Gemini Papers: How to enable an ecosystem of connected digital twins?

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Executive Summary

This paper is the third of three, addressing the What, Why and How of ecosystems of connected digital twins.[1]

- It details the necessary approaches to enable useful ecosystems of connected digital twins
- It urges the need for an industry wide socio-technical change at individual, organisational, sectoral, national and international levels
- It highlights the complexity of the road ahead and the need for collaboration across industry, academia and government on a national scale
- It sets out the collaborative approach to develop common national resources for data sharing across organisational and sectoral boundaries

This paper states that an ecosystem of connected digital twins should be developed with adopters, in the open, as a public resource. It shows that a socio-technical change programme is required to support the social, human connections between organisations and sectors which allow for the transfer of data and knowledge.

We know a paradigm shift is required to break down silos in policy formulation and implementation that are producing suboptimal outcomes. We know we must collectively recognise the built environment as a system of systems and manage it accordingly with more collaborative models built on trust. That way we can create a built environment whose explicit purpose is to enable people and nature to flourish together for generations.

Contents

How does a nation enable an ecosystem of connected digital twins?

A successful ecosystem of connected digital twins will only emerge when we are able to share high-quality data securely and resiliently across organisational and sectoral boundaries.

This will require strong collaboration between industry, academia and Government to improve information management maturity in organisations and break down silos across the industry. We must recognise the connection between high-quality data sharing and added value to business, people and nature.

This level of national change will only occur if we have the right culture, delivery vehicle, values and resources. Collaboration, coordination and alignment in a socio-technical framing will build strong ecosystems of connected digital twins.

Right culture – strong leadership, collaboration and improvement

Enabling data sharing across organisations and sectors needs a strong boundary spanning leadership that fosters a culture of collaboration and improvement across industry, academia and government. Organisations and individuals should be empowered to work together on growing an ecosystem of connected digital twins for the public good.

Right values and ethics

Enabling connected digital twins is a long term industry transformation and it is essential that the journey is grounded and driven by the right values and ethics.[2] The Gemini Principles[2] sets out core values to drive alignment and the first principle states that digital twins must be used to deliver genuine public benefit in perpetuity. It is important to consider what is defined as the good, who defines it, and how it is distributed throughout society.

Ethics are addressed ensuring that a clear definition of public good, quality and value is established. We must ensure adequate representation across all stakeholders and users. Interpretations will be inherently different across a range of perspectives, and if unchecked could perpetrate or increase discriminatory structures in society. Digital twins, from their inception, need to take an 'ethics-by-design' approach with 'baked in' digital ethics at the foundations, rather than simply responding to ethics consideration.

Right delivery vehicle

The delivery vehicle for enabling an ecosystem of connected digital twins should coordinate and align, rather than command and control.

Coordinate between industry, academia and government

Proactive coordination, engagement and alignment between industry, academia and Government will ensure that efforts are channelled in the right direction and minimise the risk of technical divergence. This will require coordination between major organisations and initiatives driving digital twins - such as the DT Hub, Alan Turing Institute, the Centre for Protection of National Infrastructure (CPNI), Cyber-Physical Infrastructure and the Central Digital and Data Office in the UK.

Adopt a top-down bottom-up approach

A middle-out approach brings together a specialist led top-down approach and a community led bottom-up approach. Looking top-down helps to ensure a strong strategy and route to standard practices, while bottom-up approaches engage many of the practitioners already working in this field to highlight knowledge gaps.

Foster extreme collaboration

The delivery vehicle should encourage extreme collaboration between developers and investors in digital twins, to enable knowledge sharing, connections and the development of best practice. Collaborative communities, such as the DT Hub, encourage conversation between practitioners and stakeholders. Sectors such as manufacturing, agriculture and robotics are already using digital twins and connected digital twins to make informed decisions. As we create an ecosystem of digital twins, we will benefit greatly through sharing learning across sectors.
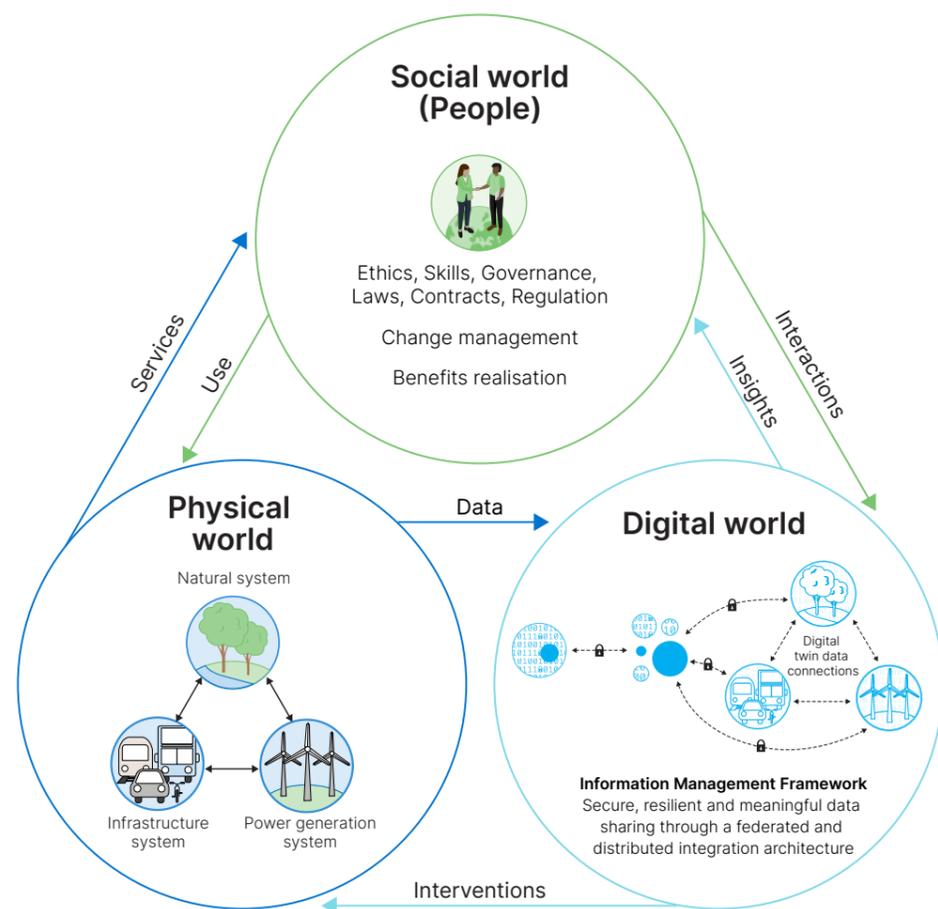
Figure 1. Linked socio-technical resources to enable ecosystems of connected digital twins

Right resources

Success will hinge on organisations' information management maturity and their ability to access and use the right tools and resources to enable secure and resilient data sharing. Resources such as common frameworks[3], contracts[4], standards[5], learning paths[6] and others are needed to make this a success. We also must develop and improve capabilities to analyse and intervene effectively in complex system of systems.

All resources should be developed in the open with ongoing community feedback to ensure they are useful and adoptable. Many of the required resources already exist so innovation and development are needed only where solutions are missing.

A common national framework to manage shared data

Achieving the vision of data sharing at scale requires the development of core resources to be adopted by the organisations who are wishing to be part of an ecosystem of connected digital twins. This is what an Information Management Framework (IMF)[7] – a collection of open, technical and non-technical standards, guidance and common resources – could provide. It is essential to develop a scalable framework that enables integration of various digital twin use cases.

The framework will require two main technical components:

- A common language – an IMF ontology – supported by a Reference Data Library (RDL) and a Foundation Data Model (FDM) – intended to support the broadest possible scope consistently

  – An RDL forms the words of the language: it contains the classes and properties needed to enable different organisations and sectors to describe things consistently.

  – An FDM is a data model that provides the structure and meaning of data – the grammar of the language

- An Integration Architecture to support the secure, resilient sharing of data between applications and organizations. The envisaged architecture is a distributed database, where the component databases are linked by a messaging system. The messaging system uses an FDM and an RDL that all the connected systems translate into and out of.

A co-development approach

When developing a common data language (an IMF ontology), it would not be practical to first collect all the data that exists, analyse it to determine a suitable data structure, and then populate it and publish it. Therefore, the IMF is adopting a thin-slice approach, that allows to work in small incremental steps, hence allows to start small and expand. Through the thin-slice approach, large datasets are decomposed into 'thin' slices whose semantics are enriched and refactored, so as to increase their interoperability and prepare them to be compliant with quality requirements for sharing within an ecosystem of connected digital twins.

A toolkit to improve information management maturity

We must outline the different components, resources and processes that an organisation will need to put in place to achieve the right level of information management maturity in order to take part an ecosystem of connected digital twin. For instance:

- Day-to-day management of information, in particular its creation and use and assuring that it is fit-for-purpose. In particular, users need to specify their information requirements and make sure information producers are aware of them; information producers need to create information that meets those requirements.

- Governance over how information management decisions are made, avoiding that different parts of an enterprise make independent decisions leading to inconsistency and inefficiency

- Identification of the roles[8] needed and associated responsibilities: all activities related to information should be the responsibility of some role, and roles should be assigned to positions and hence to particular persons.

- Upskilling / training to give people the skills to perform their roles

- Acquisition and active management of knowledge about information management

- The development of a community of information management practitioners who can share best practice, encourage professional standards, and help set priorities for future work

A security-minded approach

A security-minded[9] approach is needed to protect intellectual assets and personal data, and to deter malicious activities and fraud. When sharing data, every organisation must consider its security needs across all of its business areas, including its assets and services.

A common roadmap and action plan

A common roadmap[10] is an essential tool for engagement and alignment that should be widely communicated and discussed in a national effort to enable connected digital twins and ensure that they are focused on delivering better social and environmental outcomes for people and nature. The roadmap should set out the journey towards the required building blocks to enable effective information sharing across organisational boundaries through connected digital twins.
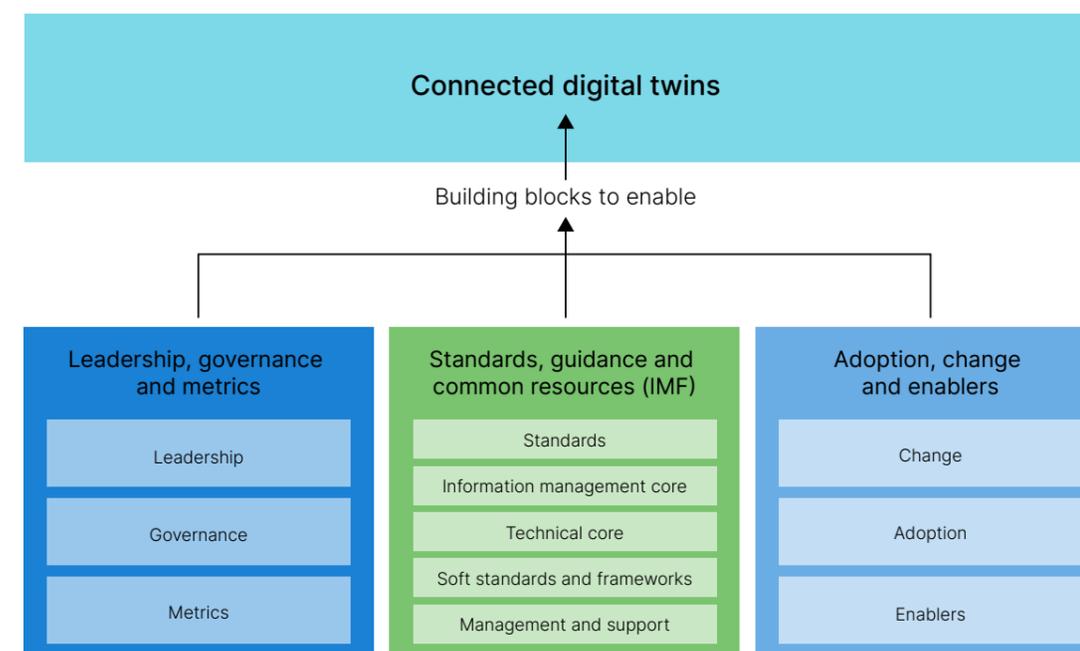

Figure 2. A common roadmap: Key components to enable an ecosystem of connected digital twins

How does the industry change itself?

Enabling an ecosystem of connected digital twins requires an industry wide socio-technical change through coordinated national actions.

Given the scale of change needed, national interventions should be coordinated, prioritised and optimised. We should evaluate what change is needed at individual, organisational, sectoral, national and international levels.

A theory of change is a key tool to articulate the set of potential interventions that a national socio-technical change programme could take to transform outputs into intended outcomes, and ultimately high-level impacts. A benefits realisation framework provides the mechanism to measure and report programme benefits and track programme progress to the high-level objectives outlined in the theory of change.

A paradigm shift is required to break down silos in policy formulation and implementation. National leadership must recognise the built environment as a complex system of systems and manage it accordingly. Government intervention is needed to support the co-development of common national resources and building capacity through training and support. Asset owners and operators are key to change by creating new market opportunities for connected digital twins through clear procurement requirements that ensures high data quality standards and interoperability of systems.

Theory of change

To make change come to life it is important to understand what drives it, how the different levers fit together and impact each other, and the journey towards the ultimate destination.

A theory of change captures the interconnected actors, levers, outputs, outcomes, impacts and enablers that comprise the connected digital twin ecosystem. It provides a clear understanding of the drivers of change and the actors involved that must coalesce to realise an ecosystem of connected digital twins, from an individual to a national level, that enables people and nature to flourish together.

To enable effective monitoring and evaluation of the intervention we need a benefits realisation framework. Based on UK best practice, including HM Treasury's Magenta Book[11], the benefits realisation framework recommends Key Performance Indicators (KPIs) to measure the progress and benefits of connected digital twins, as well as governance arrangements to support data capture, management and dissemination. Ultimately, the benefits realisation framework will make it easier to understand the transformative impact that connected digital twins is expected to realise.
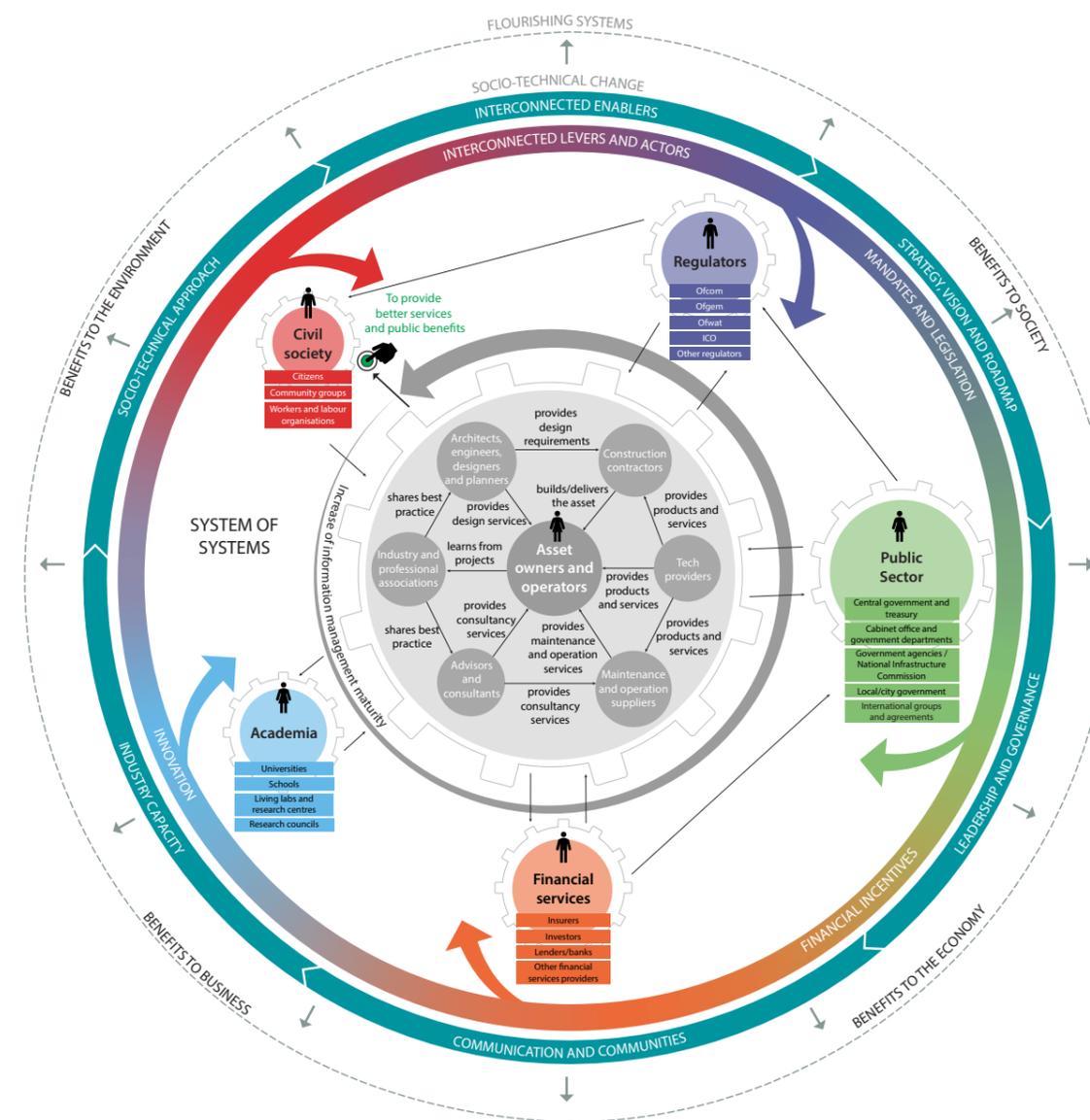

Figure 3. Theory of Change

Five levels of change

Individual change

Individual change happens with education. Change at this level will require a review of learning paths from young age school students to experienced professionals to ensure training material on connected digital twins is available for practitioners and individuals. Clear direction and guidance on future roles, skills and training needed, will ensure that individuals can be as active as organisations in realising this change. Information management experts and early adopters need to play a prominent role in the implementation of the connected digital twins. They need to be identified and engaged with among industry, academia and Government to help shape future frameworks, requirements and opportunities.

Organisational change

Organisational change is the core to establishing the ecosystem of connected digital twins as in order to change the industry all organisation need to change. We have seen that once organisations start to realise value from information management such as use of BIM, they implement steps to develop new capabilities, enhance business processes and upskill their workforce. To demonstrate support, national leadership must work with digital twin pathfinders and champions piloting connected digital twins like CReDo.[12] This must be accompanied by ongoing engagement with academia to inform the planning, development and introduction of the lessons learned into education.

Sectoral change

Industry change will be accelerated when sectors recognise the value of secure and resilient data sharing across boundaries. The built environment is a complex system of systems with interconnected processes and sector. Regulators, government departments and other sectoral groups can use this connected ecosystem to set better policies and establish the necessary regulations, policy and governance to support the change taking place.

National change

National change requires strong public sector backing. Every nation wanting to enable an ecosystem of connected digital twin should articulate a clear vision and develop a national implementation plan. This will guide strategic engagement among industry regulators in different sectors, government departments and other industry leadership at a national level.

International change

To fully realise the potential in ecosystems of connected digital twins, we must communicate with, and link to, similar efforts taking place globally.

The UK can play a leading role in shaping and developing an international ecosystem of connected digital twins to promote international knowledge sharing and build tools to address global challenges such as climate change.

Clear direction and guidance on future roles, skills and training needed, will ensure that individuals can be as active as organisations in realising this change.

Skills and innovation

There is a pressing need for organisations to have critical skills on board who understand and can deal with the information management challenges and cross industry collaborations. To achieve this there is a need for national upskilling in digital and business skills, for technical and non-technical areas.

Some of the core enablers to developing the right skills are:

- A Skills and Competency Framework (SCF)[8]; and

- A National Capability Enhancement Programme (CEP)[13].

The SCF framework identifies priority skills and competencies required across a range of national roles, organisational roles and others that are critical. This framework could act as a baseline for the industry and individual organisations in the assessment of their current capabilities to identify gaps and plan how they may be addressed. As a part of the SCF, targeted role-based training plans need to be developed to guide organisations on how to upskill their workforce to design and operate connected digital twins.

The CEP programme identifies steps necessary to bring organisations and individuals up to the level of expertise required and equip organisations with tools, guidance and materials to understand and cultivate the skills and knowledge they need. This is to provide guidance and resources to drive the development of the right skills, to the right level, to achieve the goal of enhancing industry capabilities and deliver successful ecosystems of connected digital twins.

We must develop relevant policies, programmes, training courses and supporting infrastructure to upskill capabilities across the industry.
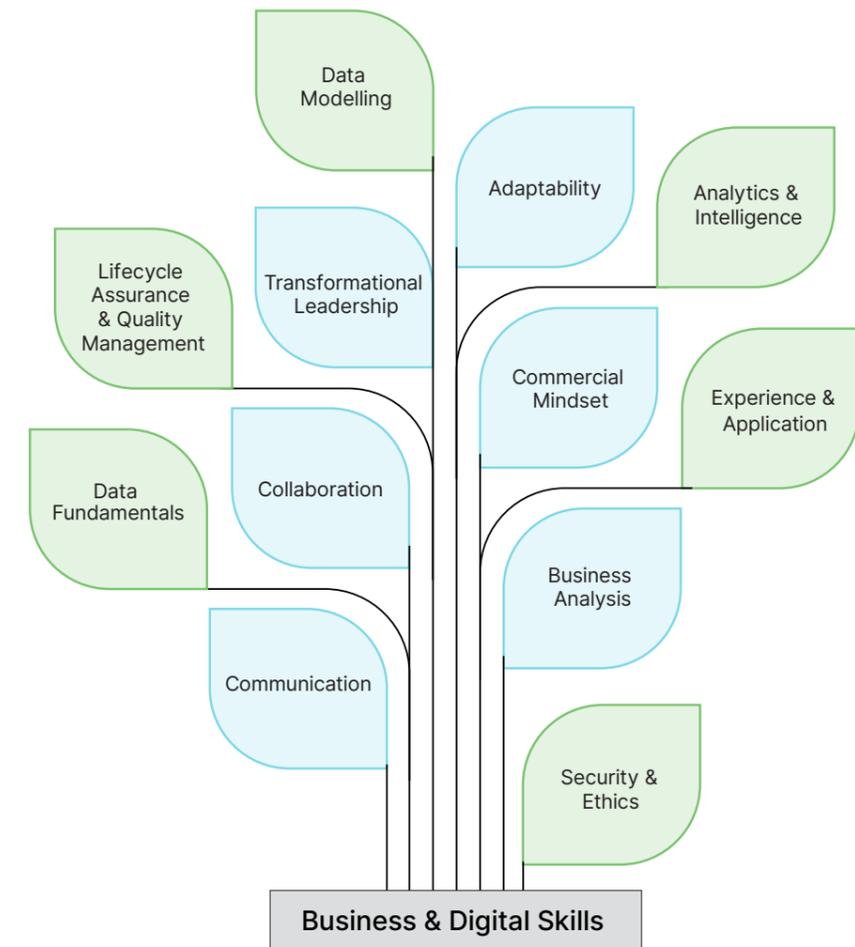

Figure 4. Business and digital skills

How do you grow a market for connected digital twins?

Connected digital twins requires businesses to think big but start small, as benefits will accrue over time through a network effect. Trust between organisations will evolve with more collaboration, which is why collaboration should be encouraged particularly from Government. This requires looking beyond transactional relationships, building trust over time, a new commercial model, updated legal frameworks and regulation. Success will depend on human and organisational factors.

We know that the full extent of the possible is still undiscovered when it comes to connected digital twins. The climate resilience demonstrator CReDo[12] and the National Underground Asset Register[14] have made significant progress in raising awareness of the benefits of cross organisational data sharing. As the networks grow the perceived value of adopting digital twins will also grow and their utilisation will ultimately become a necessary commercial choice. On the road to mass adoption and standardisation, funding mechanisms are needed to make sure capital is applied appropriately to projects and opportunities where the greatest benefit can be found.

Looking beyond transactional relationships

Collective knowledge sharing will motivate industry parties to establish wider connections and a more open knowledge sharing culture, through the prospect of enhancing each individual organisation's capabilities. A wider adoption of relevant international standards[15-18], that provide guidance on how organisations can map and manage their business relationships.

Exploring new commercial models

Current commercial models can fail to incentivise collaboration and data sharing across organisations. Businesses tend to be reluctant to commit the resources required to share information or to improve information management maturity due to lack of appreciation of benefits. Consequently, there is a need to develop better commercial models to break down barriers by connecting information, organisations and processes.

Setting the right legal and regulatory frameworks

Legal barriers are another blocker to sharing data between organisations in secure and resilient ways. It is often the role of lawyers to protect the assets within organisations and avoid providing competitive advantages to others. It is crucial that legal professionals are involved in the conversation early on, with the process becoming even more complex when the network of digital twins crosses national or regulatory borders. Some of the key areas that need to be considered by lawyers working to develop connected digital twins[4] are:

- Liability
- IP Rights/Copyright
- Data restrictions
- Responsibility
- Technical specifications
- Security and integrity

Engaging with regulators is essential to shape and identify the correct structure of responsibility and set the terms of reference for connected digital twins. Connected digital twins can release huge value to regulators, but also regulating data sharing is essential to preserve the commitment to public good as connected ecosystems of digital twins develop across typical sector boundaries.
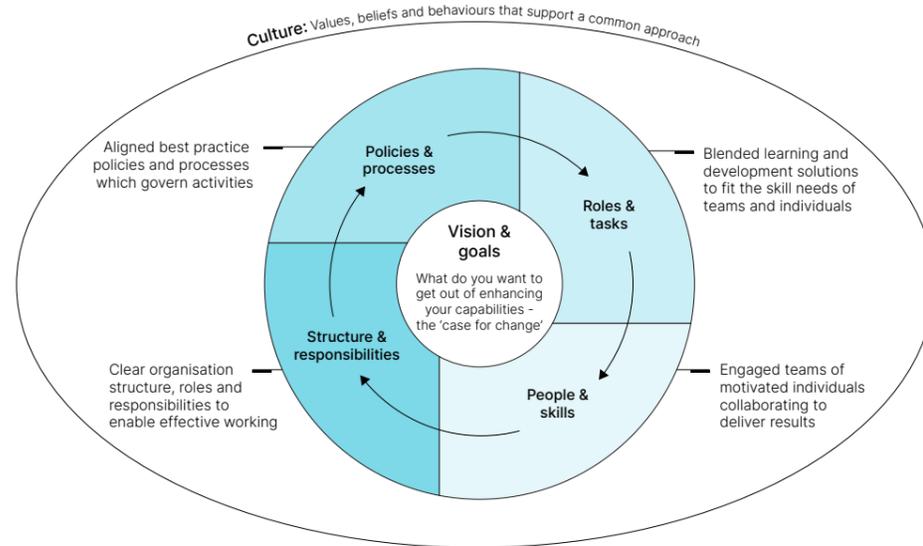
Figure 5. Common approach supported by culture

Working on adoption from the start

Widespread market adoption of open shared national solutions depends on whether the need for change to achieve technical progress and societal benefits is well understood, accepted and fully supported by senior leaders. Success requires a socio-technical programme to communicate benefits, coordinate key initiatives, facilitate co-development of a common framework that is adoptable and usable. This requires extreme collaboration between government, education, academic and professional institutions, industry bodies and the supply chain.

We should create the right environments for organisations and individuals to share lessons and knowledge, turn experience into best practice, guidance and ultimately into standards. Developing the right communities like the DT Hub[19] is essential to creating the right environment for adopting common national resources such as the IMF and enabling an ecosystem of connected digital twins.

Industry players that are taking a lead and who are pioneering connected digital twins will use this platform to share their journey and how it benefited their organisations and individuals, thus promoting good practice and driving adoption across other organisations.

How can we make this happen: What you need to know and what must happen next

CDBB has done the foundational work. We know that:

- Collaboration, coordination and alignment between industry, academia and Government in a socio-technical framing is essential to build strong ecosystems of connected digital twins.

- Industry-wide change is required. Technical solutions are necessary but not sufficient.

- Many technical solutions already exist. Innovation and development are needed where other solutions are missing.

- Success requires a socio-technical change programme on a national scale.

- Success also depends on human and organisational factors.

- Work must be people-led and technology-enabled.

How society can act as good stewards of the natural environment is a key question of the 21st century. Our tools and digital innovations present a wealth of opportunities to work in new ways, unlocking value and delivering sustainability at a scale not possible previously.

This is only feasible when we consider both the technical and the social, ensuring we bring all stakeholders along. By looking at our infrastructure, assets and processes at a systems level, we can immediately see where the connections exist.

Through ecosystems of digital twins, it is possible to make these connections accessible, legible and actionable for change: if we do it in a principled and purpose-driven way.

End notes

1. The Cyber Physical Infrastructure Vision: (https://www.gov.uk/government/consultations/enabling-a-national-cyber-physical-infrastructure-to-catalyse-innovation) uses the term 'federated digital twins' when referring to 'connected digital twins'.
2. Digital Twins: Ethics and Gemini Principles: https://digitaltwinhub.co.uk/projects/digital-ethics/
3. A pathways towards an Information Management Framework - a 'Commons' for Digital Built Britain: https://www.cdbb.cam.ac.uk/news/pathway-towards-IMF
4. IMF Legal Pathway Workshops: https://digitaltwinhub.co.uk/projects/imf/legal-pathway/
5. Standards Roadmap: https://digitaltwinhub.co.uk/projects/standards/standards-roadmap/
6. Skills resources: https://digitaltwinhub.co.uk/projects/skills-and-capability
7. Information Management Framework: https://digitaltwinhub.co.uk/projects/imf/what-is-the-imf/
8. Skills and Competency framework: https://digitaltwinhub.co.uk/files/file/64-skills-competency-framework/
9. Developing a Security Minded Approach: https://www.cpni.gov.uk/developing-security-mindedness-approach
10. Key components to enable connected digital twins: https://digitaltwinhub.co.uk/components-for-connected-digital-twins/
11. Magenta Book: https://www.gov.uk/government/publications/the-magenta-book
12. CReDo: https://digitaltwinhub.co.uk/projects/credo/what-is-credo
13. A National Capability Enhancement Programme: https://digitaltwinhub.co.uk/files/file/78-capability-enhancement-programme/
14. The National Underground Asset Register: https://www.gov.uk/government/collections/national-underground-asset-register-nuar
15. ISO 8000 Data quality: https://www.iso.org/standard/65344.html
16. ISO 44001 Collaborative business relationship management system: https://www.iso.org/standard/72798.html
17. ISO 30401 Knowledge management systems: https://www.iso.org/standard/68683.html
18. ISO 9001 Quality management systems: https://www.iso.org/standard/62085.html
19. DT Hub https://digitaltwinhub.co.uk/forums