influence of the civil engineering profession (see graph, facing page).

> To move away from 'new build' as our default solution, how do we change civil engineers' culture and job satisfaction, from 'new builders' to 'problem solvers' within existing assets?
>
> **Engineering Rebellion online Strategy Session audience member**

It will be important that the focus on decarbonisation does not come at the expense of the other Sustainable Development Goals, not least for maintaining the support of the public who are, understandably, concerned with the quality of their environment, the economic opportunities of their children and the strength of their communities.

This shift to a much wider range of outcomes jostling for prominence alongside time, cost and quality concerns within projects has profound implications for engineering practice. Strategy, optioneering and design practice will all have to reflect a wider set of parameters. Commercial, procurement and delivery models will change and new priorities, such as carbon measurement and assurance, will emerge. ICE will need to

UN Sustainable Development Goals

The 17 UN Sustainable Development Goals are a universal call to action to end poverty, protect the planet and ensure that by 2030 all people enjoy peace and prosperity.

sdgs.un.org

support civil engineers and infrastructure businesses to implement these changes.

In a mature economy such as the UK's, the carbon cost of new build, combined with the sheer size of our stock of infrastructure seem likely to push engineers to focus on meeting people's needs by getting more out of existing networks. No-build or low-build solutions that exploit technology and data are already being rolled out, while modern methods of construction offer hope for drastically reducing waste and inefficiency, while distributing opportunities to work in the industry more equally around the country.

The climate needs to be higher up the agenda for all institution activities to help create the right environment to support the implementation of low-carbon solutions

ICE What Makes Good Design? report

ICE's What Makes Good Design? report

ICE asked 900 members from a range of civil engineering sectors and organisation types, who were at different career stages and working in different areas of the project lifecycle, about their experiences of design. Published in July 2021, one of the key findings was that issues related to the climate emergency were not considered often enough.

The survey found that only 15% of civil engineers always considered greenhouse gas emissions and climate adaptation in their work. About 60% felt these two issues should be given more importance.

The factors limiting their ability to consider these issues were:
- A lack of joined-up thinking on projects
- It is not part of the project brief/there's no incentive
- Industry perception that it adds time and money

Download the report at ice.org.uk/knowledge-and-resources/briefing-sheet/what-makes-good-design-report

Future civil engineers and civil engineering businesses will need to focus on adaptability in the face of accelerating technological change. This will be more important than making bets on individual technologies or skill sets.

Today The digital skills of civil engineers and their use of data and new technologies varies widely, influenced by age, training and the projects they work on.

Changes The pace of change is accelerating. The traditional distinction between design and build is beginning to dissolve and attention is shifting to operations and integration. In parallel, infrastructure services are being more closely tailored to individual users. Manufacturing, retail and many services have already been transformed by this combination of technological change and greater responsiveness to the needs of consumers.

The future Digital transformation will continue to have unpredictable consequences. In this uncertain environment, adaptability is the core capability, alongside a willingness to embrace lifelong learning and constant upskilling.

In the next 10 years, the one certainty is that there will be increasing technologically driven change in how the public use services that depend on physical infrastructure. Electric vehicle charging stations and digital water meters are two technologies that are already with us but seem certain to grow exponentially.

We can also already see some genuinely transformational developments. In cities such as Helsinki, Stockholm and Singapore, 'Mobility-as-a-Service' is taking off, allowing people to select and pay for door-to-door journeys across multiple transport modes via a single platform. In the medium term, many organisations are already planning for the impact of driverless vehicles.

If these trends take hold, then organising an engineering business or an individual career around the delivery of capital projects within a single sector, mode or technical discipline could rapidly become an anachronism.

Engineering businesses are already starting to respond, with many recasting themselves as whole-life partners for infrastructure owners, rather than simply designers or constructors. These businesses typically stress their ability to unlock value from an interlocking digital and physical system right through the lifecycle of assets and networks.

The Government-led push on building information modelling (BIM) has played a role in accelerating these trends. What began as a means of improving the productivity and effectiveness of capital projects is morphing into a movement to use full-blown digital twins – and, more importantly, the underlying data behind them – to blur the distinction between 'design' and 'build' and shift attention to the categories of 'operate' and 'integrate'.

The long-term consequences of these trends are difficult to predict. What is certain is that a much greater focus on the user, combined with productivity-enhancing technology, has radically altered the shape of sectors such as retail and manufacturing in the past couple of decades.

An adaptable mindset and a willingness to constantly invest in upskilling is going to be as important as making big bets on specific skills or technologies. The profession does, however, have a big opportunity. Civil engineers who understand data science can work with pure data scientists who lack their deep domain knowledge. Infrastructure clients and owners will need people who understand the hard engineering science behind an algorithm and who can use the insight from data to provide expert engineering advice through the lifecycle of their assets.

> Engineers need to be more aware of the difference between efficiency and effectiveness – the profession could be accused of being very efficient at delivering entirely wrong solutions. How can engineers be trained/retrained to recognise this fundamental?
>
> **Engineering Rebellion online Strategy Session audience member**

Low productivity growth has bedevilled the sector for decades – and not just in the UK

What is Project 13?

Project 13 is a partnership initiative of ICE.

It seeks to develop a new business model – based on an enterprise, not on traditional transactional arrangements – to boost certainty and productivity in delivery, improve whole-life outcomes in operation and support a more sustainable, innovative, highly skilled industry.

www.project13.info

3 Flatlining productivity

Future civil engineers can embrace new roles as integrators, solution developers and specialist-generalist engineers and play a key role in turning around the infrastructure sector's low productivity.

Today The whole of the construction sector knows it has a problem with low productivity. Civil engineers and other professionals tend to focus on improving the areas of projects and programmes under their direct control.

Changes Technology is accelerating rapidly, creating many opportunities for productivity improvements – but also challenges for integration. At the same time, new delivery and operational models, such as Project 13, are replacing a collection of transactional relationships with a single enterprise focused on improving the productivity and performance of an infrastructure owner's assets.

The future New roles are emerging that combine a deep understanding of the problem at hand with a sound knowledge of the capabilities of technologies and the roles of fellow professionals. These roles have been described as "specialist-generalist" and these engineers will need to be adaptable and draw on their technical skills to define the opportunity.

Over the past decade, output per worker in manufacturing grew by 50% and there has been productivity growth of 30% in the services sector[1]. Output per worker in the construction sector has, by contrast, remained flat. This is hardly surprising as low productivity growth has bedevilled the sector for decades – and not just in the UK.

This poor productivity has multiple causes, including badly coordinated design processes, over-specification, a silo mentality, inefficient commercial and procurement processes, slow embrace of standardisation and modern methods of construction, and a low level of investment in R&D, skills and training.

Equally, there won't be one solution, but as this report has already shown, technology, data, automation and other aspects of what is often called Industry 4.0 are going to play a big role in finally cracking the sector's productivity problems.

This is going to create new roles for some civil engineers. One unexpected consequence of implementing new technologies – especially at a time of very rapid technological change – is that different technologies work in slightly different ways that don't always 'match up'. Identifying the causes of such mismatches, and devising solutions, requires engineers with a sound understanding of multiple technologies in addition to a solid grounding in more traditional technical skills. They also need systems integration skills so that the performance of technology – and the interface with human beings – can be effectively coordinated.

A recent paper in IStructE's journal described this type of role as a "specialist-generalist technical lead", while the Association for Consultancy and Engineering has spoken in similar terms about "solution developers". These engineers will be just as important as the existing design, commercial and construction leads.

The specialist-generalist or solution developer role needs to be hyper-adaptable and post-holders will need a sound understanding of the role and techniques of other professionals within the construction industry and beyond. They will also need data analysis skills and be adept in the human side of collaboration to bring solutions together successfully.

This idea of a key role for an integrator is also central to the Infrastructure Client Group's Project 13 model. Here, the role is to mould owners, advisers and suppliers into a single team, dedicated to improving the productivity and performance of the owner's assets.

> With a multidisciplinary approach you can have a combination of different types of people – mathematical, creative and scientific – it's about teamwork.
>
> **Engineering Rebellion online Strategy Session audience member**

[1] Mace (2017), Insights – Moving to Industry 4.0

4 Growing complexity and uncertainty

Future engineers will need to cope with greater complexity and uncertainty – demanding more systems thinking and use of scenario-based forecasting.

Today Civil engineers typically focus on their elements of a project, working for an owner who is primarily concerned with their assets or network. Less attention is paid to how elements of a project interact and are integrated. There is also less attention paid to the dependencies between assets and networks with different owners.

Changes Assets and networks are becoming more complex, as are the interactions between different infrastructure networks. This creates new vulnerabilities and a heightened risk of cascading failures simultaneously affecting transport, water, energy and communications. Systems-level approaches to the planning, design and operation of infrastructure are therefore starting to attract more interest (see box on SAID, facing page).

The future Engineers will need to deal with the growing recognition that infrastructure is a system of systems – which includes the interface with its users and the natural environment. Engineers will need to develop the skills of systems-level thinking to optimise the performance of these overlapping networks. This will extend to their ability to deal with clients and policy makers who will need help to create strategies that join the dots to create the best outcomes for society.

To cope with increased complexity and uncertainty, scenario-based forecasting will also need to replace many traditional methods used to set strategy and generate performance requirements for individual assets. The problems encountered in completing Crossrail are testament to the fact that infrastructure assets are becoming more complex – with complicated civil engineering needing to be integrated with an array of technology and services.

Complexity is also growing at the network level – for example, the electricity grid and distribution network are now dealing with the growth of intermittent renewables and new, smart ways of managing demand – with more change on the horizon.

Lastly, scaling up to system-of-systems levels reveals greater interdependency between networks, with communications and power acting as a sort of spine for the national infrastructure. To be resilient in this world, engineers need to move beyond thinking about just individual assets and the risk to their performance to thinking about the impact of their work on the system as a whole – and how best to understand and manage unwanted interactions.

Engineers will need an approach to design and asset management that better takes into account simultaneous, cross-network demands – for example, between housing and urban infrastructure, or between the energy system and the expected surge in electric vehicle ownership.

This growing complexity also demands more systems-level thinking in infrastructure strategy and also at the project level when identifying the performance requirements for individual assets.

In the past, engineers have perhaps been guilty of hiding behind the spurious accuracy of simple forecasts extrapolating a straight line from past to future in passenger usage or energy demand. If this was ever valid, it certainly cannot stand against the uncertainty created by the current level of complexity and rate of change.

Engineers will need to make greater use of scenarios to help them map the systems they are working on. Intelligent use of scenario-based forecasts will also provide insights into how the elements of those systems may interact under different circumstances, highlighting vulnerabilities and opportunities to increase resilience.

> My experience in contracting is that many engineers do try to focus on outcomes and user benefits, but the way clients set up projects works against this.
>
> **Engineering Rebellion online Strategy Session audience member**

Systems thinking

Using a systems approach to address climate issues could improve joined-up thinking in the industry.

ICE has created a Systems Approach to Infrastructure Delivery (SAID), a model that can be used to help deliver better outcomes for infrastructure owners and users.

Read the report: ice.org.uk/knowledge-and-resources/briefing-sheet/a-systems-approach-to-infrastructure-delivery

There is an urgent need for the sector to change its workforce profile to exploit the opportunities created by digitisation

5 Competition for the future workforce and the demand for greater diversity

The construction and infrastructure industry will need to move beyond simply managing a skills pipeline and work out how to tap into the reservoir of talent available to the infrastructure sector.

Today The construction and infrastructure sector suffers from endemic skills shortages and recurring recruitment crises. At the same time, study after study highlights the industry's failure to attract and retain more women and people from black and minority ethnic (BME) and other minority backgrounds. Employers think primarily in terms of a skills pipeline that runs through age 16-18 public examinations and university into graduate training schemes through to chartered membership of a professional institution. Transfer in and out of the industry, and between professional specialisms, is limited.

Data held by ICE reveals there are 13,625 female members, 75,805 male and 44 with other preferred gender identity. Some 63% of members are white British. Full ethnicity data can be viewed via the Fairness, Inclusion and Respect Committee page on the ICE website.

Changes The drive to meet societal expectations of diversity and fairness, to generate teams capable of diversity of thought and grasp the opportunities created by digitisation demand an urgent rethink of the sector's workforce profile.

The future Employers will have to work out how they can more effectively draw on the reservoir of talent that exists in schools, universities and in all parts of society and the economy.

Engineering and construction have struggled to recruit, train and retain enough people for decades. The Construction Industry Training Board quotes that up to 30% of the contracting workforce is due to retire within 10 years, while analysis from the Royal Academy of Engineering (RAEng) suggests the UK has an annual shortfall of 59,000 engineering graduates and technicians[2]. The problem is highlighted by the fact that engineering roles account for about 50% of the Home Office's list of 'shortage occupations' that qualify for preferential treatment in the immigration system.

The sector also has a chronic problem with representation and diversity. In 2019, RAEng reported that female participation in the profession was only 12% compared with 46.9% in the overall UK workforce (civil engineering at 16.6% is the highest-performing discipline). In terms of ethnicity, only 8.1% of engineering professionals are from BME backgrounds, compared with 12.7% in non-engineering sectors and 12.2% in the general population[3].

An ageing, disproportionately male, white workforce is not helpful in recruiting from a younger generation that the Association for Consultancy and Engineering recently described as "the most diverse to enter the workplace" and for whom "monocultures are a major negative"[4]. It is also clear that continuing to rely on a workforce with this narrow profile will not help the industry to access the new skills needed to exploit opportunities presented by new digital technologies and to respond to the UN SDGs.

The sector needs to change its demographics – and that needs a new approach to attracting its workforce. Talent 2050, a study from the National Centre for Universities and Business (NCUB), offers of a glimpse of what that new approach might be. The NCUB says real change won't come until the engineering sector ditches the idea of a 'skills pipeline', where the main route into the industry is accredited courses at academic universities. This approach rules out huge swathes of people as potential recruits.

A better metaphor is to think of the UK's schools, colleges, universities and people already working in the wider economy as a 'reservoir' of talent that contains the diverse skills that need to be combined to solve 21st-century engineering challenges and optimise the benefits that derive from digital technologies.

Fairness, inclusion and respect

ICE monitors the diversity of its members and its Fairness, Inclusion and Respect Committee has surveyed members to understand racism in civil engineering. It has created an action plan and anti-racism toolkit.

Download: ice.org.uk/about-ice/governance/how-we-work#ice-fairness-inclusion-and-respect-action-plan

[2] Royal Academy of Engineering (2019) Engineering Priorities for our Future Economy
[3] Royal Academy of Engineering (2019) Engineering Skills for the Future – The Perkins Review Revisited
[4] Association for Consultancy and Engineering (2020) The Future of the Workplace

This mental shift has big practical implications. Recruiters need to give less weight to the length of time a candidate has spent in the sector and be more open to bringing in skills from outside. If people from the gaming industry, for example, can bring their digital skills to infrastructure projects, it would be self-defeating to erect unnecessary barriers.

The challenge for the professional engineering institutions (PEIs) is more complex. In many ways they are, for good reasons, a pure example of pipeline thinking. The Grenfell Tower tragedy shows that the public needs to have confidence in professionals who can be assessed for currency, capability and competence – and one way of achieving that is through a linear process of academic study, experience, assessment and ongoing audit.

One way forward could be to promote the pipelines from the 40 PEIs as being crucial streams feeding the construction and infrastructure skills reservoir. It could also be the basis for assessing if some important streams are missing and need further support. ICE's proposal to introduce a Chartered Infrastructure Engineer qualification is a good example of this kind of thinking.

> Does ICE need to re-look at its process for incorporating members from diverse backgrounds as we continue to find out more about the unequal access to opportunities in mentoring and training that many from those backgrounds face?
>
> **Engineering Rebellion online Strategy Session audience member**

The Chartered Infrastructure Engineer

In 2016, ICE, the Institution of Engineering and Technology and the Institution of Mechanical Engineers commissioned Professor John Uff CBE QC FREng to undertake a wide-ranging review of the engineering professional landscape. The final report was published in March 2017 as the Uff Review: www.raeng.org.uk/publications/other/uk-engineering-2016

ICE has spent the intervening years addressing many of the recommendations. We have improved advice to government(s); promoted civil engineering in schools; shared engineering knowledge with a raft of organisations; accredited a broader range of academic courses and looked at how to engage and support members of the engineering profession who are not currently professionally registered.

After much debate, the Trustees recommended that ICE apply to register the protected title of 'Chartered Infrastructure Engineer'. It is important to note that registration for Chartered Engineer (CEng) remains with the Engineering Council; as a professional engineering institution, we are licensed to assess and qualify aspiring engineers to that standard.

The title Chartered Infrastructure Engineer is a protected title, like the Chartered Civil Engineer descriptor – and, as such, it would be 'owned' by ICE to recognise chartered engineers in our part of the engineering profession. The qualifying process (educational standard, professional development and professional review) would remain at the same very high standard set for chartered civil engineers.

■ For more information visit ice.org.uk/about-ice/governance/governance-updates

6 Value replacing volume as the basis for reward

Future civil engineers will need to adapt their business models to cope with technological change, new user demands and what clients are willing to pay for.

Today Historically, civil engineers have been appointed on the basis of their inputs and remunerated on the basis of time and their level of skill and expertise.

Changes Technological change is moving well beyond automating the mundane tasks on which junior engineers cut their teeth. Big data and artificial intelligence are encroaching into higher-value areas traditionally reliant on the judgment of experienced professionals. In parallel, strategic challenges such as net zero and the need to level up economies mean clients are looking to derive a wider range of value through the whole lifecycle of assets and networks.

The future Civil engineering businesses will have to develop products and services that allow them to be paid on the basis of the economic, social and environmental outcomes they deliver – and convince clients they are worth paying for. New forms of engagement will continue to develop between clients and the supply chain, and between supply chain organisations. The structure of the sector may change, with many initiatives, such as the Government-funded Construction Innovation Hub, trying to push it towards the centralised product platform model commonplace in sectors such as car manufacturing.

In 2015, Richard and Daniel Susskind made a big impact with their book, The Future of the Professions. It is worth revisiting what they said about the impact of digital technologies, big data and artificial intelligence on professional roles. The Susskinds argue that "increasingly capable machines" are rapidly expanding their ability to outstrip the performance of humans in an increasing number of areas where professional judgment and experience had previously attracted a premium. When this is combined with the digitisation and free distribution of much basic knowledge, the result is a growing reluctance to pay high prices for professional services – and more work delivered by machines or by freelancers and outsourced labour.

In the infrastructure sector, we can see this at work in the growing use of generative design tools and, as projects move into delivery, the deployment of drones, robots and other technologies that can deliver greater levels of accuracy and reliability than humans.

This means that many business models – for example, those that combine streams of routine, low-cost tasks performed by junior staff alongside more complex, creative, unpredictable and expensive tasks performed by senior professionals – are becoming increasingly unsustainable. In short, by outcompeting humans, digital technologies are removing the revenue streams that help to ensure commercial viability for engineering businesses.

To make good this loss, professionals need to be able to charge high prices for new services. The Susskinds suggest this means:

- Far greater focus on identifying what customers want
- Work that is more proactive than reactive
- The mastery of huge bodies of data, including identifying, building and trading datasets with others
- Improving communication skills and the value that can be derived from that – for example, identifying clients' unrecognised problems.

This will demand increasingly multidisciplinary work because the problems being tackled do not lend themselves to being organised in ways that map on to traditional boundaries between professions.

In its work on the Future of Consultancy, the Association for Consultancy and Engineering (ACE) has begun to explore what this will mean in practice. ACE has identified a series of alternatives to selling inputs – normally staff time, by the hour. These include both output-based business models – e.g. bundling a product with consultancy advice – and models whereby payment is based on supporting the securing of an outcome – e.g. some forms of alliancing. These 'value not volume' models all demand that engineers get much better at teasing out what their clients value. ACE suggests framing this in terms of how engineers will work with clients to enhance five types of capital; natural, social, manufactured, financial and human.

Similarly, the Infrastructure Client Group has developed Project 13. Under this model, infrastructure owners replace a series of transactional contracts with a single semi-permanent enterprise embracing their main supply-chain partners. Participants are then rewarded based on performance and outcomes, not volume of work.

Watch Richard Susskind's Strategy Session:
ice.org.uk/eventarchive/ice-strategy-cov-id19-ai-and-future-civil-engineer

The future civil engineer thinks differently…

Bristol University held a workshop with its fourth-year Civil Engineering MEng students using the Engineering Rebellion literature review and seven skills profile disrupters identified by the steering group. Below are a sample of the questions posed and responses.

Q: Will 'big data' analysis and AI surpass professional judgment? How can the industry adapt to remain relevant if this is the case?

Human judgment will be required to deal with new or unprecedented challenges as AI won't be trained to deal with this.

Q: What new business models and ways of working will allow us to focus more on societal purpose, outcomes and whole lifecycles above outputs and capital expenditure?

Engage with a wider range of stakeholders before working on the project, such as talking to local residents about what exactly they need or want.

Monitor success of the project in operation – and report on lessons learnt: were there any unexpected outcomes?

More regimented and consistent method of tracking progress against the UN SDGs for all projects – how is the project actively tackling societal or environmental issues? Could it be made part of the planning requirement?

A business model that better incorporates the 'why' for a project, rather than dictating an output.

Q: What other digital developments do you think civil engineers should be embracing?

Monitoring of project performance post-construction to gain a better understanding of how well the project meets aims in operation, which can inform design going forward.

Q: How far will civil engineers need to be skilful persuaders of stakeholders or empathisers of users to gain the backing required for new infrastructure projects to go ahead?

Being honest with regards to the benefits and drawbacks of solutions with stakeholders will help to develop trust between the design team and stakeholder relationships. The demonstration of empathy is important for the stakeholders as they will appreciate being understood and considered.

Training a workforce to be empathetic may be difficult, and is not necessarily something that can be enforced by policy making. Could these traits simply be down to personality? Will persuasiveness and empathy become job criteria?

■ *With thanks to Dr Neil Carhart, University of Bristol lecturer in infrastructure systems in the Department of Civil Engineering*

03 Seven disrupters: Our analysis of trends

Through our work exploring the six strategic trends shaping the sector, we identified seven disrupters of the current civil engineering skills profile:

1. Net zero and sustainability benefits will become central to project outcomes.
2. Business models will demand greater collaboration to deliver more value through the asset lifecycle.
3. Diversity and the profile of construction workers has to change: people will need to come into the industry from a much wider set of channels.
4. Digital will create a demand for people with the adaptability needed to understand and work with a wide and rapidly changing set of digital technologies.
5. Productivity will need to improve rapidly. Engineers will have to master the skills and behaviour that will allow innovative practices, techniques and materials to be deployed.
6. Systems thinking will be needed at the project, network and system-of-systems levels.
7. Upskilling will be constant – civil engineers will need to adopt a proactive attitude to lifelong learning.

These disrupters require that the industry will need to do things differently

These disrupters require that the industry will need to do things differently and that all of the people working within it, including civil engineers, will need different skills and capabilities. It is difficult to predict how the strategic trends will play out and how the disrupters will manifest themselves.

The next chapter uses these disrupters as the basis for five scenarios. As with all scenarios, these are not predictions. The future is unknowable and is likely to contain elements of all of these scenarios – and many factors that haven't been considered. Scenarios do, however, challenge our assumption that the future will be like the present and focus this study on how the world might look through the eyes of an engineer working in these environments.

	01 **Resilient mega-cities**	02 **Dispersed settlements**	03 **Extinction express**	04 **Greentocracy**	05 **Covid-19**
SCENARIO HEADLINE	Political leaders have failed to address climate change at the national or international level. Cities are at the centre of climate resilience.	The failure to tackle climate change extends to the city level, leading to a mass exodus to smaller, highly dispersed settlements.	The world is split between large 'safe hells', poor quality environments for the impoverished and 'safe-environments' for a small elite.	The main priority is to restore global eco-systems. The population is clustered into dense, high-rise mega-cities with the rest of the globe designated as eco-system recovery zones.	The overriding priority is to halt the spread of viruses while keeping the economy functioning.
IMPLICATIONS FOR CIVIL ENGINEERS	Civil engineers need to take a leadership role bringing together specialists and stakeholders to make climate-resilient city infrastructure happen.	Civil engineers take on a hyper-local focus and are drawn from the communities in which they live.	The majority of civil engineers find themselves creating elaborate infrastructure projects to protect the elite from eco-system collapse.	Civil engineering is an extremely prestigious career, vital for the functioning of mega-cities and for managing the human relationship with the recovering eco-systems.	Civil engineers focus on reducing virus transmission via the use (or not) of infrastructure.

04 The future: Five scenarios

Future civil engineers will need to make greater use of scenario-based foresighting techniques to guide strategic thinking.

To explore the implications of the disrupters, Engineering Rebellion deployed a set of future scenarios. As with all scenario exercises, this wasn't an exercise in predicting a single future but instead an effort to use this technique to provide a way of thinking about a future that is inherently uncertain. The idea was not to be deterministic about the future but to get comfortable with looking ahead and making predictions.

Three of these scenarios were drawn from existing work by the American Society of Civil Engineers (ASCE) plus work by consultancy Arup and a further one was created from a review of more than 100 industry reports or web pages about the response to the Covid-19 crisis.

The full scenarios are set out in Engineering Rebellion: The Scenarios (available to download from ICE's website), alongside a visual representation of the relative importance to each of the seven disrupters identified in Chapter 2. Headlines from each scenario are summarised here.

All of the scenarios are quite extreme, even exaggerated. This is deliberate. By taking the trends in Chapter 2 to their logical extremes, different thinking about the possible futures for civil engineers is required. This doesn't make those futures any more knowable, but it helps in assessing what skills and capabilities could look like across any of the futures. Just as important, it allows experiences from the past two centuries of civil engineering to be challenged.

Direct conclusions from the scenarios are circumspect. Skills, systems thinking, adapting to changing business models and adaptability to technological change are common features across these futures.

Our broader conclusion is clearer. The exercise demanded different thinking which has been immensely valuable. The engineering profession needs to get more comfortable with uncertainty and ambiguity and be more willing to challenge inherited wisdom. How this can be best achieved requires more thought – and we recommend that this is something that ICE dedicates more time to unpicking. ICE should also work to stay abreast of such scenario-modelling techniques given the rapid pace of change in the sector.

The engineering profession needs to be more willing to challenge inherited wisdom

ICE needs to realise the idea of a ‘skills reservoir’ that can draw in talent from across age groups and economic sectors

05 Conclusions and recommendations

Studies into the future civil engineer can easily default to producing a long, detailed list of characteristics: individuals with multidisciplinary skills and knowledge, coupled with strong leadership skills, creativity, empathy, collaboration, innovation and political savvy. When none of these individuals emerge, the cycle starts again and further studies are commissioned.

This time feels different. Climate change is an existential threat, technology is transforming business models and the sector has woken up to its diversity challenge. We can’t afford to be back here in five years asking the same question – we need to think differently.

The civil engineer in the infrastructure team

One starting point is to stop asking every individual civil engineer to develop a growing list of skills and think about how they are supported to work more effectively with the rest of the increasingly multidisciplinary teams that deliver infrastructure projects.

This study, which draws on a lengthy literature review and wide engagement, identifies a range of characteristics that will be needed to deliver work that meets the future needs of society. We will need project definers, lateral thinkers, sages, niche technical, experts, coders, digital model builders, inventors, community engagers, strategists, policy experts, commercial specialists – the list goes on and will vary with time and place.

All engineers will possess some blend of the capabilities and characteristics needed, but none will have all of them – and Engineering Rebellion is not an exercise in telling them that they should.

It is more important that we convey the message that the biggest challenges the future civil engineer will face are inherently multidisciplinary, that collaborative delivery is not a fad but a necessity that technological change will only accelerate, and what people want from infrastructure will continue to become more complex. This means that a growing proportion of what industry needs may not be traditional civil engineers at all, or people qualified by ICE.

This is an opportunity, not a threat. The members of the infrastructure team will include natural collaborators, introverts and extroverts. Someone will still need to understand the physics and the maths. The industry will need people who are excited by the problem-solving at the start of new projects as well as the people who get their satisfaction from getting them over the line.

These teams will have to be more diverse, drawing on the skills and experience of a much wider range of people from a broader set of backgrounds. Civil engineers who want to will have opportunities to lead, joining the dots between these disparate inputs to create solutions that are sustainable, flexible and do a much better job at meeting the needs of society.

Our main message to ICE is therefore that it should focus on how the future civil engineer can thrive and collaborate as part of the infrastructure team. Achieving this will bring out the best in the profession and ensure it is much better placed to meet the challenges of the 21st century.

Embracing the future civil engineer

Faced with cyclical skills crises in the sector, ICE could redouble its efforts to promote civil engineering in schools and colleges, particularly with women and people from minority ethnic groups.

However, Engineering Rebellion found that the construction and infrastructure industry will not meet its needs by thinking solely in terms of a ‘skills pipeline’, leading from people taking STEM subjects at school, through university and into graduate training schemes.

ICE may wish to explore how it could work with PEIs and many other stakeholders to realise the idea of a ‘skills reservoir’ that could draw in talent from across age groups and economic sectors. The reservoir idea also means finding ways for skilled people to move between roles and even in and out of the civil engineering profession.

The potential introduction of the Chartered Infrastructure Engineer and opening up of the Associate class of membership are useful starting points, but the institution could take a much more radical look at the routes in, out and back in again to the profession. The institution could ask what it would take for ICE to offer something

of value for anyone in the infrastructure team. For example, how could someone from the games industry with the digital skills to contribute find their way easily into the sector?

Key capabilities and upskilling

Achieving net zero carbon emissions and meeting the wider UN Sustainable Development Goals are the technical and moral challenges of this generation. The scenarios at the heart of Engineering Rebellion show that the threat of climate change is existential, at least for much of the planet's population. ICE needs to think about what this means for the licence to practice it provides to professionals.

More broadly, the study found that agility and a culture of continuous upskilling was needed to deal with accelerating change. This doesn't hold only for professionals aspiring to senior leadership positions who are perhaps already well served. ICE could explore what it can do to support and perhaps cajole members.

There is a strong case for compulsory upskilling of all members so that anyone practising under ICE's qualifications can demonstrate a baseline competence in how to manage these issues. It could also provide more support for those looking to take their competency to higher levels in these crucial areas.

The scenarios exercise also pointed to the importance of capabilities around systems thinking, operating under value-based business models and digital if engineers are to thrive in any of the futures this study has explored. Dealing with the sector's poor productivity performance also featured strongly. ICE's future programme of Continuing Professional Development should reflect these findings. In this way the institution will truly be helping civil engineers to think differently and embrace the breadth of change needed for the years to come.

The scenarios at the heart of Engineering Rebellion show that the threat of climate change is existential

Established in 1818 and with more than 95,000 members worldwide, the Institution of Civil Engineers exists to deliver insights on infrastructure for societal benefit, using the professional engineering knowledge of our global membership.

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