

Flourishing systems

Re-envisioning infrastructure as
a platform for human flourishing

This paper advocates a vision
for infrastructure that is:

People-focused – recognising the
fundamental role of infrastructure in
the social, economic and environmental
outcomes that determine the quality
of people's lives.

Systems-based – recognising infrastructure
as a complex, interconnected system of
systems that must deliver continuous
service to society.

It articulates how the industry should
re-envision itself to unlock greater
value for people, from the systems.

Forewords

The UK Government has made clear that it places infrastructure at the centre of its vision for the nation – investing in infrastructure to level up prosperity and wellbeing across the country.

Digitalisation, built on secure, resilient data sharing, has an important role to play in achieving this. As we emerge from the Covid-19 pandemic, it could be that digitalisation has reached a tipping point. The lockdown has required us to adapt quickly to digital ways of working, proven the robustness of telecommunications systems globally, and shown the need for improved data.

Data has a central role to play in controlling infection as economic and social activity resumes, and in adapting the operation of all forms of social and economic infrastructure to be resilient in the different conditions that are likely to persist long after the last cases of Covid-19 have been reported.

As we move ahead with recovery, our increased comfort with digitalisation will be essential for addressing many of the big, systemic challenges that we face, from rebalancing the UK economy for the benefit of under-represented communities, to managing the causes and effects of climate change by reducing carbon emissions to net-zero by 2050.

This paper shines a light on the systemic nature of many of today's issues and opportunities – AI and the data economy, the future of mobility, clean growth, and meeting the needs of an ageing society. Seeing our economy, our society and the infrastructure that supports them from a new perspective – seeing them as systemically connected – may be the key we need to achieve our ambitions.

Fergus Harradence

Deputy director for construction, Department for Business, Energy & Industrial Strategy



**Department for
Business, Energy
& Industrial Strategy**

The service of citizens – society – is enshrined in the term ‘civil engineering’, coined by John Smeaton more than 250 years ago. Since then the infrastructure created by civil engineers has grown to the point that society wholly depends on it. All professionals working across the built environment must be aware of and fulfil our duty to keep infrastructure, our life-support system, working for the benefit of citizens.

This paper talks about desirable outcomes.

A desirable outcome is not necessarily what I or you want for ourselves, but what is in the common interest. Agreeing those outcomes will involve much discussion, in which society must have broad and balanced representation. It is essential that we understand the problems we are trying to solve, the make-up, interdependencies and performance of our built and natural environments, and how our management of them affects society.

Some tools for achieving desired outcomes are to hand. In Project 13, we have an outcomes-oriented approach to delivering and managing infrastructure that is ready to be scaled-up. Among the many promises of digitalisation are an improved ability to make sense of challenges and opportunities that have hitherto been too big to handle, and to make better decisions that result in better outcomes.

As the fourth industrial revolution gathers greater pace, significant changes are becoming possible. This paper, encouraging us to view infrastructure as a system of systems in the service of society, describes the change we should seek to bring about.

Paul Sheffield

President, Institution of Civil Engineers



From our founding purpose in 1847 “to give an impulse to invention likely to be useful to the world” to our present-day mission statement of “improving the world through engineering”, the Institution of Mechanical Engineers has a long history of developing systems and machines to benefit people and society.

Developed over time, our nation's infrastructure has inevitably become a complex system of systems. Yet whilst infrastructure and society have become increasingly connected, our built environment has become ever more vulnerable to social, economic and environmental pressures. With engineering now truly multidisciplinary, we must consider whole system thinking when developing and sustaining the assets and networks that make up our built environment.

We welcome this paper, and the call to develop a systems-based vision of infrastructure, with a renewed focus on people, connections, sustainability and digitalisation.

As an engineering community, we must collaborate across disciplines and sectors to resolve the most urgent issues facing our nation. And as society, we must invest in innovations and technologies that can truly enable a platform for human flourishing.

Prof Joe A McGeough

President, Institution of Mechanical Engineers

**Institution of
MECHANICAL
ENGINEERS**

This paper crystallises out some critical thinking by a number of key experts and influencers across the infrastructure sector. It provokes new thinking and ways of seeing how existing and new infrastructure can be used to support a better, fairer and more sustainable society and world, especially when the potential of exploiting digital methods is included.

The paper was brought together before the coronavirus pandemic, which brings a profound additional international imperative to ensure our infrastructure is being used and developed in responsible, ethical and sustainable ways. There is much new thinking to do and collaborative action to take together.

I hope this paper makes a contribution to stimulating a better future for all. My thanks and congratulations to all those who contributed to it.

Dr Peter Bonfield OBE

President, Institution of Engineering and Technology

IET The Institution of
Engineering and Technology

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Burgess G, Enzer M, Schooling J et al.
‘Flourishing systems’

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The central ideas in this paper are simple and radical: that the purpose of infrastructure is human flourishing and that infrastructure is a system of systems. We must envision and manage infrastructure accordingly.

We have created an amazing, complex machine on which we wholly depend. Without it, our lives would be immeasurably worse. Society would not survive. That machine is infrastructure – our built environment.

However, we don't appreciate the relationship between the machine and our wellbeing. Therefore, we don't set objectives in terms of outcomes for people and society.

And although we understand each part of the machine, we do not manage it as a whole. Therefore, we don't know how to address its systemic vulnerabilities or make it work better.

If we envision, plan and manage infrastructure differently, we can make it what it should truly be:

A platform for human flourishing.

By re-envisioning infrastructure in this way we improve our ability to...

1. deliver desirable outcomes for people and the wider environment
2. integrate new assets properly into the existing system
3. release available value from what we have already built
4. provide the resilience that society requires of its infrastructure
5. unlock the potential of digital transformation across the built environment

Why now?

Because we must. And because we now can.

Infrastructure and society are becoming more connected at an ever-faster pace so risks of failure can cascade faster and wider than ever before. Challenges like reducing carbon emissions to net-zero and making society resilient to the physical effects of climate change are systemic and require systems-based solutions.

And technology now makes systems-based thinking and action possible.

Key concepts

Flourishing – Going back to Aristotle and beyond, the concept of human flourishing has been at the heart of the most basic of philosophical questions: what does it mean to live well? 'Eudaimonia', sometimes translated as 'happiness', but best understood as 'human flourishing', is the ultimate good that people aim for, both as individuals and as society. More than personal wealth, honour or pleasure, it requires external conditions that are beyond the control of individuals but are related to the choices we make.

Systems – A system is a connected collection of interrelated and interdependent parts; a complex whole that may be more than the sum of its parts. A system is influenced by its environment, defined by its structure and purpose, and expressed through its function. Infrastructure is the interconnected 'system of systems' that provides the physical foundation for our society. It does more than just provide water, power or transport services; it helps to make cities liveable, boosts quality of life and supports productivity and prosperity, all in the context of its interface with the natural environment.

How should we envision, plan and manage infrastructure?

We must develop a systems-based vision of infrastructure with renewed focus on:

People – a focus on **outcomes and human flourishing**, because infrastructure provides essential services on which people and society depend.

Connections – a focus on **interconnected infrastructure**, existing as well as proposed, because infrastructure is a system of systems.

Sustainability – a focus on **the long-term viability of infrastructure** and the society it supports, so infrastructure must be sustainable, secure and resilient as a system.

Digitalisation – a focus on **developing infrastructure as a cyber-physical system** because digital transformation is key to unlocking greater value from the built environment.

Flourishing systems is the third in a series of ‘principles’ papers that re-imagine infrastructure and the wider built environment:

Smart Infrastructure defines smart infrastructure, where physical meets digital, and sets out its core value proposition – that better decisions, based on better analysis of better data, drive better outcomes for people.

Gemini Principles defines digital twins for the built environment – connected digital representations of assets, processes and systems – and describes national digital twins as ecosystems of connected digital twins. Gemini Principles suggests the values that should guide the development and use of the UK’s National Digital Twin.

Who is this paper for?

This paper is for you!

It is for industry influencers and leaders – within government, owners/operators and their supply chains, and academia – who can all make a difference to the way we define and run the infrastructure industry.

People

People perspective

Human flourishing is the fundamental purpose of infrastructure.

Systems perspective

There is an enduring interdependency between infrastructure and society – it is a socio-technical system. Desirable outcomes for society should set the objectives for infrastructure.

Key message

Recognising the overarching purpose of infrastructure – to support and serve people and society – we must get better at delivering interconnected outcomes: social outcomes, environmental outcomes and economic outcomes.

Systems > services > outcomes

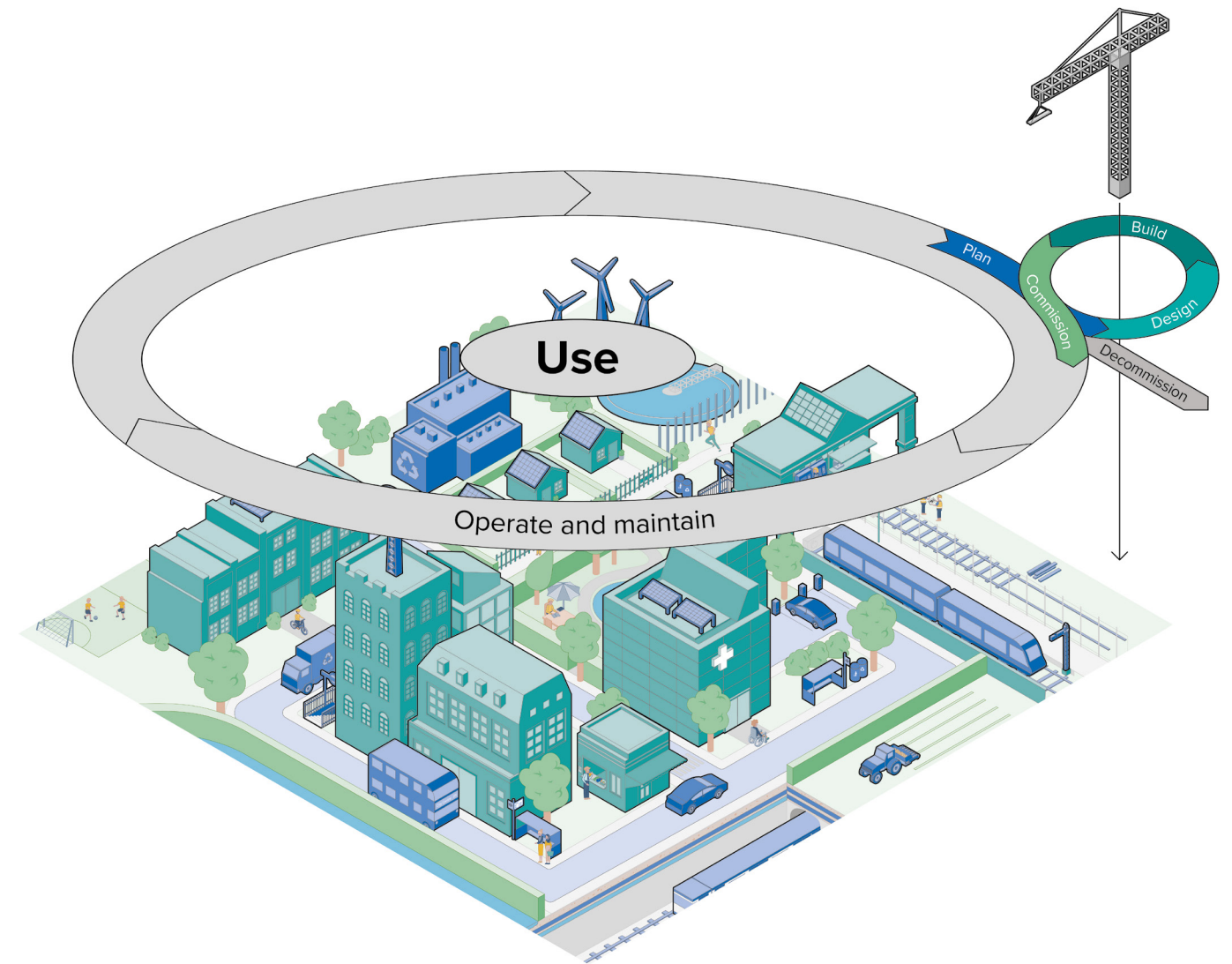
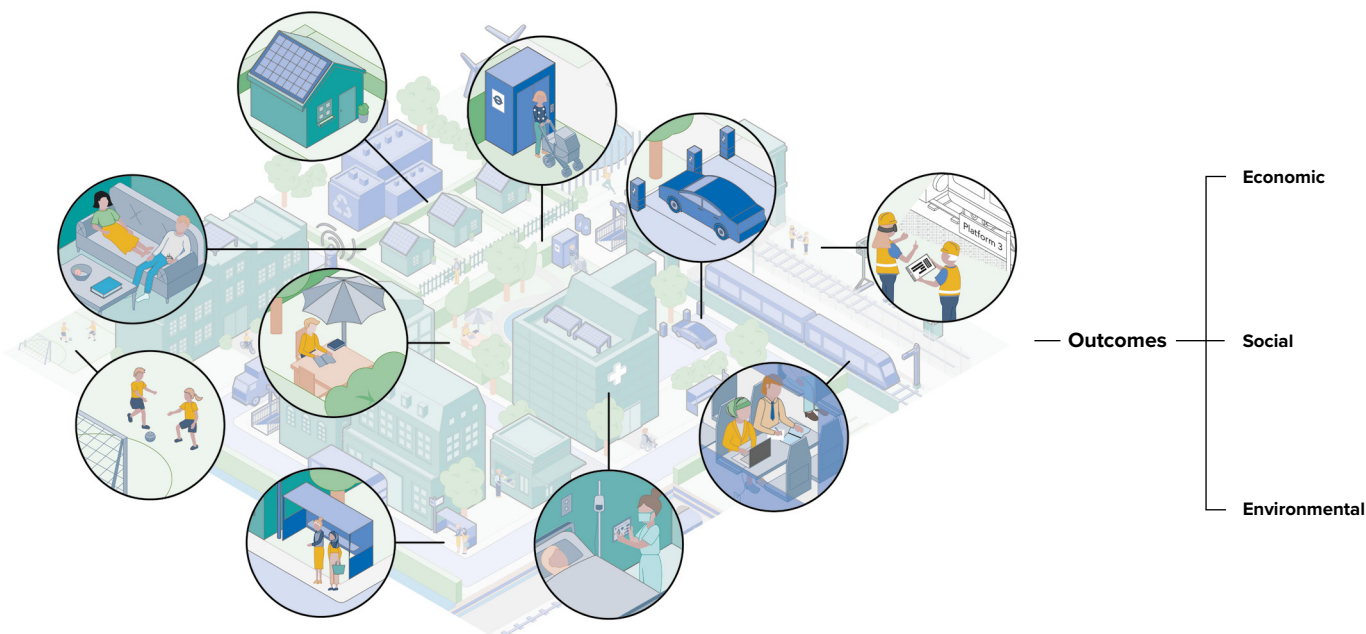
The balance between social, environmental and economic outcomes is an ethical and political matter. While this paper does not aim to set that balance, it does encourage discussion between the infrastructure industry, government and society about what outcomes are desired from infrastructure. And, critically, it seeks to recognise those outcomes as the objectives for the industry.

When human flourishing is the goal, then infrastructure becomes the system that delivers the services that enable the desired overall outcomes. The objective for infrastructure must be to deliver these.

Value must be defined accordingly. The 'construction industry' has traditionally defined value in terms of outputs and initial cost. A people-focused 'infrastructure industry' would consider value in terms of outcomes and whole-life cost.

Project 13¹, developed by the Infrastructure Client Group, champions this approach. And the work of the Construction Leadership Council and the Construction Innovation Hub to align procurement processes with this definition of value is very welcome.

Servitisation of infrastructure – framing it as a service – puts people first and enables us to start seeing infrastructure as a 'system of services', for example, 'mobility as a service' in transport.



The 'use' of infrastructure is at the centre of everything, because people are

With a people-focused view of infrastructure, the 'use' of the system should be the start and end point of all other system processes. The addition of each asset and its subsequent lifecycle must be understood in relation to the broader system.

In this way, all infrastructure projects can be seen as 'interventions' on the system. Such a view would help the industry to integrate new assets, of all sizes, into the system more effectively.

A people-focused 'infrastructure industry' would consider value in terms of outcomes and whole-life cost.

Connections

People perspective

People and society are dependent on infrastructure. Only by taking a holistic view can the complexity of this socio-technical system be understood and mastered.

Systems perspective

Focus on delivering desired outcomes from existing as well as proposed assets – the whole of our built environment.

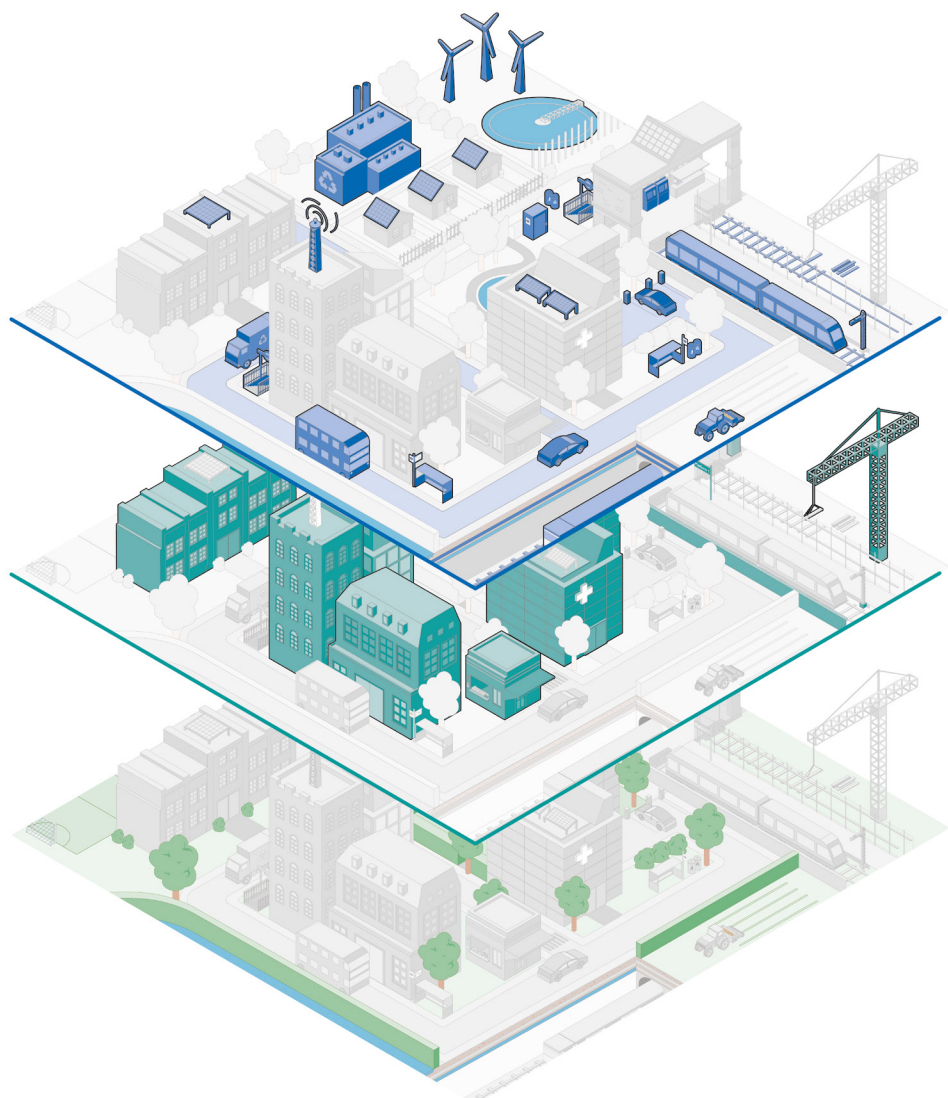
Key message

Infrastructure has become a complex, highly interconnected system of systems. That should be reflected in the way we run the industry.

Look at what we've built

In the UK, we've been seriously building infrastructure for more than 200 years and we have also been connecting it all up. Now, assets and networks are inextricably linked across social and economic infrastructure, and with the natural environment. Our built environment has effectively become a system of systems².

Our infrastructure has become the most complex and most essential machine ever built. Yet, significant strategic investment is still required to upgrade or supplement it in order to accommodate population growth and demographic shifts, address climate change, deliver increased digital and physical connectivity, and achieve a higher level of resilience against various potential disasters³.



Assets and networks are inextricably linked across social and economic infrastructure, and with the natural environment.

Interconnected and interdependent systems

Economic infrastructure

- Energy
- Telecommunications
- Transport
- Waste
- Water

Social infrastructure

- Hospitals
- Prisons
- Schools
- Commercial, industrial and residential buildings
- Public space

Natural environment

Interconnections and interdependencies between economic and social infrastructure and the natural environment include ecosystem services, flood alleviation, recreation, resources and waste disposal.



Our built environment is an interconnected system of systems

Silos in policy, decision-making, development and operation produce suboptimal outcomes. A paradigm shift is required: we must recognise infrastructure as a system of systems and manage it accordingly.

Connected thinking

While each new asset was built to a plan, the system of systems that has emerged has neither an overall design nor a strategy for its interconnections, resilience or long-term outcomes.

This needs to be addressed because silos in policy, investment decision-making, development and operation produce suboptimal outcomes. For example, the shift towards greater use of electric vehicles will clearly need a strategy that is shared between the transport and energy sectors – who funds the charging infrastructure, and beyond consuming power, what contribution should vehicles make to the grid? A paradigm shift is required: we must recognise infrastructure as a system of systems and manage it accordingly.

The capabilities and tools to enable such a paradigm shift are already becoming available, such as systems engineering, complexity science and federated digital twins. We now need a systems-based strategy for national infrastructure.

National infrastructure strategies must address the whole system, existing infrastructure as well as new. To get more from what we already have, as well as from what we will build, we must address the connections and interdependencies between sectors.

Measuring infrastructure performance

We need effective metrics for infrastructure performance. These must address:

System performance –
how effective and efficient the system is

Service performance –
how it feels for the end-users

Such metrics would allow the status quo to be understood, improvement targets to be set and progress to be measured.

Some important existing measures, such as construction productivity, are concerned only with asset creation, while major national metrics like GDP growth and productivity do not capture elements of development, such as progress towards achieving net-zero greenhouse gas emissions or increasing resilience of the infrastructure system as a whole. A focus on infrastructure’s contribution to human flourishing would invite closer examination of whether its ultimate objectives for society are being met.

Key questions

We need to understand infrastructure better if we’re to manage it better. These questions, derived from ‘enduring questions’ of Australia’s infrastructure needs⁴, indicate what we need to know about our system of systems.

- | | |
|-----------------------------|---|
| Infrastructure baseline | <ul style="list-style-type: none">• What infrastructure do we have?• What is its capacity, geospatial location and value?• What is the condition of the infrastructure?• What services does it provide? |
| Infrastructure performance | <ul style="list-style-type: none">• How well does the infrastructure perform as a system?• How well does the infrastructure perform as a service for end-users?• What is the connection between infrastructure performance and key national metrics? |
| Infrastructure impacts | <ul style="list-style-type: none">• What are the environmental impacts of infrastructure?• What are the social impacts of infrastructure?• What are the economic impacts of infrastructure? |
| Infrastructure use | <ul style="list-style-type: none">• How do people use infrastructure?• How do businesses use infrastructure? |
| Infrastructure systems data | <ul style="list-style-type: none">• What infrastructure systems data exists?• What is the quality and consistency of infrastructure data?• What additional data would enhance decision-making?• Which better decisions would improve outcomes? |

Sustainability

People perspective

Ensure that society's evolving needs can be met by the built and natural environments. Forever – for as long as we want society to exist.

Systems perspective

Make infrastructure systems sustainable, secure and resilient in order to promote the long-term viability of the society it supports.

Key message

It will become increasingly difficult to sustain infrastructure and society unless the system itself becomes sustainable, secure and resilient.

Sustained and sustainable

Infrastructure is an amazing interconnected machine that underpins and serves society. For as long as we want society to function, we must keep that machine working – and develop it to meet evolving needs. This will become increasingly difficult unless we address the challenges of material resource constraints, pollution, the impacts of climate change and transition of the whole economy to net-zero greenhouse gas emissions.

Today's infrastructure has been sustained over time through maintenance, repair and adaptation. However, sustained is not the same as sustainable. Our system of systems is resource-hungry and wasteful, vulnerable to environmental, social and economic pressures, and at risk from accidental or malicious security breaches. The system itself must become sustainable, secure and resilient.

Infrastructure must work within its fair share of the planet's means. Energy and materials inputs and waste outputs must be within the environment's capacity. At a high level it's simple, but in practice will require concerted effort by the industry over the years to come.

We urgently need to shift the dialogue towards making the system sustainable, thinking about cross-system effects and addressing future as well as present challenges. For example, the shift towards electric cars must reduce whole-system impacts, not just emissions; the impact of lithium mining and managing spent batteries must be part of the equation.

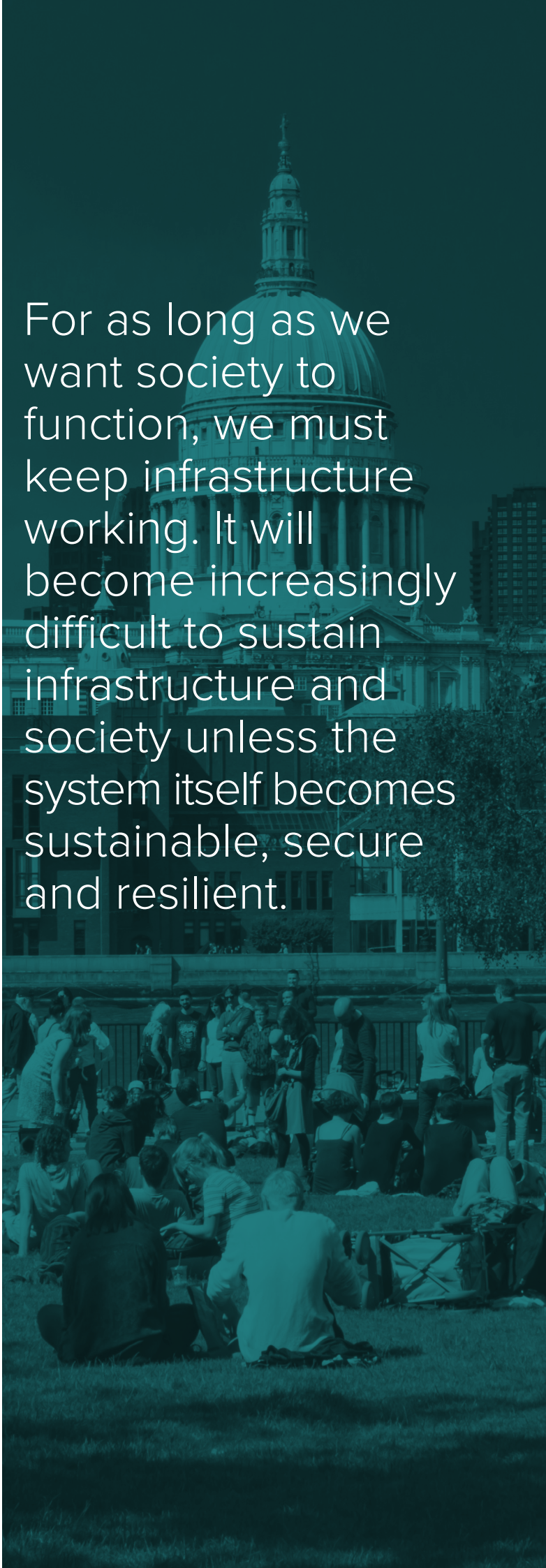
Where infrastructure systems have failed it hasn't taken very long for effects to cascade, knocking out critical services and, in some instances, challenging social order. Examples include the flooding of Lancaster, UK, during Storm Desmond in 2015⁵, the impact of Hurricane Katrina on New Orleans, USA, in 2005, and the failure of municipal waste management in Athens, Greece, in 2010⁶. In its 2020 Global Risks Report (and consistently for the last decade), the World Economic Forum places the failure of critical infrastructure among the top 10 risks to the global economy, ranked by likelihood and severity of impact⁷.

There has been modest progress in reducing infrastructure carbon emissions. Parts of the industry have recognised that reducing carbon can reduce cost⁸ – leading practitioners are achieving in excess of 60% carbon savings on capital investment programmes and 30% in operation. Yet, beyond a handful of pioneering companies, engagement is low.

We have even further to go on resource efficiency and moving towards a circular economy.

Digital technology can help here, enabling us to:

- manage assets through their lifecycles
- manage material resources through many lifecycles – a key enabler of the circular economy in infrastructure
- understand and manage complex trade-offs that are required between sectors – for example, to achieve net-zero greenhouse gas emissions



For as long as we want society to function, we must keep infrastructure working. It will become increasingly difficult to sustain infrastructure and society unless the system itself becomes sustainable, secure and resilient.

Sustainable Development Goals

In 2015 the United Nations set out 17 global Sustainable Development Goals (SDGs) with 169 subtargets, almost three-quarters of which are directly or indirectly influenced by the provision of infrastructure⁹. Infrastructure can contribute significantly towards achieving the SDGs. But infrastructure itself must be sustainable. This requires us to consider how each asset-level intervention affects the system.



Infrastructure underpins sustainable development¹⁰

Infrastructure itself must be sustainable. This requires us to consider how each asset-level intervention affects the system.

Hard and soft solutions

Recognising that infrastructure is systems-based and interconnected reveals that 'soft infrastructure' is also necessary – frameworks and organisational structures to understand, plan, co-ordinate, manage and get more out of the systems, and make them sustainable. Soft infrastructure helps to protect hard infrastructure from failing, and to protect people from the consequences of failure.

Extrapolating from data on the construction industry¹¹, it is estimated that around 15% of the UK's workforce are employed in the built environment. For infrastructure to be sustainable, the people who sustain the system of systems must themselves be supported in their wellbeing and safety, their employment security and in the development of their capability.

Digitalisation

People perspective

We must ensure that, in harnessing the power of information and data, we deliver better decisions which lead to better outcomes for people and society.

Systems perspective

Make infrastructure a cyber-physical system to realise the benefits of digital transformation across the built environment.

Key message

Improved decision-making requires that digital assets be properly valued and managed. Without a systems view of infrastructure, we will not be able to access the full value of digital transformation.

Infrastructure must get smart

With the ongoing digital transformation of the infrastructure industry, we have the opportunity to deliver huge benefit for people – for whom infrastructure ultimately exists. Part of this is economic benefit, estimated at £7bn/year for the UK¹².

Digital transformation encompasses how we:


- function as organisations
- deliver new assets
- operate, maintain and use existing assets

Bringing digital and physical assets together creates cyber-physical systems – smart infrastructure. Effectively, this is applying the fourth industrial revolution to infrastructure¹³. Making better use of asset and systems data is central to this vision because better analysis of better data enables better decisions, producing better outcomes.

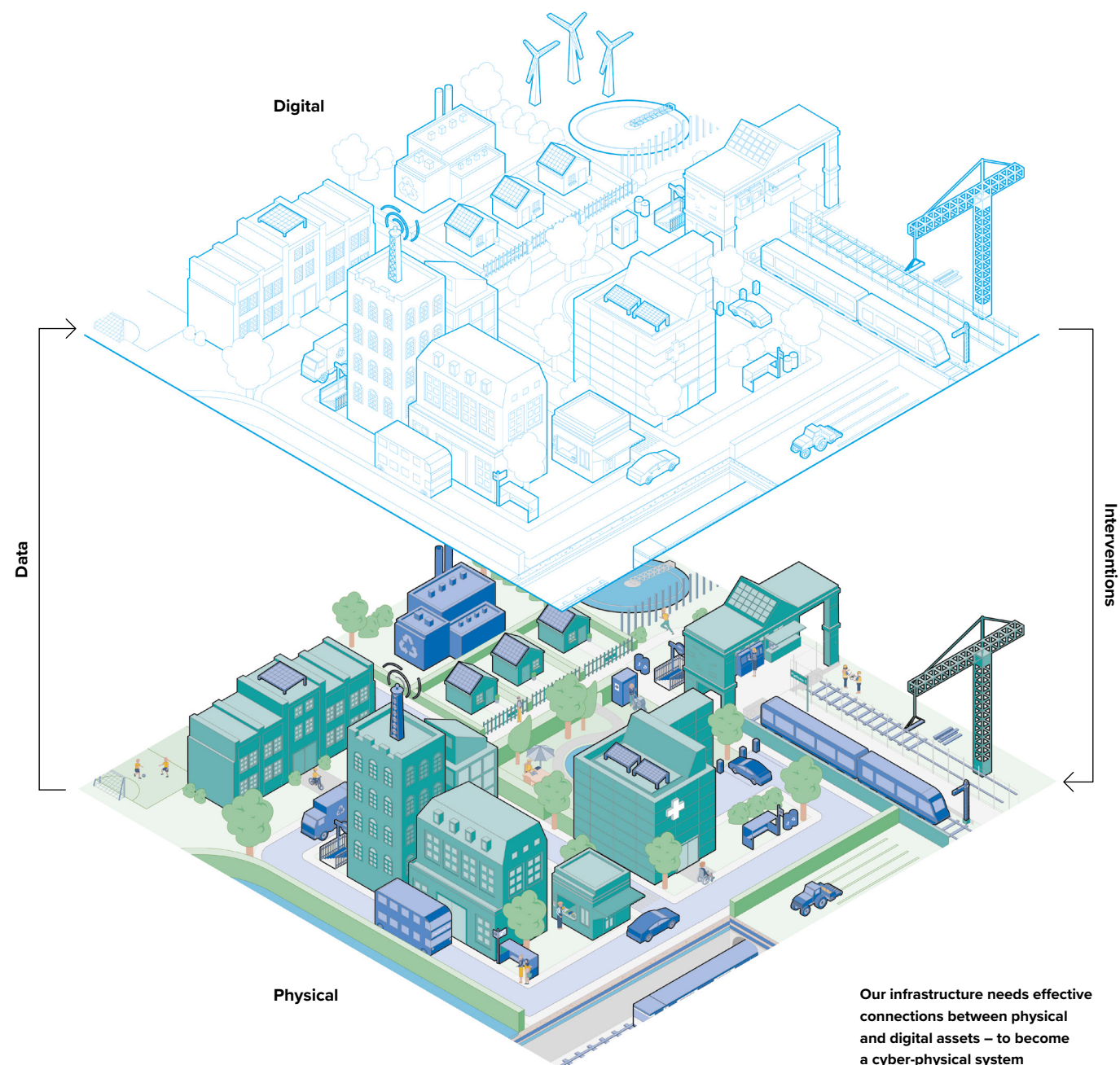
As part of this, we must recognise digital assets, such as data, information, algorithms and digital twins, as genuine ‘assets’, which have value and must be managed effectively and securely. In time, as data and digital assets become valued, data itself will be seen as infrastructure¹⁴.

Through better collection, curation and connection of data, we will create new digital assets of value for owners, operators and end-users – society. And nations.

Accurate and accessible records of our infrastructure and built environment will aid present and future decision-makers.



We must recognise digital assets, such as data, information, algorithms and digital twins, as genuine ‘assets’, which have value and must be managed effectively.



Twins that talk

Managing complex interconnected systems requires appropriate tools. Digital twins (see box) have been used successfully in the manufacturing and aerospace industries for this purpose and they promise to release similar value in infrastructure¹⁵.

Through secure data sharing, digital twins can be federated to help us monitor, understand and make more informed decisions across infrastructure networks and sectors. ‘National digital twins’, envisaged as ecosystems of connected digital twins, have the potential not just to mirror, but also to help manage and get more from the system of systems that is national infrastructure.

Transformation is within reach

We are at a point where the vision for effective digitalisation of the whole of the built environment is no longer an impossible dream. In the UK:

- The increased adoption of building information modelling (BIM) enabled by the UK BIM Framework¹⁶ lays an excellent foundation in information management for the industry.
- Soon, technologies such as the internet of things, artificial intelligence, and augmented and virtual reality could be integrated within digital twins to support decision-making.
- The Information Management Framework¹⁷ is being developed – an industry standard for creating interoperable systems data, which will make secure, resilient data sharing between organisations and across sectors achievable. The framework is key to unleashing the information economy and achieving federated digital twins – and ultimately the National Digital Twin¹⁸.

National data strategies must address infrastructure data – how to ensure that data from assets and systems in the built environment is used to create value for the public good. Such strategies should encourage secure, resilient data sharing across organisational and sector boundaries, including within government. In tandem, national infrastructure strategies must address digital as well as physical assets.

As our built environment and the wider economy become more information-based, associated soft infrastructure will be required to keep pace. In particular, new frameworks, organisational structures and business models will be required to understand, plan, manage and regulate cyber-physical infrastructure and the related data infrastructure.

National digital twins – ecosystems of connected digital twins – have the potential not just to mirror, but also to help manage and get more from the system of systems that is national infrastructure.

Digital twin – a realistic digital representation of assets, processes or systems in the built environment; what makes it a twin is the data connection between digital and physical.

Information management framework – a proposed framework to enable effective information management in the built environment. Its intent is to help put the right information in the right hands at the right time to make the right decisions.

Interoperability – the ability of two or more systems to exchange information and to use the information that has been exchanged.

Next steps

1. Industry vision

- Recognise infrastructure as a system of systems that provides a platform for human flourishing.
- Re-envision the infrastructure industry accordingly and socialise a people-focused, systems-based view of infrastructure.

2. National infrastructure strategy

- Develop national infrastructure strategy¹⁹ so that it provides a systems-based view of infrastructure and addresses both existing and proposed infrastructure.
- Provide strategies that advance digitalisation and address digital as well as physical assets.

3. National data strategy

- Address infrastructure data when developing national data strategy²⁰, so that data from assets and systems in the built environment is used to create value for the public good.
- Provide strategies that support secure, resilient data sharing across organisational and sector boundaries, within and beyond infrastructure.

4. Performance and resilience metrics

- Develop reliable national metrics for infrastructure to address its performance and resilience as a system and as a service.
- Develop understanding of the relationship between infrastructure performance and key social, environmental and economic metrics.

5. Sustainability

- Develop system-based tools, such as connected digital twins, to inform and enable strategies for addressing systemic challenges.
- Address resource use and efficiency, making a deliberate move towards the circular economy in infrastructure.

Contributors, consultees and reviewers

Sister Margaret Atkins – Canonesses of St Augustine
Dr Barry Blackwell – Department for Business, Energy & Industrial Strategy
Alexandra Bolton – Centre for Digital Built Britain
Prof Denise Bower, OBE – Mott MacDonald
Prof Tim Broyd – University College London
Dr Gemma Burgess – University of Cambridge
Amelia Burnett – Centre for Digital Built Britain
Simon Duddy – Office for National Statistics
Matt Edwards – Anglian Water Services
Mark Enzer – Mott MacDonald and Centre for Digital Built Britain
Dale Evans – DE Advisory and Infrastructure Client Group
Simon Evans – Arup and IET Built Environment Panel
Prof Mark Girolami – University of Cambridge and Alan Turing Institute
Prof Jim Hall – University of Oxford
Mark Hansford – Institution of Civil Engineers
Fergus Harradence – Department for Business, Energy & Industrial Strategy
Sarah Hayes – Independent consultant
Dr Anne Kemp, OBE – Atkins and UK BIM Alliance
Prof Roger Kemp – Lancaster University and IET Energy Policy Panel

Nirmal Kotecha – UK Power Networks and Infrastructure Client Group
Alex Luck – Alex Luck Associates
David McKeown – Institute of Asset Management
Andy Mitchell, CBE – Tideway and Construction Leadership Council
Richard Petrie – buildingSMART International
Dr Tomas Sanchez Lopez – Office for National Statistics
Dr Jennifer Schooling, OBE – University of Cambridge, Centre for Smart Infrastructure & Construction
Kerry Scott – Mott MacDonald
Miranda Sharp – National Digital Twin Programme
Sam Stacey – Innovate UK
Davide Stronati – Mott MacDonald and World Federation of Engineering Organisations
Neil Thompson – Atkins and IET Built Environment Panel
Will Varah – Infrastructure & Projects Authority
Hannah Vickers – Association for Consultancy & Engineering
Keith Waller – Construction Innovation Hub
Robin Webb – Department for Business, Energy & Industrial Strategy
Prof Jennifer Whyte – Imperial College London, Centre for Systems Engineering & Innovation
Melissa Zanocco – Infrastructure Client Group

Designer: Lex Wilson – Mott MacDonald
Editor: Andrew Mylius – Mott MacDonald
Illustrator: Alice Hunt – AliceHuntDesigns

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Comment on Flourishing systems
enquiries@cddb.cam.ac.uk

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