Gemini Papers: What are connected digital twins?

cdbb

Executive Summary

This paper is the first of three, addressing the What, Why and How of ecosystems of connected digital twins. Together, these papers are our legacy to those who will carry the baton into the future.

This What paper describes key terms and concepts essential to building on CDBB's work to date. In reading this report you will understand:

- What we mean by a digital twin;
- What a system of systems approach is;
- What we mean by connected digital twins;
- What is the role of connected digital twins within and across sectors; and
- What the Gemini Principles are and the role they play.

Some of the most challenging problems and exciting opportunities lie at the intersections between human behaviour and technological innovation. Our work proves that connected digital twins are essential tools to address such challenges. Through consultation and collaboration with partners across government, academia and business, CDBB has identified the requirements for a common framework to create shared data connections between digital twins, that will span organisations, sectors and structures, to inform better outcomes for people and nature. This paper lays out a consensus-built understanding of the building blocks fundamental to this approach.

We know that, when done right, infrastructure serves as a platform to connect the built environment, the natural world and human world in a way that allows all three to thrive. Systems thinking provides a useful way to help us understand and embrace this world of opportunity. Sharing data enables us all to break down silos and look at problems from a holistic view, crucial to alter the course of climate change through collaborative responses. We are confident that, by increasing the openness and availability of shared data between people, organisations, and institutions, we can generate better outcomes for people, society and nature.

Gemini Papers: What are connected digital twins?

Contents

What do we mean by a digital twin?

A digital twin is a digital representation of a physical asset, process or system[1]. It is distinguished from any other digital model by its dynamic connection to the physical twin. A digital twin unlocks value by supporting improved decision making.

Digital twins are tools that enable us to go through the information value chain more efficiently – turning data into insights that enable improved decisions and provide better outcomes.

Digital twins should not be constrained by definitions. They can connect to a variety of assets, processes, and systems using a variety of technologies, data types, data collection methods, analysis models, visualisation techniques and intervention types. The composition of a digital twin is driven by its use case and the purpose it serves.

The degrees of digitisation and digitalisation may also vary. By not constraining digital twins to a specific definition, we look beyond the potential complexity and realise their true value. Outside of the built environment digital twins are used in other sectors such as manufacturing, agriculture and the automotive industry. We recognise that each sector uses diverse digital twins in different ways and to a different scale.

Digital twins should be systems-based, purpose-driven and outcome-focused.

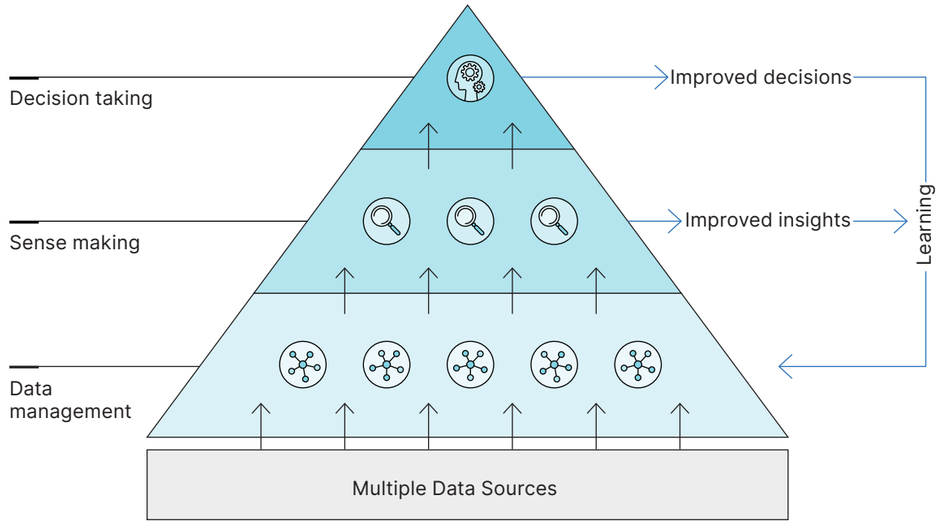

Figure 1. The information value chain: showing the connection between data and better decisions that lead to better outcomes

Describing the foundational elements of a digital twin[1]:

Physical part

The physical twin can be an asset, system or process.

It can be a tangible asset like a building or a bridge, a train component or a lake. It can be a process - a repeatable set of decisions - where a series of data collection, analysis and interventions can be monitored and managed by a digital twin. It can be a system where a collection of assets or processes come together to enable a service.

This demonstrates the relationship between assets and processes, where the interdependencies between these elements may otherwise be too complex to understand.

By looking at systems such as the built environment in holistic way a digital twin is more valuable than the sum of its parts.

Data feed

The data connection is a fundamental part of a digital twin. The data requirements are set by the purpose of the digital twin and the decisions it is enabling. The frequency, fidelity and extent of the data is variable; some twins may require real time data sharing while others may provide less frequent data updates. Data can come from multiple sources beyond the physical twin to better understand the context of a decision. Feedback is important to ensure that decisions are providing the desired outcomes therefore feedback is another key data feed.

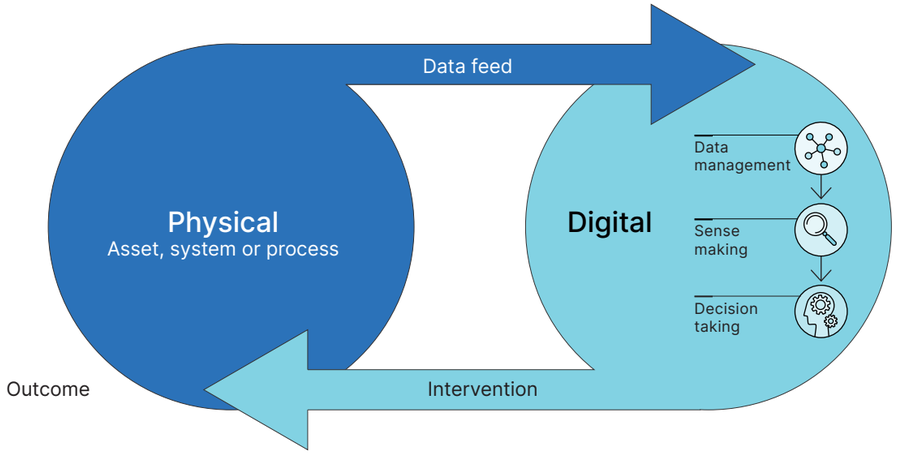

Figure 2. The foundational elements of a digital twin

Digital part

By bringing together the required data, analysing it through simulations or models and visualising it, the digital twin enables improved decisions and intervention on the physical twin. The type of visualisations depends on the use case, it can be as stripped back as displaying the raw data, a schematic representation, or it may be an immersive visual experience using virtual or mixed reality. Visualisations may just provide a window into an automated digital twin or aid a user in making more informed decisions. In other words, visualisation requirements are driven by how humans are featured in the loop.

Interventions and outcomes

Interventions is about delivering better outcomes. They are the product of the information value chain. Depending on the purpose of the digital twin, the intervention could be an automated process or a manual task. It can be a preventative measure to avoid an event, rectifying an issue or a reaction to an external action on the physical twin. An intervention can also be an evolution, where dynamic insights show the way to take action more efficiently, safely or sustainably.

What is a system of systems approach?

A system of systems approach applies systems thinking to the built and natural environment. A system is a connected collection of interrelated and interdependent parts; a complex whole that may be more than the sum of its parts. It is influenced by its environment, defined by its structure and purpose, and expressed through its function.

The built environment and infrastructure are 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[2].

The built environment is made up of economic and social infrastructure, which also involve political, institutional and commercial systems. In infrastructure and the built environment, we often understand the elements of a system, yet we struggle to manage it as a whole due to its inherent complexities. Connected digital twins are essential tools that help us understand and better manage this complex system of systems. We must adopt systems-based thinking to address systemic vulnerabilities. Within complex systems, there are always levers, or points of intervention, where a small shift can precipitate larger benefits.

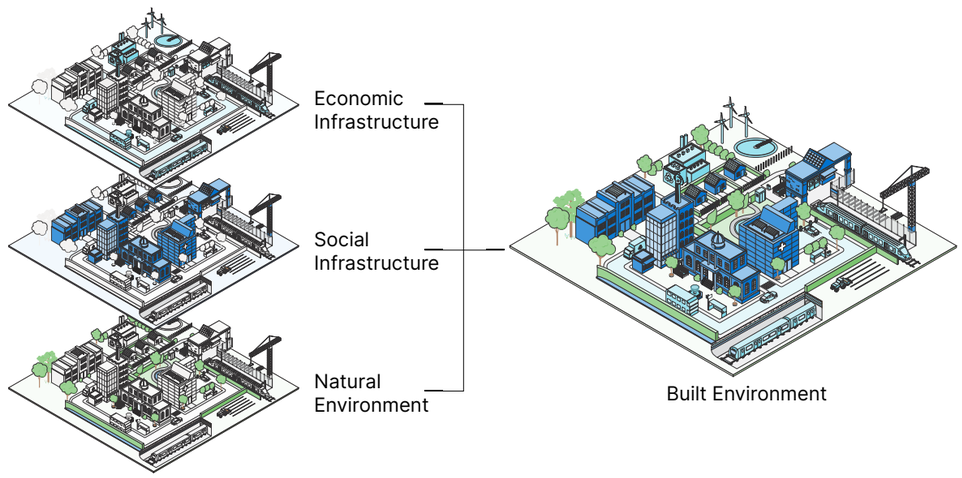

Figure 3. The built environment is an interconnected system of systems

Economic infrastructure

Economic infrastructure generates a substantial proportion of emissions. In the UK; energy, transport, waste and wastewater sectors accounted for over 66% of greenhouse gas emissions in 2019[3]. Economic infrastructure encompasses these sectors as well as telecommunications and water. The drive towards net zero is leading to new sectors such as hydrogen which requires new infrastructure. These assets and services are required to sustain economic activity, and all have a different degree of complexity which can be difficult to understand.

Social infrastructure

Social infrastructure includes services and facilities that meet local and strategic needs and contribute towards a good quality of life[4]. Social infrastructure can include homes, hospitals, schools, sports centres, religious facilities and commercial, industrial and residential buildings. They rely on economic infrastructure to operate and make up the most obvious part of our built environment.

Natural environment

The natural environment provides the foundations of the built environment, the economy, society and the planet. It is the original source of everything from fresh water and food to materials and medicine. It plays a critical role in regulating water cycles and temperature; buffering against extreme weather events; preventing the spread of disease; recycling nutrients and storing carbon; and ensuring the health and wellbeing of society.

Digital infrastructure

Digitalisation has led to a new digital infrastructure. Through connectivity, telecommunications and systems integration we can sense and connect almost to any physical item or structure, from household objects through to elements of a highway bridge’s structure. The rising number of systems containing physical and digital links creates scope for ecosystem of connected digital twins and complex cyber-physical systems characterised by automated decision taking or decision support using the collected data. This in turn can improve performance, service and add value locally and across the system.

What are connected digital twins?

Simply put, connected digital twins are digital twins that are connected across organisational and sectoral boundaries.

Connected digital twins, or federated digital twins as referred to by the Cyber Physical Infrastructure vision[5], are tools to understand the complexities of interconnected systems and provide better insights to enable better decisions and interventions.

Like systems in the physical world, digital twins can be connected to form a large, evolving ecosystem of connected digital twins. By sharing data across organisational or sectoral boundaries we can better understand interdependencies between systems and make smarter decisions. This is not possible using siloed thinking. CDBB has outlined a framework where shared data is used to inform - but not control - other digital twins within a connected network. This keeps members of the network safe from unwanted interventions. Data owners can push and pull information from the published digital twins and data users can request information in line with their needs.

Organisations that have developed an asset, system or process digital twin should be able to share their information with other organisations. Staying within a sector can reduce the number of barriers, as there are often fewer actors between which to build trust. However, it is not where the greatest value may be.

Connected across organisational and sectoral boundaries

An ecosystem of connected digital twins requires adoption of a common framework to share data across organisational boundaries. An Information Management Framework (IMF) outlined in the report 'The Pathway towards an Information Management Framework' sets out the requirements to enable meaningful, secure and resilient data sharing across organisation and sectoral boundaries. At a technical level what is needed is semantic interoperability across the systems of systems to enable an ecosystem of connected digital twins to grow.

Connected digital twins will also require social connections such as contracts. Highlighted as one of the key pillars in the Gemini Principles; trust is fundamental. Understandably, data owners can be protective of their data. It is important to help them understand the possibilities and value of an ecosystem of connected digital twins. Adopting a common framework for data sharing has many benefits such as minimised costs and friction across the ecosystem as it grows. Collaborating on the rules allows a larger market for connecting digital twins with a maximised public good.

Connected digital twins, are tools to understand the complexities of interconnected systems and provide better insights to enable better decisions and interventions.

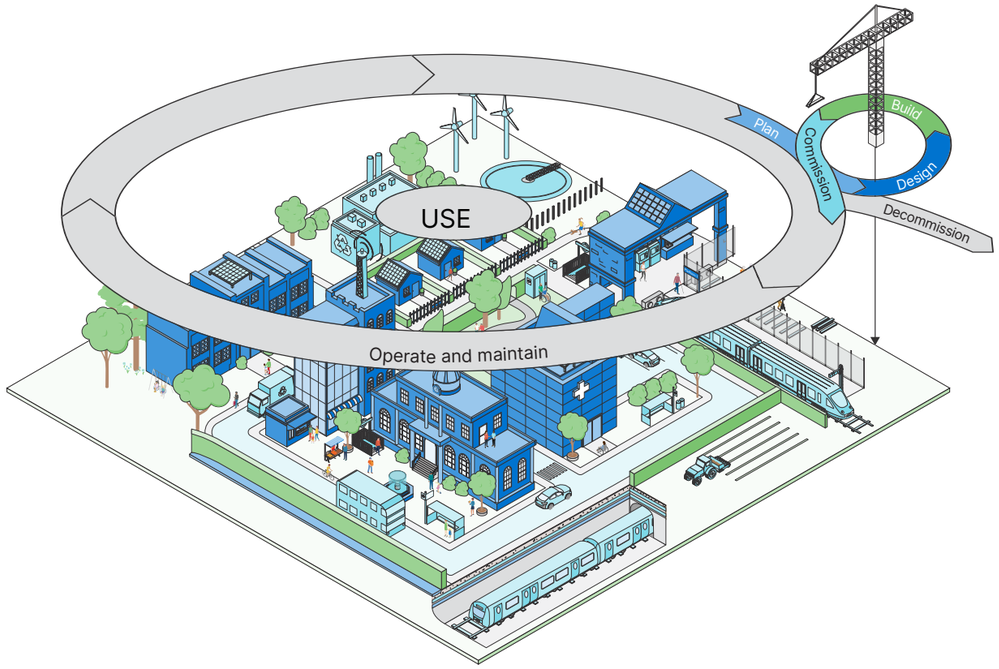

Figure 4. Understanding the lifecycle of complex and evolving systems

Defined by connections and outcomes

A strong ecosystem of connected digital twins should connect processes, technology and organisations to deliver positive outcomes for people, society and nature by making better decisions, faster. Overlooking the connections or outcomes will prohibit the systemic shift that digital twins can provide. Currently available technology means the technological links are achievable, although it is more difficult to achieve the social links.

Connections of processes, technology and organisations

Timescales for the use and management of infrastructure far exceed the plan, design, build and commission phases. With the shift towards the circular economy, retrofitting and refurbishing existing assets is of growing importance as focus is being placed on embodied carbon. The evidence is clear: we can unlock more value from current assets by focussing on the connections between these processes.

Value is realised when information flows between processes. An ecosystem of connected digital twins, using a common approach such as the IMF, provides a structure to share information with as little resistance (cost and time) as possible. Information silos also occur within regulators and governmental departments. Cross organisational relationships enable the open transfer of information required for an organisation to benefit from an ecosystem of connected digital twins.

Outcomes for people, society and nature

It is critical that digital twins are developed to provide positive outcomes for people, society and nature. Digital twins can provide better outcomes by enabling transparency and better insights into the impact of decisions on people and nature. By placing people at the centre, systems are being designed and optimised to meet the needs of the individual; from health and wellbeing, to mobility, access to essential resources, and economic opportunity. Digital twins must aim to benefit society by creating opportunities to ensure that specific targets, as well as more intangible benefits, can be measured, considered and optimised for decision-making. Connections between twins provide the systems view to demonstrate the quantifiable benefits of societal wellbeing, especially when those economics are entangled in complexity (e.g., green space and good air quality improve health, maximise working hours, and so support the economy).

Integrating data from natural systems with that from the built environment provides the information to ensure ecological and geo-physical limits are not surpassed. Nature-based solutions (NbS) aims to restore habitats and protect ecosystems while also improving air quality, people's wellbeing and reducing the urban heat island. Having spent decades degrading natural systems and replacing them with resource intense assets and services, it is important that an ecosystem of connected digital twins is driven by outcomes for nature as well as human interest, recognising the interdependencies between the built and natural environment.

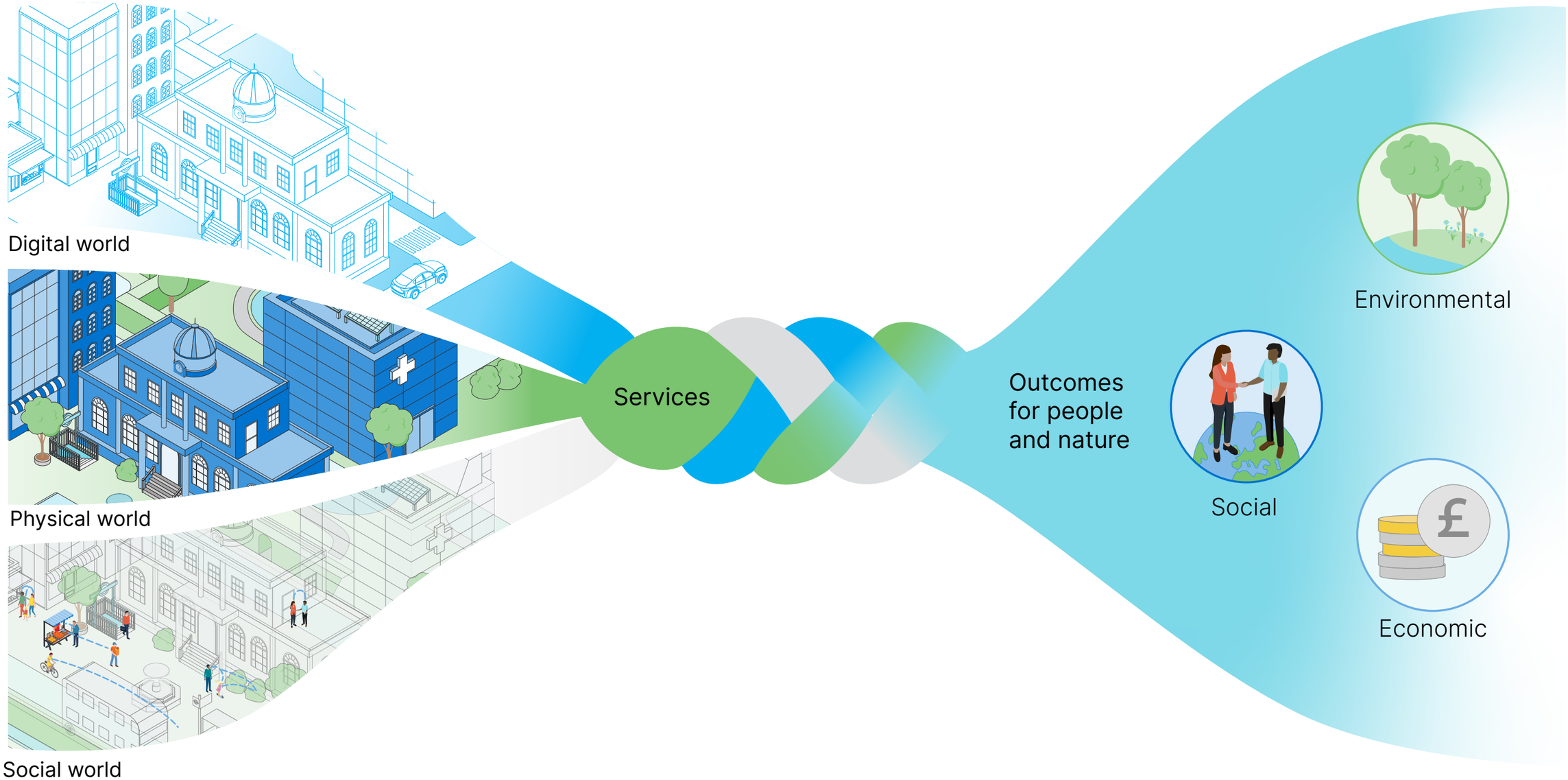

Figure 5. Intertwined worlds are connected to deliver outcomes for people and nature

What role do the Gemini Principles play?

Published by CDBB in 2018, the Gemini Principles are the conscience of connected digital twins – nine guiding values to build consensus for the development and ongoing evolution of the National Digital Twin. The principles create alignment within the programme and keep the focus firmly on the overall objective, which is to deliver genuine public good. The principles enshrine the intention that all digital twins have clear purpose, must be trustworthy, and must function effectively.

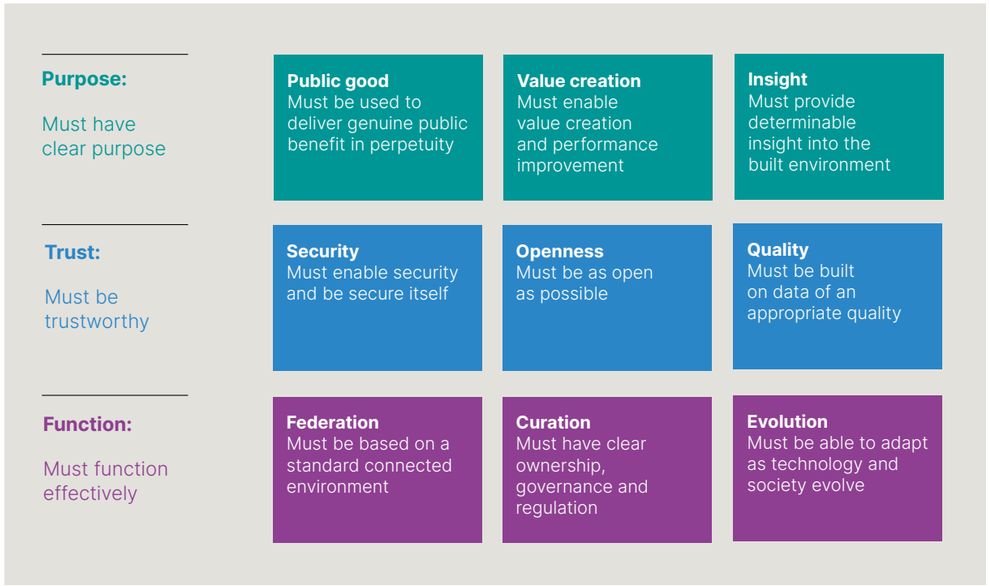

Figure 6: The Gemini Principles

Purpose

Designing purpose-driven digital twins delivers diverse solutions with model fidelity to suit the task. Combining purpose-driven models into an ecosystem of connected digital twins ensures individual models continue to serve the needs of the primary user while also creating accessible data for the wider society.

In order to provide public good, the purpose of an ecosystem of connected digital twins need to be values guided. While the ownership of data is becoming more valuable and increasingly foundational to the economy, digital twins must aim to go beyond commercial gain.

Only once the intervention is performed on the physical twin, is the value of a digital twin fully realised. It is these outcomes that bring economic, social and environmental benefits to the real world. Being outcomes focused ensures that the benefits are central to a digital twin, and avoids the twin simply being a repository of data without influence.

Trust

To ensure an ecosystem of connected digital twins delivers maximum benefits to people and the natural world, organisations must “collaborate on the rules, and compete on the game”. Aligning on the rules requires cross organisation collaboration that can be difficult to facilitate, with companies often being protective over information. By collaborating on the rules with public good at their core, organisations can compete, innovate and deliver increasingly successful and sustainable solutions.

Ecosystems of connected digital twins are to be ‘secure by design’ protecting personal data, sensitive information, commercial interests and intellectual property. The secure data shared within an ecosystem of connected digital twins must be of a minimum standard to enable decisions, however it must still be suitable for the intended purpose.

Function

A systems-based approach ensures that ecosystems of connected digital twins help to solve the problem of understanding the increasingly complex and growing built environment. Decisions made at a building or process level can often impact multiple parts of the system. As the time passes, the built and natural systems will evolve and so must the ecosystem of connected digital twins.

Quality data management is essential for the function of an ecosystem of connected digital twins. The data contributing to a connected digital twin is clearly and transparently owned, governed and regulated. Federated models form the ecosystem of digital twins. To manage the data across sectors, the ecosystem of digital twins must be flexible, accommodating different approaches to modelling, data types and data collection.

What you need to know: What must happen next

CDBB has done the foundational work. We now have a consensus-built understanding of key terms and concepts essential to the future of ecosystems of connected digital twins. This includes:

- What we mean by a digital twin
- The significance of a systems of systems approach
- What we mean by connect digital twins
- The role of connected digital twins within and across sectors
- The connections and outcomes enabled by digital twins
- What the Gemini Principles are and the role they play

To carry the baton into the future it is essential that:

- The information value chain of a digital twin should always be present. Data must be used to produce insights and decisions that lead to interventions to the physical twin. An ecosystem of connected digital twins uses a common framework to create shared data connections between digital twins, that will span organisations, sectors and structures.
- We recognise that systems can quickly become too complex to understand without appropriate tools. The built environment has been developing over centuries, creating one of the most complicated systems known.
- A digital twin is not defined too closely. Doing so may exclude possible use cases while the technology is still maturing within the construction industry. We know that digital twins are varied and should be fit for purpose.

By creating an ecosystem of connected digital twins we can make strategic decisions that consider entire systems, driving positive change for humans, nature, and the planet.

End notes

1. Describing digital twins : https://digital-twins.kumu.io/describing-digital-twins
2. Flourishing systems: https://www.cdbb.cam.ac.uk/files/flourishing-systems_revised_200908.pdf
3. The second national infrastructure assessment: baseline report: https://nic.org.uk/app/uploads/Revised-Second-National-Infrastructure-Assessment-Baseline-Report.pdf
4. The London plan - The spatial development strategy for Greater London: https://www.london.gov.uk/sites/default/files/the_london_plan_2021.pdf
5. The Cyber-Physical Infrastructure - Empowering innovation, people, robots and smart machines to enhance prosperity, resilience, sustainability and security: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1053955/cyber-physical-infrastructure-vision.pdf

DOI: https://doi.org/10.17863/CAM.82194