A Systems Approach for Ensuring Carbon Neutral Constructions and Improving Construction Productivity

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Objectives of the Talk

- To demonstrate how construction productivity and sustainability could be improved using a Systems approach.

- To introduce a range of research and innovation in construction materials and technologies which could improve construction productivity and carbon footprint.

Outline of Presentation

- Productivity and environmental challenges in the construction industry
- Justifications for a Systems approach to deal with the challenges
- Building productivity and sustainability through technological innovations
  - ✓ ICE Low Carbon Concrete Routemap
  - ✓ Precasting and 3D printing
  - ✓ Construction robotics, Artificial Intelligence & construction informatics
  - ✓ Structural Health Monitoring and whole life management of infrastructure
- Concluding remarks and recommendations

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The Productivity Gap – A Historic Fact

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AVERAGE VALUE ADDED BY EMPLOYEES PER HOUR WORKED

Global economy

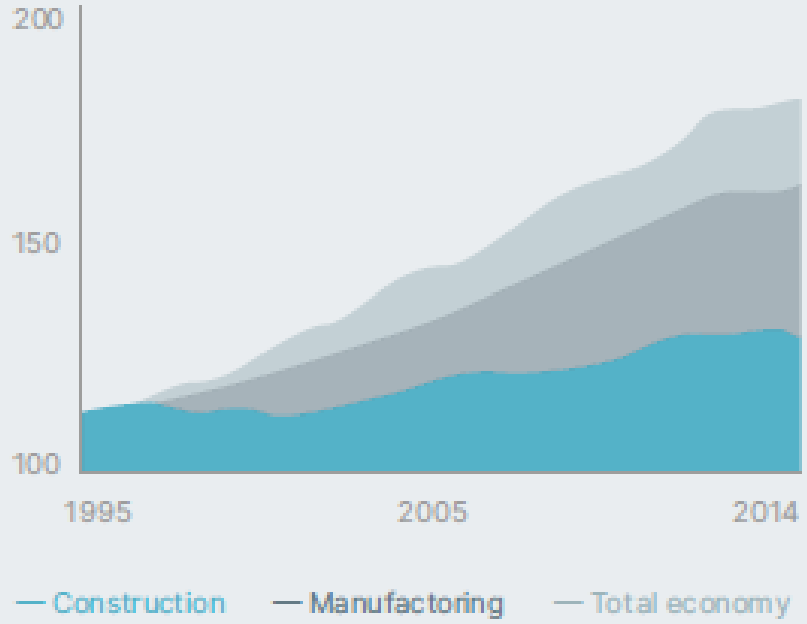
$37/hour

Global construction sector

$25/hour

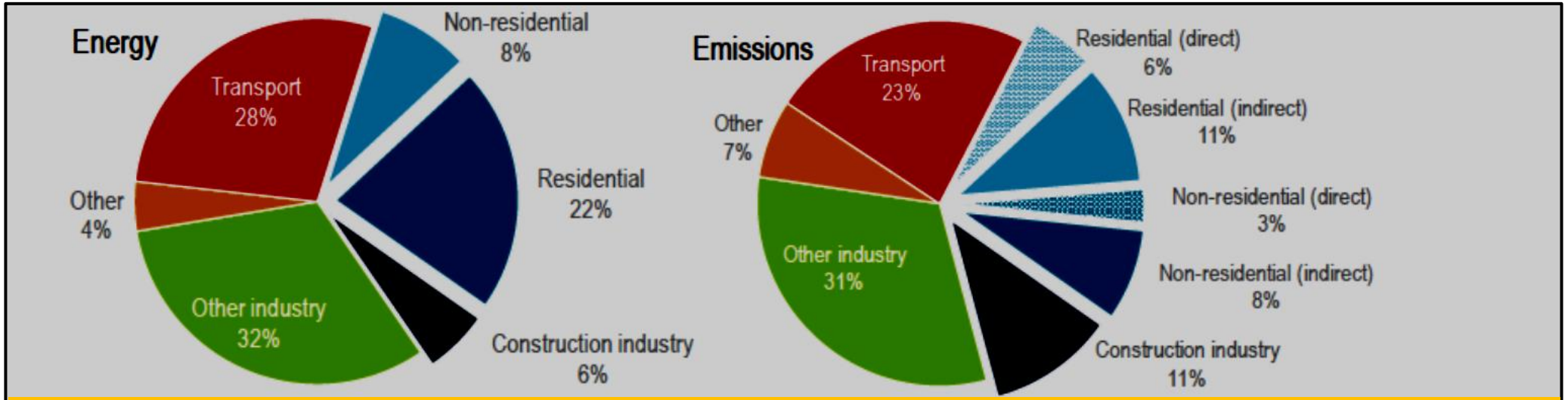
Productivity gap **$1.63 trillion**

GLOBAL PRODUCTIVITY GROWTH TRENDS



Sources:
McKinsey & Company, 2017;
Disperse, The new approach to Building Productivity, 2020

Global Share of Buildings and Construction Final Energy and Emissions, 2018



Source: Global Status Report for Buildings and Construction, International Energy Agency, 2019

Buildings and construction sector:

- 36 % of final energy use
- 39% of energy and process-related carbon dioxide emissions in 2018
- 11% of which is from manufacturing building materials and products such as steel, **cement (~8%)** and glass.

Net Zero Whole Life Carbon Roadmap for the Built Environment

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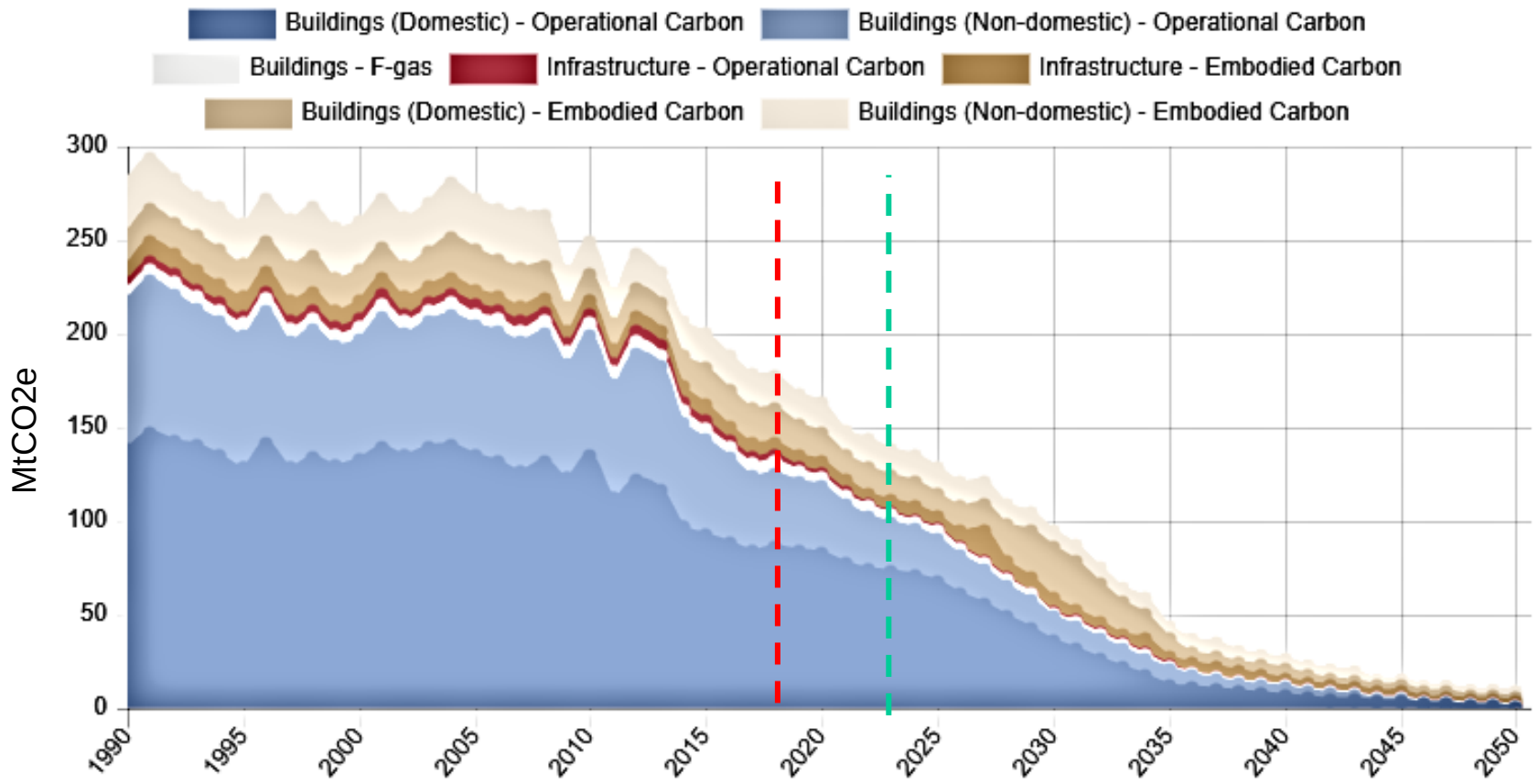
Historic (1990-2018) built environment emissions (MtCO2e) , alongside projected emissions from the built environment (2018 through to 2050)



Baseline year 2018

Current year 2023

Source:

https://www.ukgbc.org/ukgbc-work/net-zero-whole-life-roadmap-for-the-built-environment/

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Systems Approach to Infrastructure Delivery

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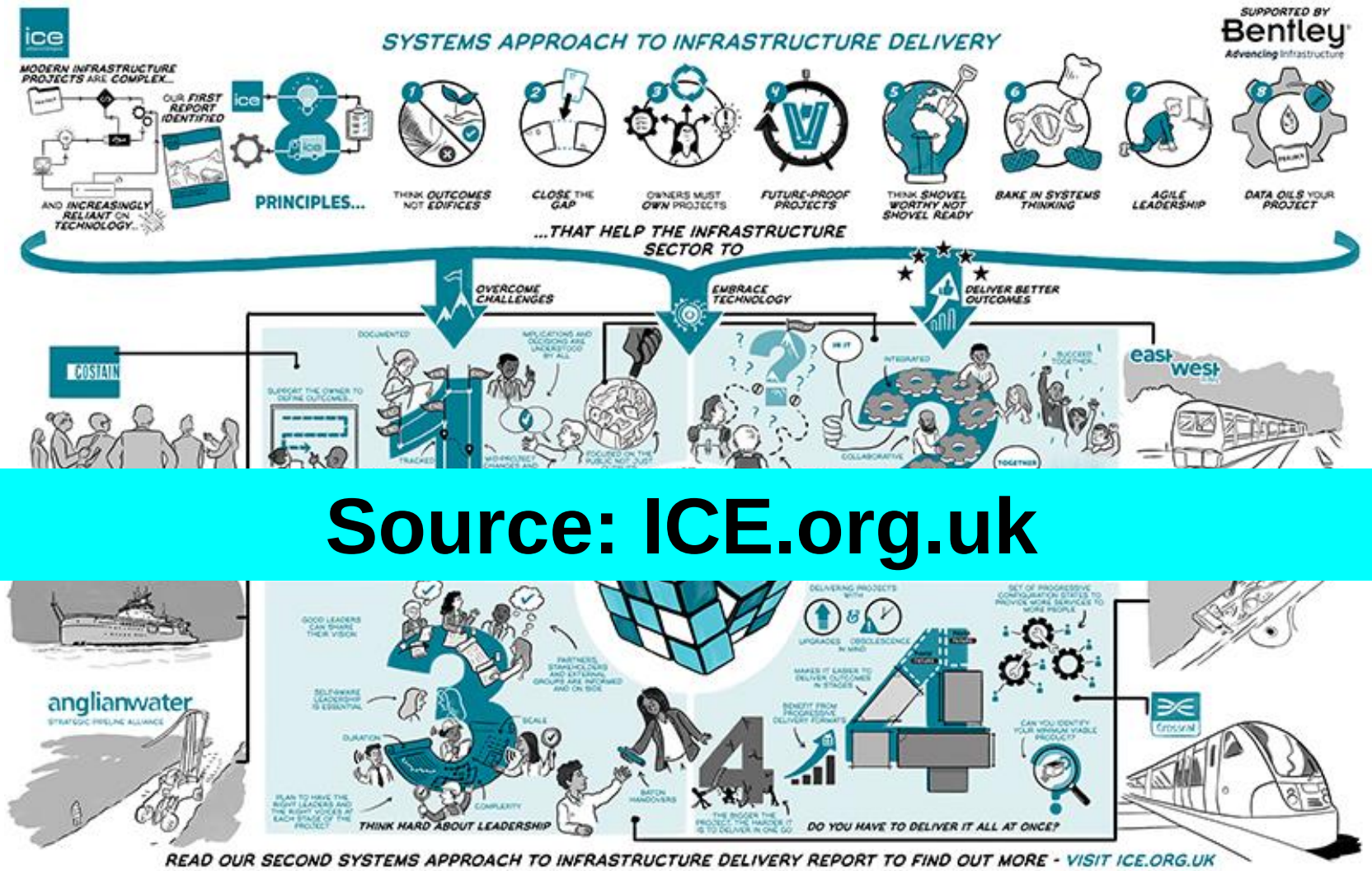


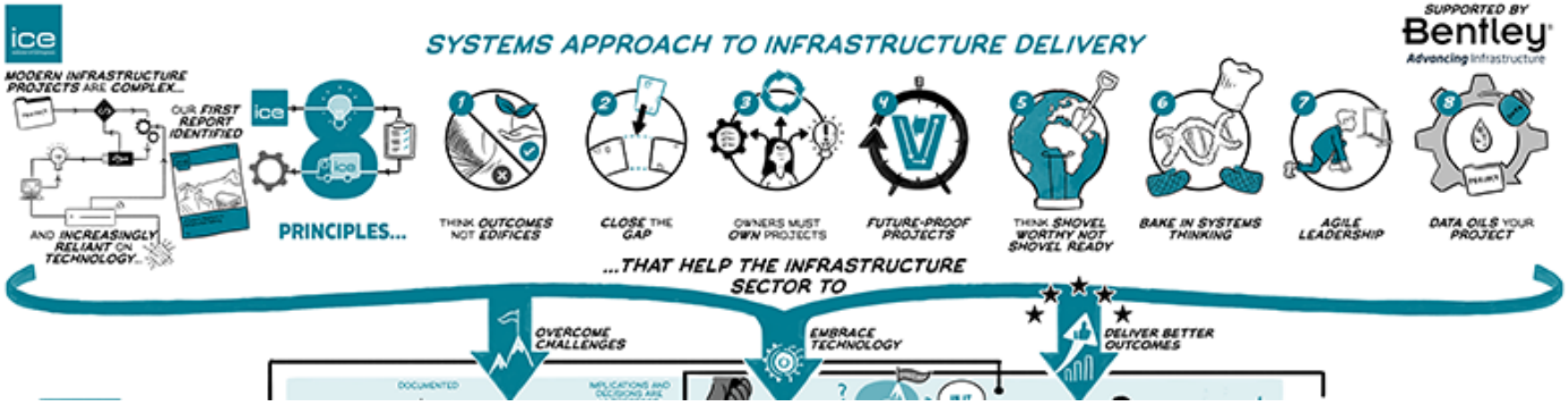
Source: ICE.org.uk

Systems Approach to Infrastructure Delivery

- **Systems thinking** embraces the idea that the whole is more important than the sum of its parts; that is, understanding of how all of the component parts of a project work together to meet a common objective.
- **Systems engineering** is the application of systems thinking to engineering design and management. It helps different teams working on individual components of projects to stay aligned to a common goal.
- **Systems integration** is the practical task of bringing together all of the components and taking them into service as a single, fully-functional system.
- **The 'extended system'** refers to the socio-political environment in which a project is to be delivered and the many – often hundreds – of stakeholders who can influence it.

Source: ICE.org.uk

Systems Approach to Infrastructure Delivery



Overcome challenges

Embrace technology

Deliver Better outcomes

Strategic Principles

1) Think outcome, not edifices
2) Close the gap
3) Owners must own projects
4) Future-proof projects
5) Think shovel worthy, not shovel ready
6) Bake in systems thinking
7) Agile leadership
8) Data oils your project

A SYSTEMS APPROACH WILL TRANSFORM HOW WE:

1) Conceive 2) Plan 3) Deliver & 4) Operate

Source: **ICE.org.uk**

Systems Approach to Infrastructure Delivery

Successful Case Studies in the UK

1) Tideway
2) British Antarctic Survey's Infrastructure Modernisation Programme
3) Crossrail
4) East West Rail
5) Anglian Water's Strategic Pipeline Alliance
6) Costain's systems approach capability

Cross-cutting lessons

1) Keep the end in mind throughout the project
2) Ensure we really are all in this together
3) Think hard about leadership
4) Do you have to deliver it all at once?

Source: ICE.org.uk

Principal Lesson

"Construction's traditional, 'heroic' style of leadership is not fit for purpose for modern projects – the sector needs to adopt leadership models that spread authority and empower highly competent individuals."

Source: ICE.org.uk

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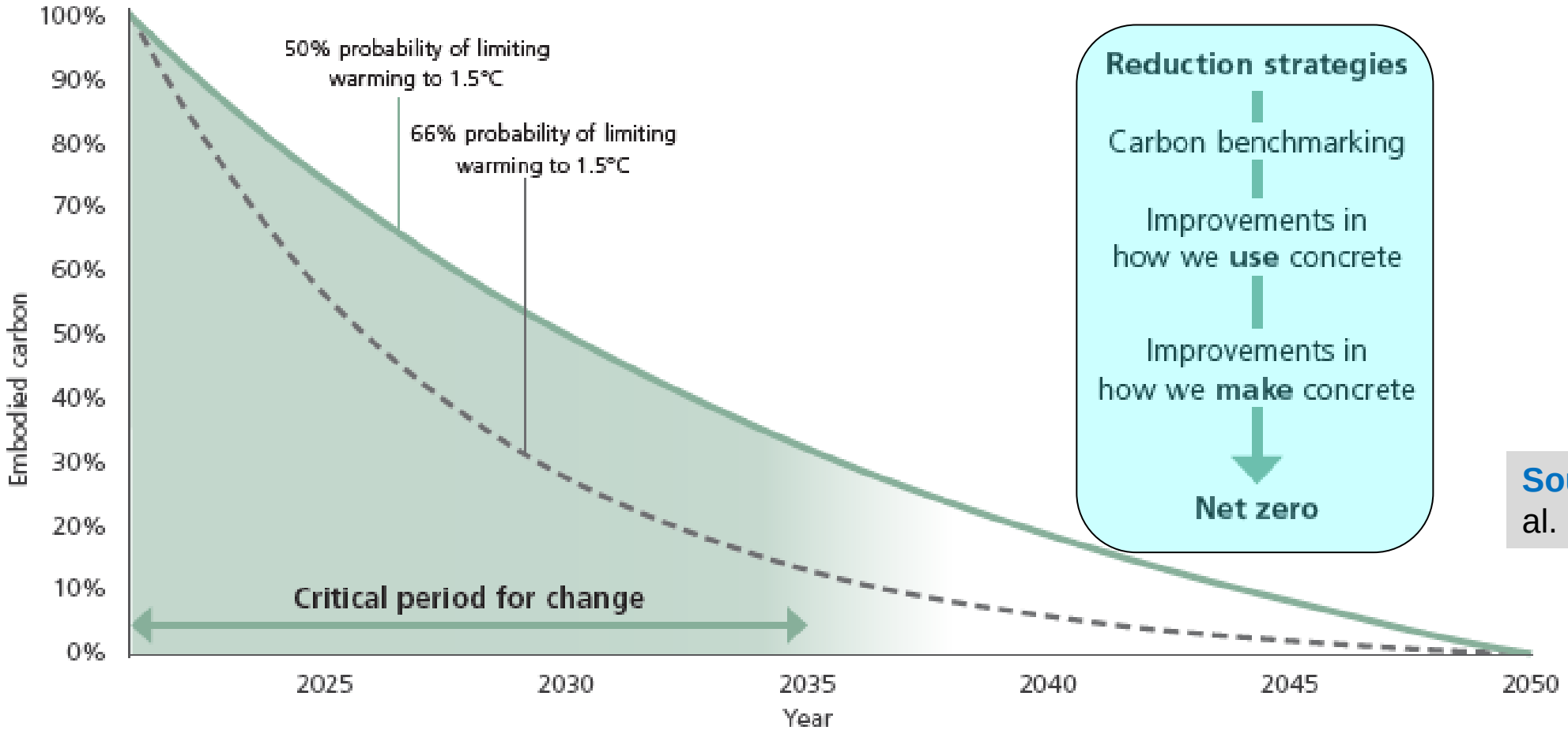
Institution of Civil Engineers Low Carbon Concrete Routemap

Goal: Net-zero concrete by 2050

Strategic focus areas:

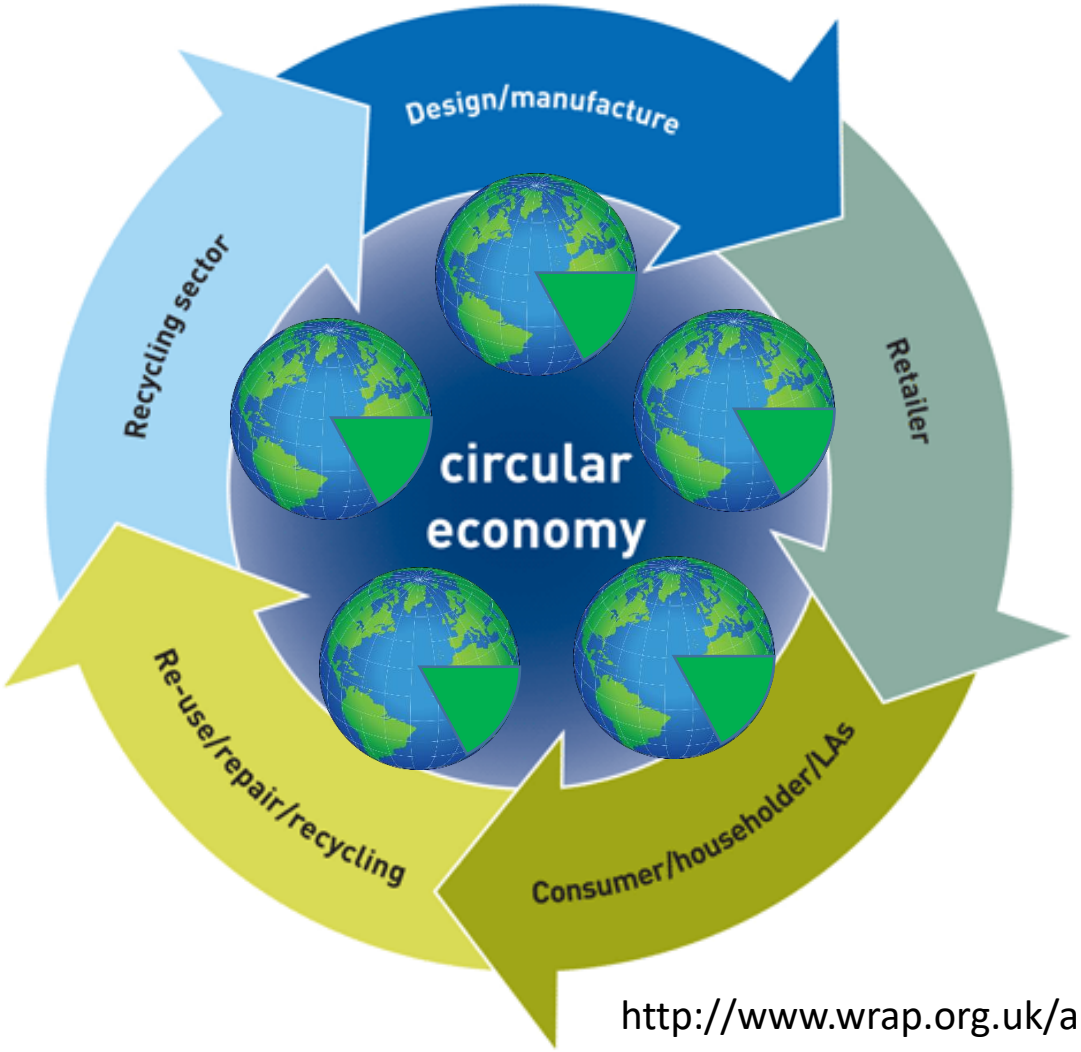
- Reduce the amount of concrete + rebar used
- Reduce the carbon intensity of concrete/rebar
- Sequester or offset the residual carbon

Idealised Reduction Rate for Embodied Carbon in Concrete



Source: Scrivener, K. et al. (2018) CCR 114, 49-56

Benefits of the Circular Economy



- ✓ Reduce waste
- ✓ Drive greater resource productivity
- ✓ Deliver a more competitive economy
- ✓ Position to better address emerging resource security/scarcity issues in the future
- ✓ Help reduce the environmental impacts of our production and consumption.

http://www.wrap.org.uk/about-us/about/wrap-and-circular-economy

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Flexi-Arch for Small to Medium Span Bridges

Tievenameena Bridge in Northern Ireland





Source: Macrete Precast Concrete Engineering, Northern Ireland

- Successfully constructed spans up to 18m
- Highly cost-effective and durable
- Instrumented bridges facilitate performance monitoring in service

Facilitating Factors

- High strength, high performance concrete
- Advances in admixture technologies
- Advances in fibre reinforced concrete
- Advances in prestressed concrete
- Advances in structural connections
- Better skilled construction workforce
- Introduction of whole life cost and life cycle analysis
- Better awareness of (concern for) sustainability

Practical Application of 3DPC

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3D printed building in Dubai (2019)

Source: businessinsider.com

3D printed neighbourhood in Houston, Texas (2022)

Source: BBC

Facilitating Factors

- Advances in materials technologies
- Building Information Models, Construction Robotics, Artificial Intelligence and construction informatics

Features

- The structure is built directly on-site
- Could use local materials
- Efficient in insulation to reduce energy consumption

Comparison Between Traditional Concrete Manufacturing Procedure and 3D Printing

- ✓ Free from formwork
- ✓ Less labour
- ✓ Saving in construction time
- ✓ Better working environment
- ✓ Less construction wastes
- ✓ Reducing risk of construction
- ✓ Reducing energy consumption
- ✓ Reducing the cost…..

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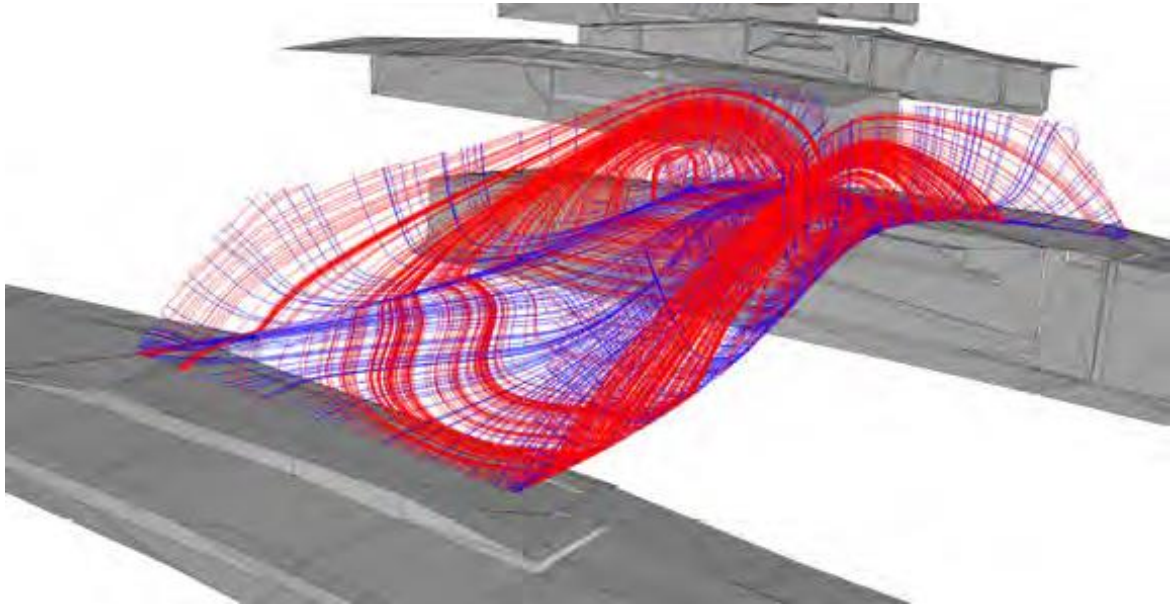
MX3D Bridge, Amsterdam, Netherlands

The world's first robot-printed steel bridge pushes the boundaries of 3D design:
Stijn Joosten, Shibo Ren, Paul van Horn, Mathew Vola



Source: The Arup Journal, Issue 1, 2022

The New Normal: Construction Robotics

Market Drivers

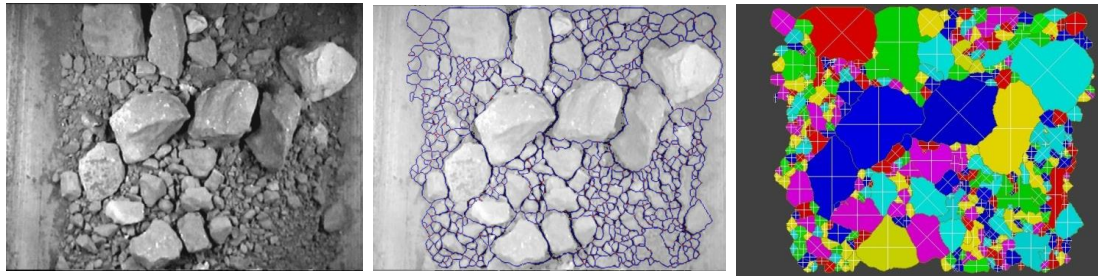
- ❖ High level of construction and growth expansion activities
- ❖ Unsafe environment, injuries to labour
- ❖ Uncertainties, such as COVID-19 Pandemic

Typical Construction Activities Using Robotics

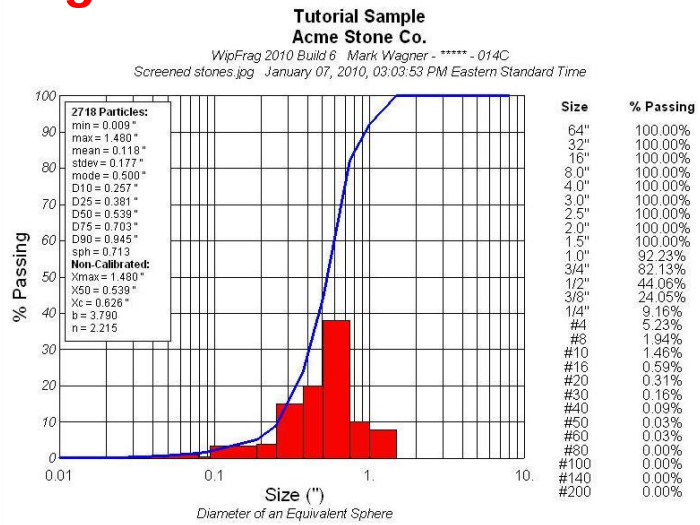
- ✓ Structural demolition
- ✓ Bricklaying
- ✓ Assembling prefabricated components
- ✓ Welding arms
- ✓ Construction of road pavements
- ✓ Unlocking of design possibilities
- ✓ Aerial surveys

Virtual Sieve Analysis

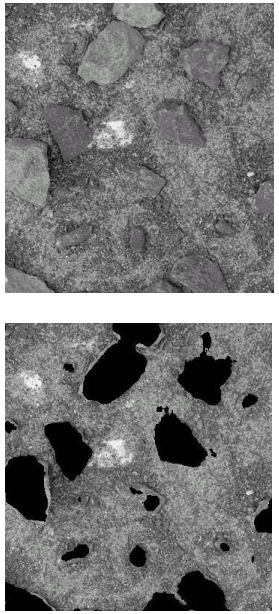
Image based characterisation of sand/gravel/concrete



Source: Murtagh, F., et al. (2004), British patent application No. 0408632.8



Optical Granulometry



Benefits

- Better understanding of the raw materials while they are in the conveyor belt in plants
- Reduced energy demand due to machine controlled characterisation of materials – recycled raw materials
- Increased packing density - concrete
- Reduced cement consumption – concrete/asphalt
- Greater quality control and confidence

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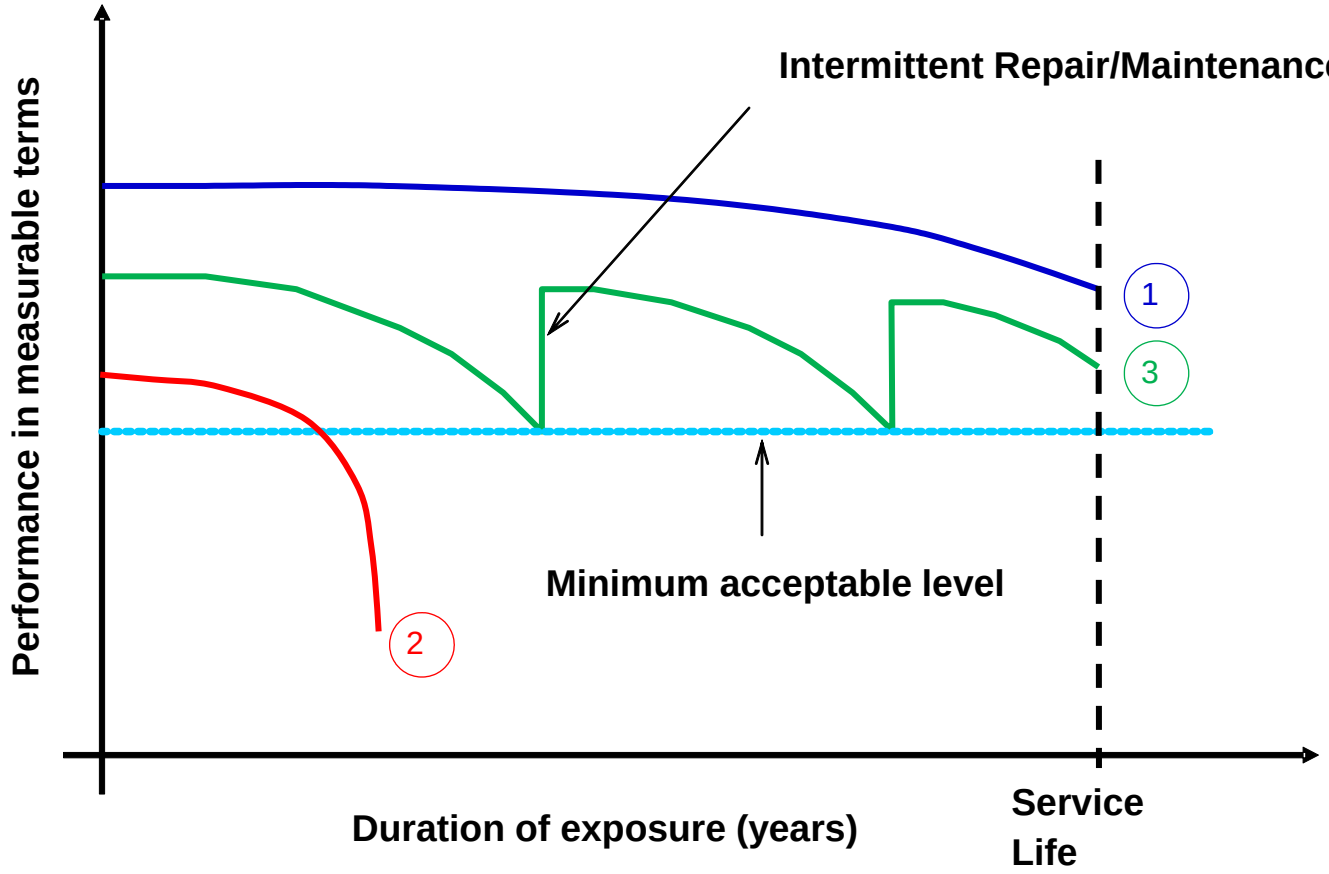
Rationale for SHM



- Early age detection of problems
- Timely intervention and management of infrastructure

An Example of SHM Project

Hangzhou Bay and the Bridge

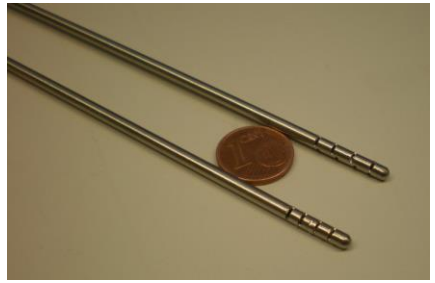
Hangzhou Bay bridge connects Jiaxing and Ningbo municipalities of Zhejiang province, China.
35.6km (22 mile) long.
Wave height 9m, wind speed >30mph.

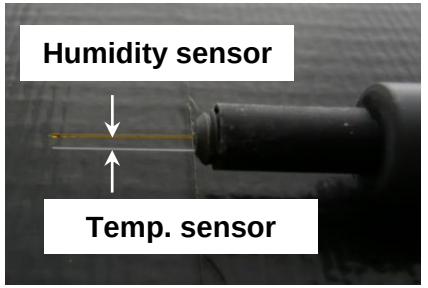
Monitoring station located at the service centre

Sensors Used in Projects

Fibre Optic Sensors

- Temperature
- RH
- pH
- Chlorides
- Strain



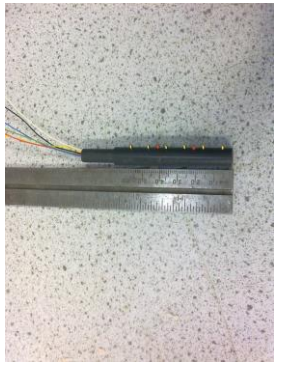


Humidity and Temperature

pH and Chloride

Electrical Resistivity Sensors

- Moisture movement
- Chloride ingress
- Carbonation
- Corrosion



Data Collection and Modelling

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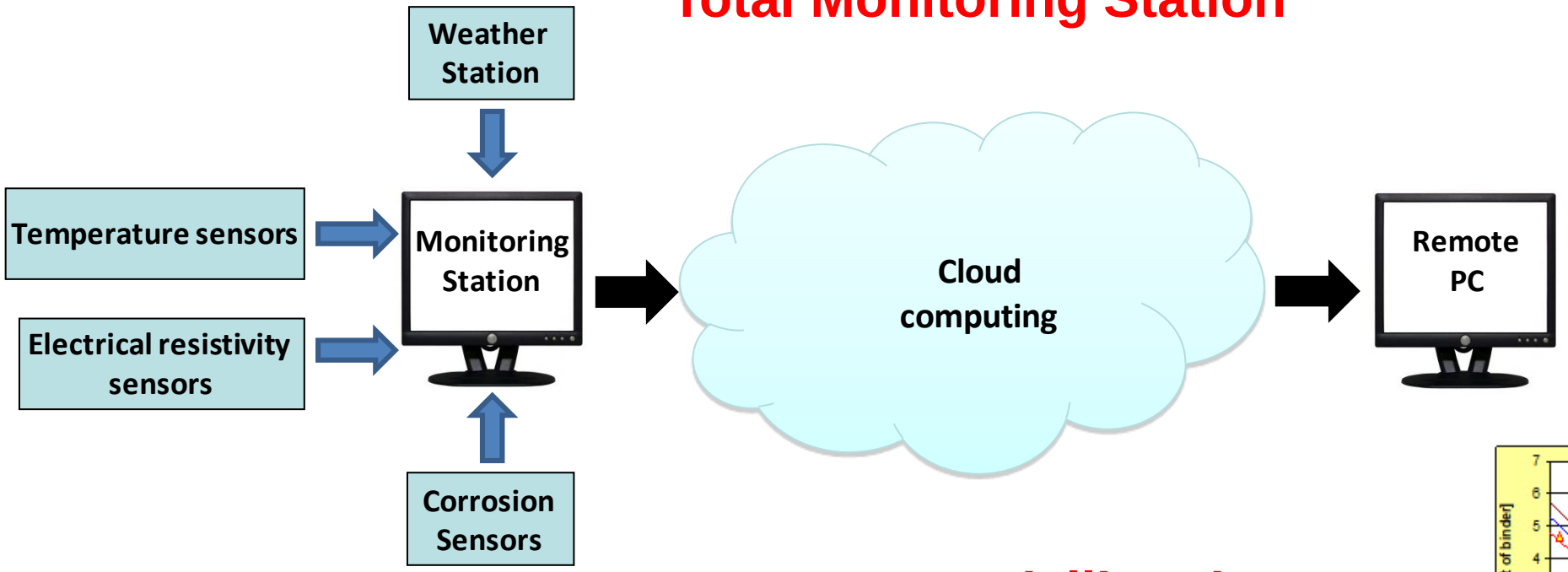
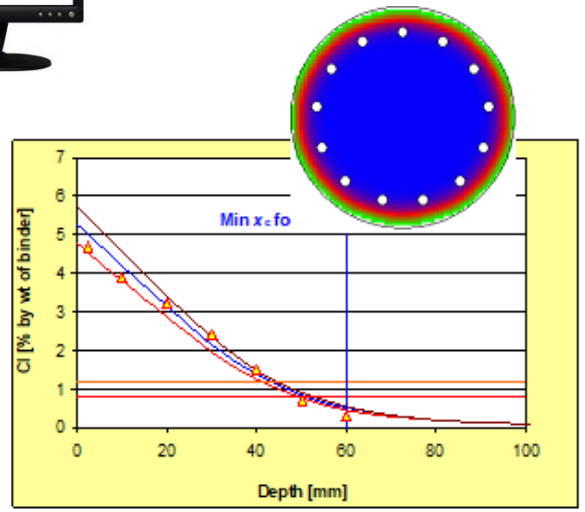
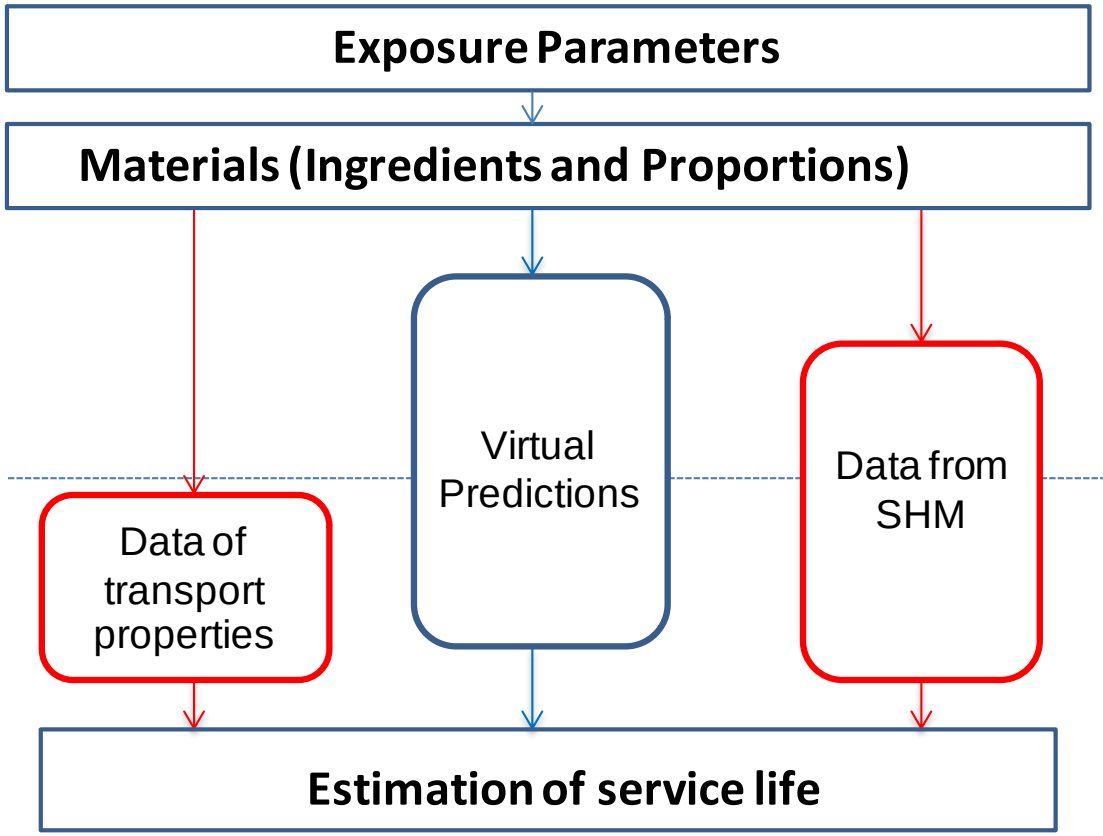
Total Monitoring Station



Modelling the Service Life using *in situ* data



Models for Predicting the Performance



Service Life Models

Fresh state

Hymostrut
µiC
Stadium
NIST

Hardened state

Life365
Stadium
NIST
ClinConc
Duracrete

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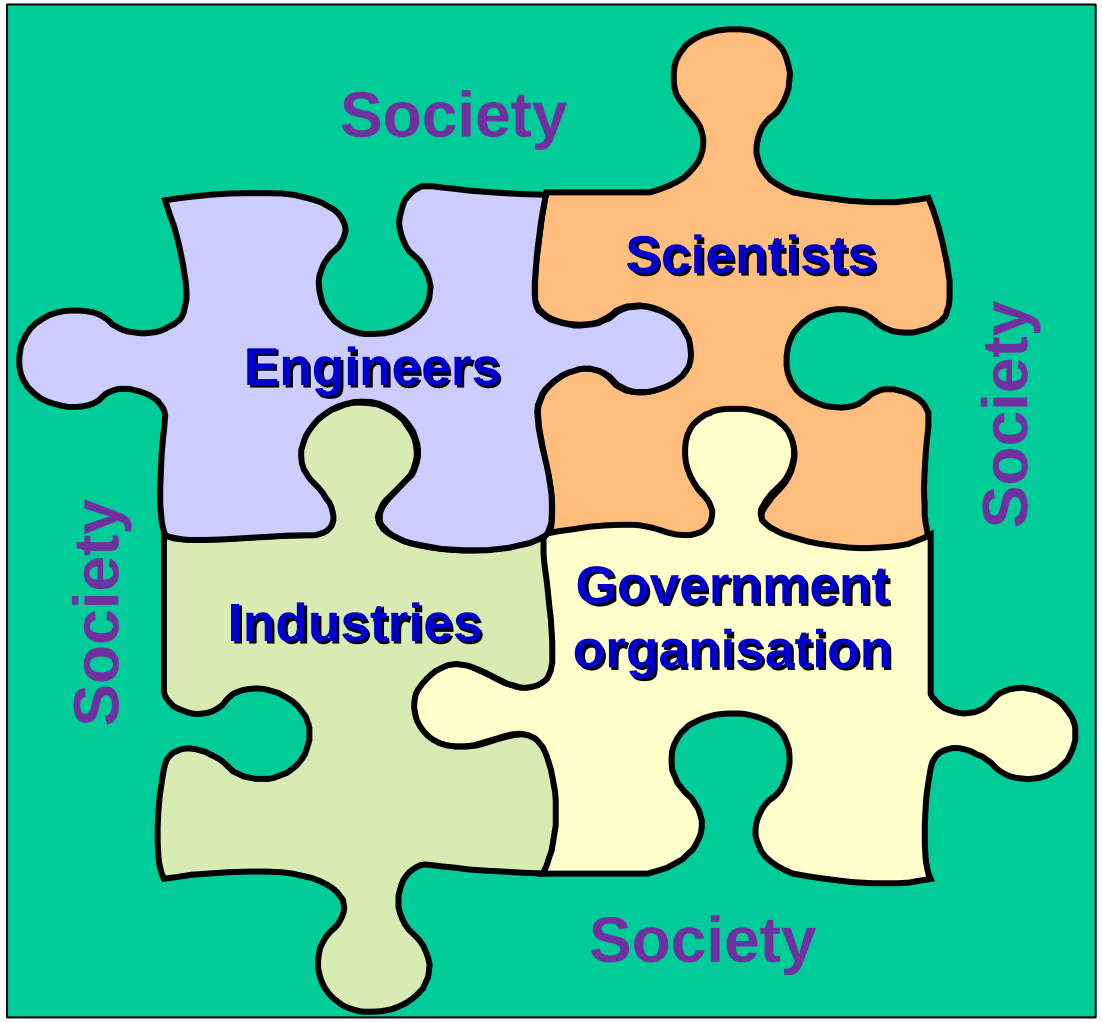
Stakeholders for Sustainable and Productive Constructions



Key Challenge

Bring together relevant stakeholders responsible for sustainable and productive constructions

AND

Build on this to develop practical approaches to deal with sustainability and productivity

By resorting to a Systems approach.

Systems Approach to Productivity and Sustainability

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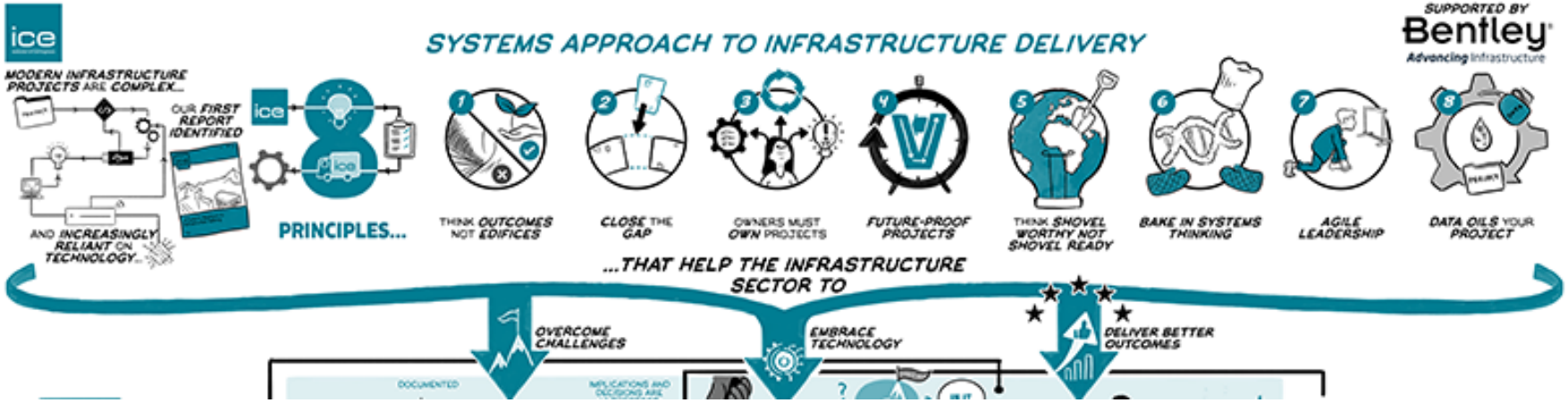

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Source: ICE.org.uk

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The systems approach could be applied to improve also the productivity and sustainability of civil infrastructure projects.

Thank you; Any Questions?

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