Cyber-Physical Infrastructure in context: Making sense of the technology landscape

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DISCUSSION PAPER

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Introduction

Policy makers and business leaders need a clear grasp of the rapidly evolving relationships between physical and digital networks and related investments, if they are to deliver productivity, growth, and value to society. The terminology that is growing up around these new technologies can become both complex and exclusive, making it hard to innovate and collaborate across these new and shifting technology, business, and language boundaries.

This document provides clear, concise explanations of the key domains that sit under the broad umbrella of Cyber-Physical Infrastructure (CPI) : networks of interconnected physical and digital systems that are capable of collecting, analysing, and exchanging data in real-time. In November 2023 the UK Government placed new emphasis on such infrastructures[1]:

> *"Cyber-physical systems connect the physical and digital domains. Data shared between physical system their digital counterparts produce insights and feed decision-making: from scenario modelling and collaboration across locations and platforms, to optimisation and even autonomous operation.* ***They are increasingly widespread and have societal, environmental and economic benefits that are significant in the short term and are expected to be globally transformational in the longer term, as network effects build****."*

The use of the term infrastructure is important because it focusses us on the value created *through* these new ways of organising both physical and digital assets, often across multiple organisational boundaries. By thinking of assets and systems as infrastructures[2] we draw attention to their multiple enabling roles, and so must address the different purposes and value creating agendas that should be considered as they are funded, designed, and brought into existence.[3]

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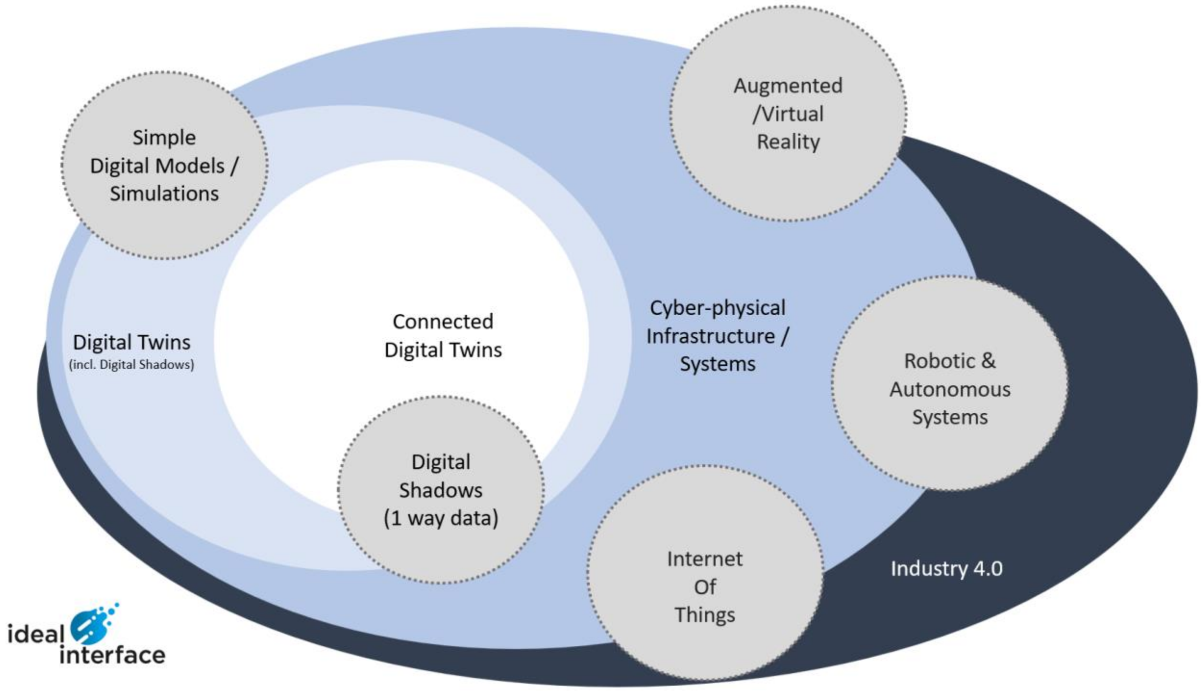
[1] The full text of this government consultation response can be found here: https://www.gov.uk/government/consultations/enabling-a-national-cyber-physical-infrastructure-to-catalyse-innovation/outcome/enabling-a-cyber-physical-infrastructure-to-catalyse-innovation-government-response-html

[2] The need to study and understand infrastructures has never been greater. We do not have time to address this topic in depth here, but reference four useful papers that look more closely at the nature, purpose and study of infrastructure (Edwards, Bowker, Jackson, & Williams, 2009; Gray, Gerlitz, & Bounegru, 2018; Larkin, 2013; Ribes & Finholt, 2009).

[3] The Digital Twin Hub's Governance & Trust Working Group produced this executive summary that extends the Gemini Papers' work on value and purpose: https://eprints.lancs.ac.uk/id/eprint/206098/1/Digital_Twin_Hub_-_Executive_Summary_Governance_and_Trust_WG_.pdf This in turn draws on the ideas in this discussion paper: https://eprints.lancs.ac.uk/id/eprint/210385/7/Digital_Twin_Ecosystems_-_Purpose_Value_and_Trust_-_Discussion_Paper_-_FORD_-_2023.pdf

Mapping the technology landscape

The figure below offers a simple visual representation of the current technology landscape, showing how different aspects of CPI relate to each other or overlap:



Cyber-physical infrastructure (CPI)

Cyber-Physical Infrastructure (CPI) describes a collection of digital and physical features of a system, joined by a network of physical and digital linkages, that together are capable of collecting, analysing, and exchanging data, sometimes in real-time. At their most useful and functional, they can be used for the creation of intelligent systems that can make autonomous decisions and respond to changes in their environment.

Individually, a system of linked assets is not necessarily an infrastructure: Only when we build an ecosystem of networked systems could it be an infrastructure on which future products, services and decision-making processes are built – i.e. a Cyber-Physical Infrastructure. These interconnected systems and the architectures, tools, platforms and data that underpin them, can enable faster and cheaper innovation by providing the building blocks for innovators to design, test, build and connect their solutions more easily.[4]

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[4] This description is adapted from the UK Government's explanations of CPI, available here: https://www.gov.uk/government/consultations/enabling-a-national-cyber-physical-infrastructure-to-catalyse-innovation/outcome/enabling-a-cyber-physical-infrastructure-to-catalyse-innovation-government-response-html

Simple digital models

Simple digital models or simulations are more limited technical representations of a system or object. They are typically less complex than a Digital Twin and can be used to demonstrate a single scenario or use case.

Digital Twins (DTs)

Digital Twin is an increasingly common term used to define a stand-alone virtual representation of a physical object, process, or system. DTs can be used to simulate different scenarios and situations, identify potential problems or constraints, and improve decision-making before implementing or making changes in the real world. Consequently, DTs can be utilised in a wide variety of sectors, not just the physical infrastructure industry, with their adoption and usage expected to increase over the next few years.[5]

They offer the following benefits to users:

- Improved decision-making: Digital twins can provide insights into the behaviour of physical objects and systems, which can help organizations make better decisions about how to design, operate, and maintain them.
- Reduced risk: Digital twins can be used to simulate different scenarios, which can help organizations identify potential problems and take corrective action before they occur.
- Increased efficiency: Digital twins can be used to optimize processes and systems, which can help organizations save money and improve productivity.

Digital Twins are widely regarded as a sub-set of Cyber-Physical Infrastructure because they utilise the same technological approach to simulations. However, they tend to be less complex, because their scope is usually limited to a specific asset or scenario.

Connected Digital Twins (CDTs)

Connected Digital Twins are an important sub-set of the wider Cyber-Physical Infrastructure ecosystem. A Connected Digital Twin integrates multiple data sources spanning a range of features or assets. By their very nature, they are designed to acquire (ingest) and provide (export) data, either in real-time or in a more scheduled batch approach, with other sources or Connected Digital Twins.

This sharing of data enables more systemic and comprehensive modelling (for example, whole transport networks, complete river catchments). Such an approach to data sharing increases their

[5] Global Digital Twin Market … poised to reach $110.1 Billion by 2028
https://www.marketsandmarkets.com/Market-Reports/digital-twin-market-225269522.html

usefulness and value, for example in their representation of 'real world' scenarios or in creating consistency between different simulations, and consequently their outputs.

It is also possible, and beneficial, to share a range of alternative predictive scenario data with different Connected Digital Twins, to simulate alternative future behaviours or end results.

Digital shadows

The term Digital Shadow and Digital Twin can sometimes be used interchangeably, however there are differences between the two. When data is captured from a physical object or system and used to drive a Digital Twin, it is known as a Digital Shadow. A Digital Shadow therefore becomes a digital version of the present and past of that system, allowing it to be used for analysis & insight, not a tool for predicting future scenarios and outcomes.

Note: In some cases, a digital shadow can be used to create a Digital Twin. For example, data from a digital shadow can be used to calibrate a digital twin before it is then used for predictive purposes.

Industry 4.0

Industry 4.0 (the shortened version of the Fourth Industrial Revolution and sometimes alternatively referred to as 4IR), is a generic term used for explaining the ongoing automation of traditional manufacturing and industrial processes using modern digital technologies.

Industry 4.0 promises a range of benefits, including: Increased efficiency and productivity (e.g. Smart factories can run more smoothly and efficiently, with less downtime and waste), Improved quality control (e.g. Real-time data analysis can help identify and prevent quality issues before they occur), Enhanced innovation (e.g. Digital twins and simulations can help businesses develop new products and processes faster and more effectively) and Greater flexibility and adaptability (e.g. Smart factories can quickly adjust to changes in demand or market conditions).

Digital Twins play an increasing role in Industry 4.0 by creating virtual representations of physical assets, such as production lines, machines, or even entire factories. Connected Digital Twins use data from the real world and each other and therefore can provide better real-time monitoring and diagnostics, predictive maintenance, etc.

Internet of Things (IoT)

IoT is often described as a system of interrelated devices, which collect and exchange data. These devices can be anything from smartphones, smartwatches, and wearable devices to smart home appliances, industrial machinery, and vehicles. In the context of Industry 4.0, IoT plays a pivotal role in transforming manufacturing processes into intelligent, interconnected ecosystems. By leveraging

IoT-enabled devices, factories can monitor equipment performance in real-time, optimize production schedules, predict potential failures, and automate tasks, leading to increased efficiency, reduced downtime, and enhanced product quality.

IoT's impact extends beyond manufacturing, revolutionizing various sectors, including healthcare, transportation, and agriculture. In healthcare, IoT devices enable remote patient monitoring, improve medication adherence, and facilitate early disease detection. In transportation, connected vehicles enhance traffic management, reduce congestion, and pave the way for autonomous driving. In agriculture, IoT sensors monitor soil conditions, optimize irrigation, and enable precision farming, boosting crop yields and minimizing environmental impact.

Sometimes the term "Industrial Internet of Things" (IIoT) is used instead of IoT to describe a network of connected devices that enables the flow of data between physical assets and the digital world.

Augmented/Virtual Reality (AR/VR)

Augmented reality (AR) is an interactive experience that enhances the real world with computer-generated visual elements, sounds, and other stimuli. These elements can be overlaid onto the user's view of the real world, creating a composite that appears to be part of the real world. AR works by using a combination of sensors, cameras, and software to track the user's movements and surroundings. This information is then used to superimpose computer-generated graphics onto the user's view of the real world.

AR is different from virtual reality (VR) in that VR creates a completely artificial environment, while AR supplements the real world. AR can be used for a variety of purposes, including gaming, education, navigation, and product visualization.

Robotics & Autonomous systems (RAS)

Robotics deals with the design, construction, operation, and application of robots. Robots are machines that can perform tasks autonomously or with minimal human input. They can be programmed to perform a wide range of tasks, from simple repetitive actions to complex decision-making. Autonomous systems, on the other hand, are systems that can operate without human intervention. They often rely on sensors, artificial intelligence, and machine learning to perceive their environment and make decisions.

Examples of autonomous systems include self-driving cars, drones, and autonomous robots. Industry is therefore unsurprisingly witnessing a surge in the adoption of Robotics and Autonomous systems across and increasing number of purposes.