

The Gemini Principles

Digital twins of physical assets are helping organisations to make better-informed decisions, leading to improved outcomes.

Creating an ecosystem of connected digital twins – a national digital twin – opens the opportunity to release even greater value, using data for the public good.

This paper sets out proposed principles to guide the national digital twin and the information management framework that will enable it.

Greater data sharing could release an additional £7bn per year of benefits across the UK infrastructure sectors¹, equivalent to 25% of total spend.²

Effective information management will enable better decisions, leading to financial savings, improved performance and service, and better outcomes for business and society per whole-life pound.

To make this possible an information management framework is necessary.

This paper seeks to build consensus on foundational definitions and guiding values – the Gemini Principles – and to begin enabling alignment on the approach to information management across the built environment.

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‘The Gemini Principles: Guiding values for the national digital twin and information management framework’

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Gemini: the Latin for ‘twins’ and, in astronomy, a northern constellation containing the bright stars Castor and Pollux.

Digital modelling of the physical world is already sophisticated and is becoming ubiquitous. Digital twins enable better use, operation, maintenance, planning and delivery of assets, systems and services.

This paper is the first deliverable from the Digital Framework Task Group, part of the Centre for Digital Built Britain. It starts to address the key recommendations in the National Infrastructure Commission’s report ‘Data for the public good’.³

Ministerial foreword

The Government has set out a clear vision and strong agenda to transform the way we deliver, operate and use our built assets by harnessing the power of digital technology, data capture, and analytics. This is being delivered via the Industrial Strategy Transforming Construction Programme and the creation of the Centre for Digital Built Britain (CDBB) at the University of Cambridge.

Our ambition is to securely harness data to create assets which are more responsive to requirements, perform better over their lifetime, use less energy and create beneficial synergies across the wider built environment. This process will take time and will require a clear roadmap and collaboration with a range of industries and stakeholders, which will be coordinated by CDBB.

The value of data grows exponentially as it is aggregated and shared between organisations. Convergence of smart infrastructure, modern methods of construction and the digital economy presents growing opportunities to use data to improve citizen quality of life and wellbeing. The nation stands to gain if we can remove the technological, commercial and cultural barriers that prevent effective data sharing. For example, the National Infrastructure Commission found that digitising asset

information of the UK's rail network could save up to £770M over the next eight years and £8.9bn in direct benefits to the UK through public sector open data.

We are in the early days of a digital revolution. It is important that the UK develops and embraces the use of an information management framework and a national digital twin in a co-ordinated and considered way. Industry also strongly aligns with the need to embrace digital, with it forming a core element of the Infrastructure Client Group's work programme, the Construction Sector Deal and leadership papers such as the Institution of Civil Engineers' 2017 State of the Nation: 'Digital Transformation' paper.

The UK's infrastructure pipeline represents more than £600bn of spend over the next decade. These projects will all be built digitally before they are built physically. We need to ensure that asset data is captured in a way that can deliver value throughout its life – a principle recognised in Government's 'Transforming Infrastructure Performance' strategy paper published last year by the Infrastructure Project Authority. As well as providing the people of the UK with transport networks, houses, hospitals and schools that are better built, this information will enable local and central government to take informed decisions to improve the services they deliver across their lives.

The National Infrastructure Commission 'Data for the Public Good' recognises that verifiable, timely and accessible data is fundamental to delivering maximum value. High quality data enables informed decisions which, in turn, underpin the successful creation, operation and use of all assets throughout their lifetime. This goes to the heart of the development of 'digital twins', be it of a single component, a whole asset, or across the entire nation.



Richard Harrington MP

The UK is now seen as in the vanguard of the digital revolution, having pioneered the systematic adoption of building information modelling (BIM) led by BEIS and the Cabinet Office. The work of the UK BIM Task Group, led by the Construction Industry Council, in promoting the application of BIM standards, tools and skills in central government departments and their construction supply chain, contributed to over £3bn of capital construction efficiency savings from 2011-15.

I welcome this seminal paper from the Digital Framework Task Group (DFTG), bringing together key voices from government, academia and industry to build consensus on the foundational definitions and guiding values needed to underpin this digital transformation. We extend our appreciation to the DFTG, its chair Mark Enzer and CDBB for all the hard work that has gone into this so far.

Richard Harrington MP

Minister for Business and Industry, Department for Business, Energy & Industrial Strategy



“Convergence of smart infrastructure, modern methods of construction and the digital economy presents growing opportunities to improve citizens’ quality of life.”

In brief

Seize the moment

Everybody knows that digital transformation is happening.

Many involved in creating and managing the built environment are already developing digital strategies and capabilities. But the full value of digital transformation cannot be realised without alignment and co-ordination across our industry.

This paper seeks to build consensus on foundational definitions and values for effective information management in the built environment.

While our industry’s digital transformation is still in its early stages, now is the time to act – for the benefit of business and the national economy, the public good and the environment.

Digital twins, and a national digital twin

Digital twins are realistic digital representations of physical things. They unlock value by enabling improved insights that support better decisions, leading to better outcomes in the physical world.

Connecting digital twins to create a **national digital twin** (NDT) will unlock extra value. The NDT will not be a huge singular model of the entire built environment. Rather, it will be an ecosystem of digital twins connected via securely shared data.

An **information management framework** for the built environment is required to enable the effective management of information that is fundamental for the creation of a national digital twin.

Purposeful, trustworthy and functional

The NDT and the framework on which it is based will enable better use, operation, maintenance, planning and delivery of national and local assets, systems and services.

Based on the notion of ‘data for the public good’, we need strong founding principles to guide the NDT and the framework through their development and on into their use. Therefore, at the heart of the framework are nine values that we are calling the Gemini Principles.

Asset owners, mayors and other leaders in the built environment should embrace these principles in the development of their own digital twins.

The Gemini Principles

Purpose:
Must have clear purpose

Public good
Must be used to deliver genuine public benefit in perpetuity

Value creation
Must enable value creation and performance improvement

Insight
Must provide determinable insight into the built environment

Trust:
Must be trustworthy

Security
Must enable security and be secure itself

Openness
Must be as open as possible

Quality
Must be built on data of an appropriate quality

Function:
Must function effectively

Federation
Must be based on a standard connected environment

Curation
Must have clear ownership, governance and regulation

Evolution
Must be able to adapt as technology and society evolve

Next

Digital Framework Task Group: The DFTG must guide co-development of the information management framework and connect leaders who are developing digital twins.

- Leaders within the built environment:**
All involved in planning, creating and managing the built environment are urged to:
1. Build consensus on the Gemini Principles
 2. Help to develop and then implement the information management framework
 3. Develop Gemini-compliant digital twins

Please share comments on the Gemini Principles: enquiries@cddb.cam.ac.uk

Follow progress: www.cddb.cam.ac.uk

Why we need the Gemini Principles

Principles matter. The National Infrastructure Commission's report 'Data for the public good' recommended the development of a national digital twin (NDT), which will become a national resource for improving the performance, quality of service and value delivered by assets, processes and systems in the built environment.

The vision for Digital Built Britain is to enhance the natural and built environment, thereby driving up commercial competitiveness and productivity as well as quality of life and wellbeing for the public. This will be achieved through better planning, delivery and whole-life management of infrastructure and the wider built environment – enabled by mustering the full power of the information value chain.

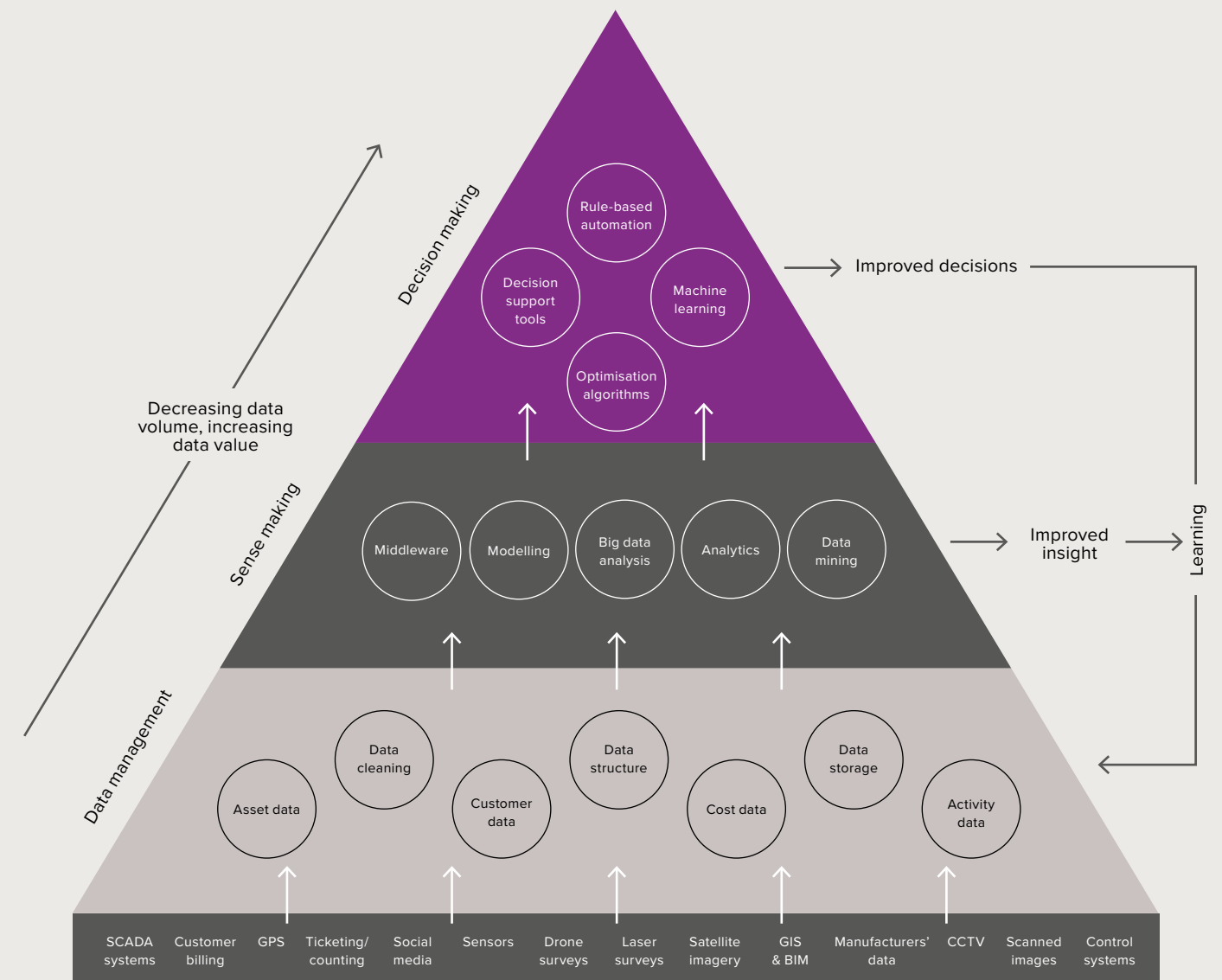
The scope includes the whole built environment, existing and new. It includes the interfaces with the natural environment and the services delivered – social, economic and environmental.

To make the NDT functional, trustworthy and useful, we need strong founding principles to guide its development and to bring about alignment across the built environment. These are the Gemini Principles.

Alignment is key

This paper sets out the proposed Gemini Principles with the aim of building consensus. Establishing agreed definitions and values from the outset will make it easier for the industry to share data later.

The information value chain: showing the connection between data and better decisions that lead to better outcomes.⁴



Definition 1

Digital twin

A realistic digital representation of something physical.

In the context of Digital Built Britain* a digital twin is “a realistic digital representation of assets, processes or systems in the built or natural environment”.**

What distinguishes a digital twin from any other digital model is its connection to the physical twin. Based on data from the physical asset or system, a digital twin unlocks value principally by supporting improved decision making, which creates the opportunity for positive feedback into the physical twin. For example:

- **Digital twin 1:** A dynamic model of an asset, with input of current performance data from the physical twin via live data flows from sensors; feedback into the physical twin via real-time control.
- **Digital twin 2:** A static strategic planning model of a system, with input of long-term condition data from the physical twin via corporate systems; feedback into the physical twin via the capital investment process.

The concept of digital twins is not new: Nasa has run complex simulations of spacecraft for decades. However, the advance of the ‘fourth industrial revolution’ is making cyber-physical systems in the built environment practical, useful and affordable, and digital twins are a key part of this.

Gartner, a global research and advisory firm, predicts that by 2021 half of large industrial companies will use digital twins, resulting in those organisations gaining a 10% improvement in effectiveness.⁵

Appropriate detail

A digital twin must represent physical reality at a level of accuracy suited to its purpose. The extent of realism depends on three essentials:

- **Data** – the quality of the data on which the twin is based.
- **Model** – the fidelity of the algorithms, the validity of the assumptions and the competence of the code at the heart of the digital representation.
- **Visualisation** – the quality of presentation of the output.

Digital twins may be developed for a range of purposes, operate at different scales or adopt different approaches to modelling. A number of digital twins have already begun to appear within the built environment, serving a variety of purposes. Many more will be created. However, few digital twins at present are connected or share data across organisations, sectors or geographies. Lack of interoperability is a key constraint.

* Digital twins can exist in many other contexts such as manufacturing and healthcare. Here, the focus is Digital Built Britain, the UK government’s programme to create a digital, integrated approach to the built environment.

** As an important point of clarification, under this definition, a digital twin of the built environment is not intended to be a ‘realistic digital representation’ of a human. A digital twin of the built or natural environment may be used to analyse how people interact with assets, processes or systems, but it is not intended to characterise the behaviour of identifiable individuals.

Large industrial companies using digital twins are expected to gain a 10% improvement in effectiveness.

Variety within the ecosystem of digital twins

1. Variety of purposes

- Digital twins can be used for many purposes:
- a. Potential futures: Strategy and planning support, running ‘What if?’ scenarios, predictive and preventive maintenance regimes
 - b. Current state: Intervention management (operation and maintenance interventions or capital investment projects), real-time status monitoring and control, diagnostics and prognostics to optimise performance and safety of assets
 - c. History: Record-keeping and learning from the past

2. Variety of spatial scales

- Digital twins may address a variety of spatial scales, including:
- a. Asset or building scale
 - b. Network or neighbourhood scale
 - c. System, city or regional scale
 - d. National scale

3. Variety of temporal scales

- Digital twins may represent any point in the lifecycle of assets, processes and systems. They can be static or dynamic and may address different temporal scales, including:
- a. Operational timescale
 - b. Reactive maintenance timescale
 - c. Planned maintenance timescale
 - d. Capital investment timescale

4. Variety of approaches to modelling

- Digital twins may use different approaches to modelling, including:
- a. Geometric and geospatial modelling
 - b. Computational/mathematical/numerical modelling
 - c. Artificial intelligence and machine learning; ‘learning systems’

Definition 2

National digital twin

An ecosystem of digital twins connected via securely shared data.



The vision for the national digital twin (NDT) is not that it will be a huge singular digital twin of the entire built environment. Rather, it is envisaged to consist of ‘federations’ of digital twins joined together via securely shared data.

Not all digital twins will be connected, only where it delivers value to do so.

Digital twins can be connected in many ways for a variety of purposes. Therefore, the ecosystem could consist of numerous federations of digital twins. The NDT would become more diverse and interconnected over time.

However, the NDT would never become ‘fully federated’ because there would be limited value in connecting every digital twin to every other digital twin. Nor would it ever be ‘completed’, just as the built environment will never be completed. Therefore, the NDT should be recognised at its inception, when the approach to secure interoperability is established, not at its completion.

Connecting digital twins across sectors

Each infrastructure owner or operator is likely to want digital twins to improve the management of their own assets. Energy, transport and water sector asset owners will, independently, each own and curate the digital twins for their assets. But by bringing them together it would be possible, for example, to model the impact of a new wastewater treatment plant on the energy and transport systems – potential power demand from pumping and aeration, or supply from onsite renewable power generation; and vehicle movements on the local road network.

Integrating data across sectors becomes even more relevant in cities, where all the infrastructure sectors come together.

The NDT would allow interdependencies across sectors to be understood in a way that organisation-level or sector-based digital twins could not satisfy.



Benefits of a national digital twin

Better decisions, based on better data, will lead to better outcomes for the public per whole-life pound.

That is the central value proposition for the NDT and for transforming information management across the built environment more generally. It is a simple articulation of the information value chain (see the diagram on page 9). The NDT and the framework will enable better use, operation, maintenance, planning and delivery of national and local assets, systems and services. Informed and guided by the Gemini Principles, the NDT and framework give:

- **Benefits to society:** Improved stakeholder engagement. Better outcomes for the ultimate customers (the public – taxpayers/bill payers/fare payers/voters). Improved customer satisfaction and experience through higher-performing infrastructure and the services it provides.
- **Benefits to the economy:** Improved national productivity from higher-performing and resilient infrastructure operating as a system. Improved measurement of outcomes. Better outcomes per whole-life pound. Improved information security and thereby personnel, physical and cyber security.
- **Benefits to business:** New markets, new services, new business models, new entrants. Improved business efficiency from higher-performing infrastructure. Improved delivery efficiency, benefiting the whole construction value chain – investors, owners, asset managers, contractors, consultants, suppliers. Reduced uncertainty and better risk management.
- **Benefits to the environment:** Less disruption and waste. More reuse and greater resource efficiency – a key enabler of the circular economy in the built environment.

Is it national, and is it truly a twin?

If the NDT is defined as an ecosystem of connected digital twins, the purist could say that it is neither national nor a twin because:

- the twins that are connected may be at local, not national, scale
- the approach will not create a singular twin
- the approach would not even create a singular federation

Nevertheless, the underlying concept of secure, resilient interoperability offers great value to the public and private sectors operating locally and nationally. Therefore ‘national digital twin’ can suitably describe the result of applying a national approach to information management within the ecosystem of digital twins.

Definition 3

Information management framework

Enabling effective information management across the built environment.

The information management framework is intended to establish the necessary building blocks to enable effective information management across the built environment. This includes the secure data sharing that is fundamental for enabling the national digital twin.

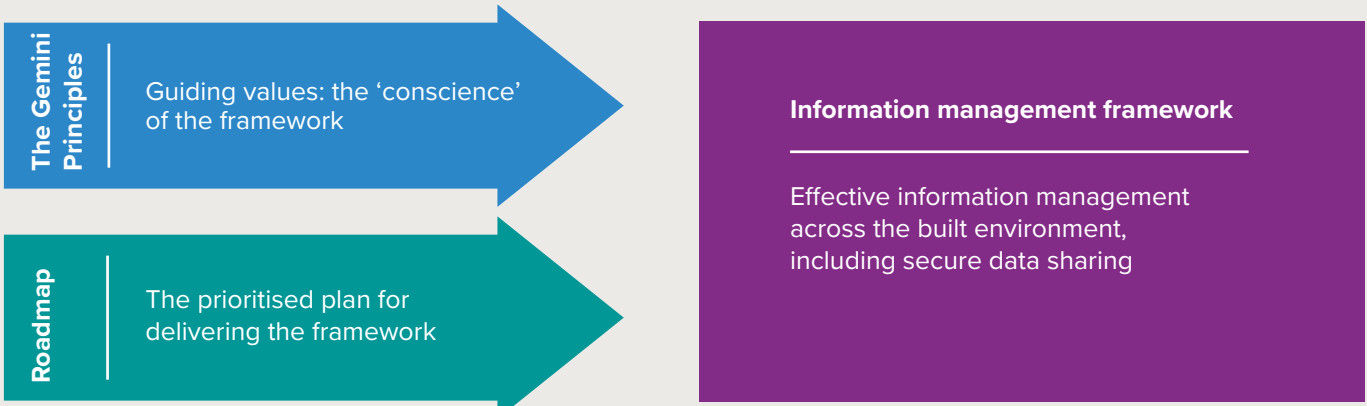
The framework will support the creation of an ecosystem of connected digital twins across the built environment.

By complying with the framework, built environment data will be potentially shareable, but it will not necessarily be shared. Data will be shared only when it delivers value and it is appropriate and safe to do so.

Organisations will be able to comply with the framework without their data being part of the NDT. But it will be to their advantage to pursue compliance because they can benefit from other digital twins if their own are compatible.

Reporting to the CDBB, the Digital Framework Task Group (DFTG) is leading the development of the information management framework guided by the Gemini Principles.

Enablers of the NDT



Key inputs are:

1. **The Gemini Principles** are the guiding values for the framework and the NDT. They are set out in full on pages 16-23.
2. **The roadmap** is the prioritised plan that shows the best route for delivering the information management framework.

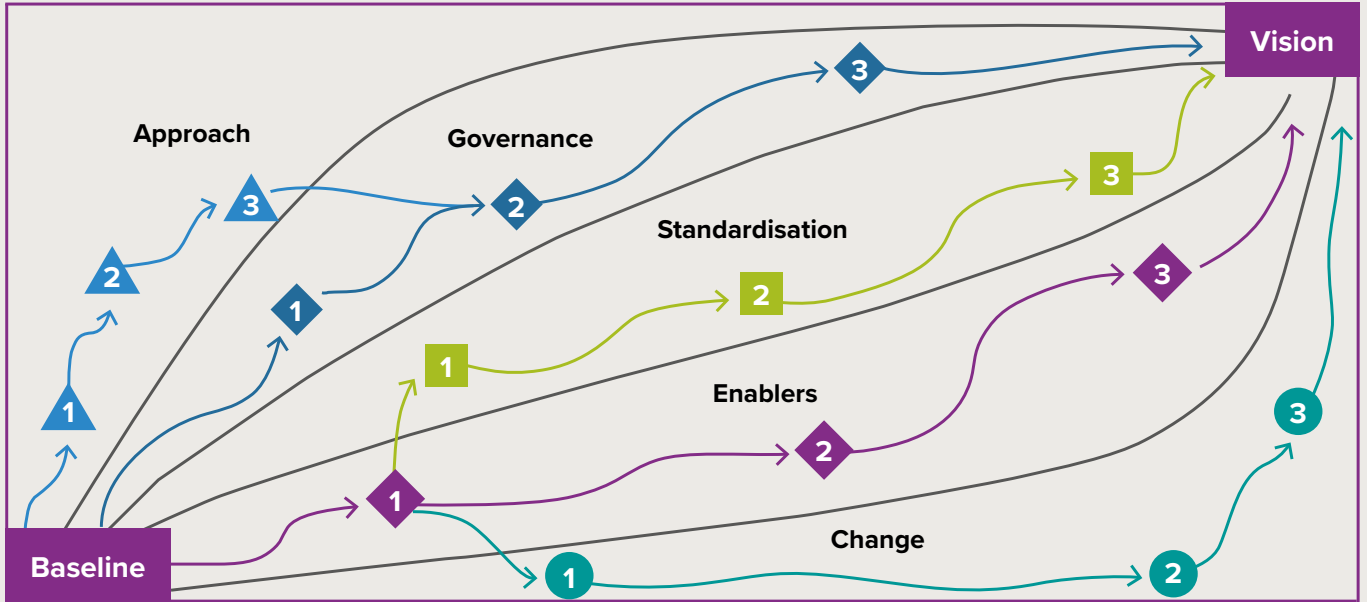
Developing the framework is a substantial challenge, requiring a number of big questions to be addressed and industry alignment with the answers. But the prize is huge.

The roadmap has been broken down into five interconnected streams to make the challenge manageable.

1. **Approach:** What is the best overall approach for realising the benefits of information management across the built environment?
2. **Governance:** What are the best structures and processes for managing the development, adoption and ongoing oversight of the framework?
3. **Standardisation:** What principles, guidance, specifications and formal standards are required?
4. **Enablers:** What potential blockers are there, and how should they be addressed? What cultural, behavioural, technological, commercial or other adjustments are necessary?
5. **Change:** What should be done to get the framework adopted across the whole of the built environment?

The Gemini Principles cut across all five streams.

Roadmap for delivering the information management framework



The Gemini Principles

The Gemini Principles will guide the development of the framework and the NDT. They are organised under three overarching headings: purpose, trust and function.

- They are intended to help the industry develop digital twins in an aligned way that can become part of the NDT.
- They are simple, but their implications are far-reaching and challenging.
- They are descriptive of intent but agnostic on solutions, so they are meant to encourage flexibility for innovation and development over time.

The Gemini Principles do not try to answer all the key questions about the NDT. Rather, they set a context within which those questions can be identified and addressed. Likewise, the Gemini Principles do not attempt to define the relative importance of the individual principles, which may vary over time. Ongoing dialogue on this subject between industry, society and government is a valuable process and should be encouraged.

Purpose: Must have clear purpose	Public good Must be used to deliver genuine public benefit in perpetuity	Value creation Must enable value creation and performance improvement	Insight Must provide determinable insight into the built environment
Trust: Must be trustworthy	Security Must enable security and be secure itself	Openness Must be as open as possible	Quality Must be built on data of an appropriate quality
Function: Must function effectively	Federation Must be based on a standard connected environment	Curation Must have clear ownership, governance and regulation	Evolution Must be able to adapt as technology and society evolve

Effective information management will enable better decisions, leading to financial savings, improved performance and service, and better outcomes for business and society per whole-life pound.



Purpose

Key statement: Each part of the NDT and the framework must have clear purpose.

Premise: The high-level purpose of the NDT is to help to improve outcomes per whole-life pound (economic, social, environmental, safety and security outcomes), so each part should have clear and transparent purpose.

Key points:
The NDT will need an ongoing and growing evidence base to substantiate it.

The constituent digital twins will have many subsidiary purposes that contribute to the shared purposes of the NDT. They should have clear statements of purpose that are disseminated among stakeholders.

Gemini Principle 1

Public good

Key statement: The NDT and framework must be used to deliver genuine public good in perpetuity.

Premise: The NDT and framework are national resources with the purpose of delivering benefits to the public.

Key points: The purpose of the NDT should start with end-users’ needs. It should help to deliver inclusive social outcomes.

‘Public good’ does not imply that the NDT must be entirely publicly funded. The principle of ‘value creation’ does imply both private and public investment in digital twins.

Gemini Principle 2

Value creation

Key statement: The NDT must enable sustainable value creation, performance improvement and effective risk management at asset, process and system levels.

Premise: Greater economic value will be released by creating an open and dynamic market related to digital twins. Improving the performance of existing and new infrastructure will increase national productivity.

Key points: The NDT must be structured to promote innovation and competition, and to ensure wide access to the benefits, consistent with the principle of public good.

The NDT must facilitate improved infrastructure performance, both as a system and as a service.

Value must be shared fairly within the NDT ecosystem.

Gemini Principle 3

Insight

Key statement: The NDT must provide determinable insight into the built environment.

Premise: Better insight based on better data will enable better decisions and lead to better outcomes for the public. The NDT must help to achieve this and it must be measurable.

Key points: The NDT must enable the generation of meaningful metrics to provide insight on performance and improvement in the built environment. This should include measures of the success for the framework and NDT.

The NDT must facilitate a response to enduring questions⁶ such as:

- What infrastructure does the nation have?
- What are its capacity, location, condition and value?
- How do people and businesses use infrastructure?
- How well is the nation’s infrastructure performing as a system?
- How well is it providing service?
- What are the environmental, social and economic impacts of existing and proposed infrastructure?



Trust

Key statement: The national digital twin must be trustworthy.

Premise: Public trust in the national digital twin is very important. Loss of public trust would constitute a serious loss of value.

Key points: The NDT must be ‘ethical by design’ and the governance and regulatory arrangements for overseeing it must be transparent, open and effective in ensuring that its operation is consistent with the Gemini Principles.

The framework and NDT must comply with the Data Ethics Framework.⁷

The NDT must also be trustworthy for the owners of the constituent digital twins so that they feel confident to contribute. This is essential for the NDT to work effectively. Therefore, issues of liability and risk must be addressed in the NDT.

Gemini Principle 4 Security

Key statement: The NDT and framework must enable security and be secure themselves.

Premise: Data security and thereby personnel, physical and cyber security are essential to ensuring the integrity of the NDT. The other principles must always be balanced against this key consideration. To do this, the framework must promote a risk-based approach, based on embedded holistic security principles.

Key points: The NDT must be ‘secure by design’. Holistic security principles must be built into it from the outset and ensure that data sharing is managed effectively.

The NDT must address:

- Protection of personal data and privacy
- Protection of sensitive national infrastructure assets
- Protection of commercial interests and intellectual property
- Mitigation of risks arising from data aggregation

Gemini Principle 5 Openness

Key statement: The NDT must be as open as possible, while remaining consistent with the principles of holistic security, so that it creates the most value for everyone.

Premise: Data benefits from network effects: it creates more value as more people use, contribute to and maintain it, subject to and supported by effective information governance to maintain data quality and provenance.

Key points: Open data, open culture, open standards, open source and collaborative models build trust, reduce cost and create more value than other approaches.

The NDT must be based on open standards, industry best practices and open application programming interfaces (API) to allow a vendor-neutral approach, with industry-agreed architecture models.

Gemini Principle 6 Quality

Key statement: The NDT must be built on data of an appropriate quality for the purpose to which it is put.

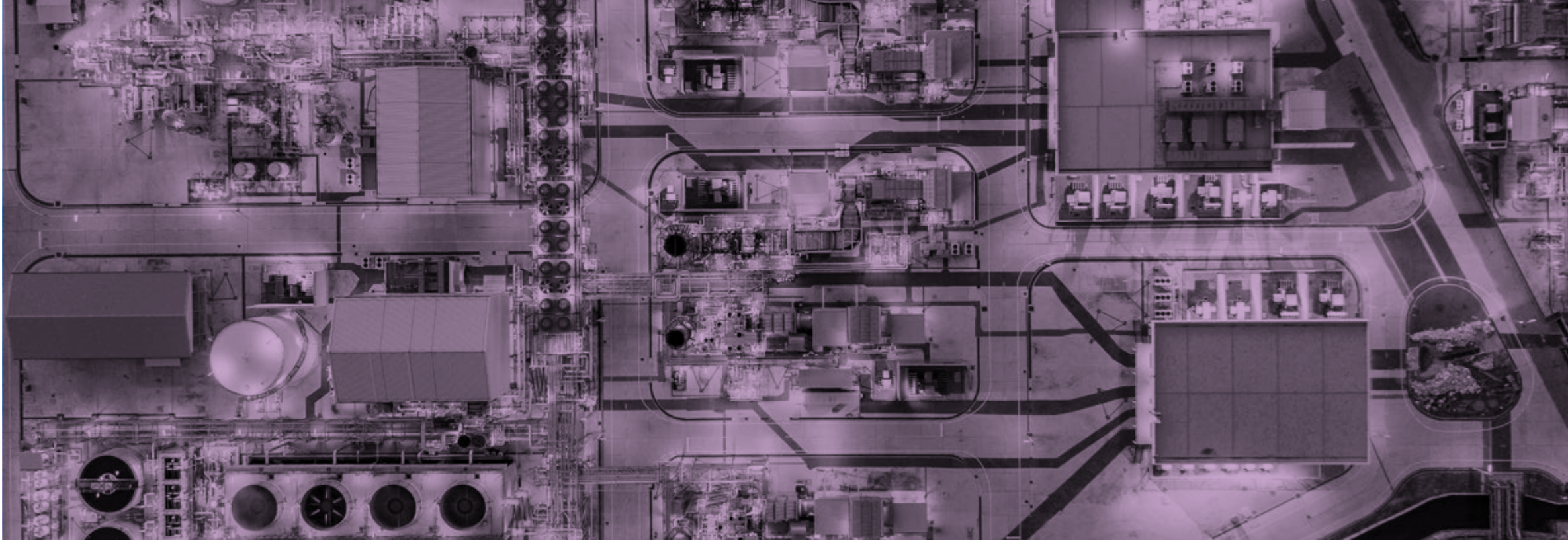
Premise: The NDT is built on data. Its function is to enable the integration of data by those who see an opportunity to create value. Therefore, that data must be of a suitable quality for the intended purpose.

Key points: ‘Quality’ only has meaning in relation to agreed requirements. Appropriate quality data is suited to the level of functionality, security and longevity required to fulfil the purpose for which it is used. Minimum standards/requirements for data quality will apply.

The success of the NDT will be judged on the quality of decisions it enables. Appropriate quality data will be necessary, but not sufficient, to enable such decisions.

The NDT must support an appropriate level of data quality and accuracy at each level of detail. The framework should support the recording of quality attributes.

The level of quality must be transparent, defined and measured.



Function

Key statement: The NDT must function effectively in support of its purpose and it must be available to users when required.

Premise: Effective information and security management is essential for the functioning of the NDT to be trustworthy.

Key points: Secure interoperability of master data sets is the key enabler of the NDT; this will need focus to make the NDT function.

A library of stakeholder co-produced and validated use cases should be developed to demonstrate the range of possible functions to other adopters.

Gemini Principle 7

Federation

Key statement: The NDT must be based on a standard, collective and connected environment.

Premise: The NDT is an ecosystem of digital twins that are joined via secure and resilient sharing of data.

Key points: The information management framework must allow a common approach to secure interoperability (to enable the federation of digital twins), including data governance across sectors.

The NDT must be able to work with:

- different classes of data and information within and across infrastructure sectors and the wider built and natural environments
- different spatial and temporal scales
- different approaches to modelling

Gemini Principle 8

Curation

Key statement: All parts of the NDT must be clearly and transparently owned, governed and regulated.

Premise: Responsibility must be taken for the framework, the NDT and for the data on which the NDT is based.

Key points: ‘Ownership’ should address data ownership – accountability for curating appropriate quality data and putting the skills and competencies in place to achieve this. Potentially, different parties could ‘own’ different data sets that need to come together.

‘Governance’ should address overall management of the ecosystem, ensure fair value share – including to the end-users – and make sure that the standards are being followed.

‘Regulation’ should drive the desired behaviours when market forces alone are not enough.

Gemini Principle 9

Evolution

Key statement: The NDT and framework must be able to adapt and develop as everything evolves (technology, society, requirements, information management, cyber-security, data science and the built environment itself). The NDT must remain useable during this period.

Premise: While technology will continue to develop, the fundamental connection between data, decisions and outcomes is likely to remain. Ultimately, the information itself may be more valuable and have greater longevity than the technology that enables it.

Key points: The NDT must be impartial to specific technical solutions, platforms and software.

With continual evolution, the NDT should have the potential to provide value as long as the built environment and the society it serves exists.

Call to action and next steps

All involved in creating and managing the built environment stand to benefit by driving effective information management. Industry leaders must act as champions and get involved, unlocking value for their own organisations, the national economy and society.

There is both opportunity and risk. The fourth industrial revolution is starting to affect all industries involved in the built environment. Those that play an active part can help to guide the direction of travel and the outcomes; those that ignore it could find themselves left behind or losing control.

Next steps for the DFTG are to:

- Develop a roadmap for delivering the framework
- Lead the co-development of the framework
- Connect the leaders who are developing digital twins

The next steps for leaders involved in planning, creating and managing the built environment are to:

- Build consensus on the Gemini Principles
- Co-develop and implement the framework
- Develop digital twins that comply with the Gemini Principles

Engage and join the conversation.

Please share comments on the Gemini Principles:
enquiries@cddb.cam.ac.uk

Follow progress: **www.cddb.cam.ac.uk**



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Simon Tucker, NDA
Peter Vale, Tideway
Jim Walker, Environment Agency
Keith Waller, IPA
Dr Matthew West, Information Junction
Michael Wignall, Microsoft

Glossary

Appropriate: Suited to functionality and purpose – of the right quality and quantity; sufficiently complete, competent, robust, secure and durable; based on correct assumptions; showing the necessary level of fidelity.

Built environment: All forms of buildings (residential, industrial, commercial, hospitals, schools), all economic infrastructure (above and below ground) and the urban space and landscape between and around buildings and infrastructure.

CDBB: Centre for Digital Built Britain, a partnership between the Department for Business, Energy & Industrial Strategy and the University of Cambridge, supported by industry. Reports to HM Government through the CDBB strategic advisory board.

DFTG: Digital Framework Task Group, part of the Centre for Digital Built Britain.

Digital: A branch of engineering knowledge and practice that deals with the creation and practical use of data or computerised devices, methods, systems and processes.

Digital Built Britain: The UK government's programme to create a digital, integrated approach to the built environment, to deliver services and growth.

Digital twin: A realistic digital representation of something physical. What distinguishes a digital twin from any other digital model is its connection to the physical twin.

Federation: A group of systems and networks operating in a standard, collective and connected environment.

Information management framework: All that is necessary to enable effective information management across the built environment. It addresses secure, resilient interoperability, which is fundamental for creation of a national digital twin. An intrinsic element of the Construction Sector Deal supporting HM Government's Industrial Strategy.

Gemini Principles: Values to guide the development and use of the information management framework and the NDT.

Integration: The process of bringing together component subsystems into one overall system.

Interoperability: A characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, at present or in the future.

NDT: National digital twin – an ecosystem of digital twins that are connected by securely shared data.

End notes

1. Deloitte. New technologies case study: Data sharing in infrastructure – a final report for the National Infrastructure Commission, November 2017
2. Office of National Statistics. Developing new statistics of infrastructure: August 2018
3. Data for the public good: www.nic.org.uk/publications/data-public-good
4. Smart Infrastructure – getting more from strategic assets: <https://www.smartinfrastructure.eng.cam.ac.uk/files/the-smart-infrastructure-paper>
5. Prepare for the impact of digital twins. Pettey, Christy: www.gartner.com/smarterwithgartner/prepare-for-the-impact-of-digital-twins
6. The concept of 'enduring questions' in infrastructure was developed by the Australian Bureau of Infrastructure, Transport & Regional Economics and is articulated in its National infrastructure data collection and dissemination plan: https://bitre.gov.au/data_dissemination/files/National_Infrastructure_Data_Collection_and_Dissemination_Plan.pdf
7. Data Ethics Framework: www.gov.uk/government/publications/data-ethics-framework/data-ethics-framework

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