The Institution of Engineering and Technology

Department for Business, Energy & Industrial Strategy

The Apollo Protocol: Unifying digital twins across sectors

A proposal to unlock the benefits of digital twins between the built environment and manufacturing sectors, supported by the technology sector

theiet.org/built-environment

In partnership with

CATAPULT High Value Manufacturing

cdbb Centre for Digital Built Britain

Construction Leadership Council

Construction Innovation Hub

Digital Twin Hub

techUK

The Alan Turing Institute

The University Of Sheffield. AMRC Advanced Manufacturing Research Centre

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The Apollo Protocol: unifying digital twins across sectors **is published by the Institution of Engineering and Technology (IET).**

Please note that the views expressed in this publication are not necessarily those of the IET. The guide only intends to identify the relevant issues and to inform a public policy debate around the topic, rather than to provide a definitive solution.

The IET's Built Environment, Design and Manufacturing, and Digital panels would welcome any comments you may have on the contents of this guide and your ideas for future publications. Please get in touch by emailing **sep@theiet.org**.

The Institution of Engineering and Technology

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1. About this report

How can the built environment and manufacturing, supported by the technology sector, break the sectoral divide, and unlock the benefits of digital twins?

This report has been published by the Institution of Engineering and Technology (IET) to examine the potential for developing environmental performance and commercial growth in manufacturing and built environment sectors. The paper finds that this would be achieved by unifying a cross-sector approach to integrating digital twins into industrial practice. *The Apollo Protocol* examines the background, context and current use of digital twins, as well as approaches to harmonising their deployment across the sectoral divide as they become ubiquitous in the industrial ecosystem. This paper has been written to assist government, policymakers, digital industry and technology professionals.

There are two key outcomes collaboration can achieve:

1. Understanding true performance: clarity about our respective systems performance and data will reduce the environmental impact of our products and services.
2. Encouraging sustainable growth: building a single value chain for data and information management will open new market opportunities and business models.

The authors of this report represent both the manufacturing and built environment sectors, as well as the digital twin and cyber-physical technology industries. Each stakeholder sector has commercial, environmental and social objectives that could benefit from a collaborative approach. The sectors could also benefit from expertise and knowledge exchange as they seek to establish a path to new business opportunities and capabilities.

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Words of support

"Developing and operating infrastructure digital twins is essential for improved decision making. By ensuring cross-sectoral quality information is available, greater value can be achieved for asset operation and wider citizen services. The Apollo Protocol articulates how silos can be broken down to deliver this vision."

Dame Wendy Hall FRS FREng Regius Professor of Computer Science University of Southampton

"Since 2016, Google web searches for the topic "digital twins" has multiplied by a factor of 25. But therein lies the problem. As more sectors adopt them, a greater need for a common language arises. The Apollo Protocol will break down this semantic barrier through thematic cross-sectoral engagement."

Professor Rab Scott, Chief Engineer – Digital, High Value Manufacturing Catapult

"Digital skills are growing in importance and shrinking in abundance, with co-dependent industries often competing for the same talent. The Apollo Protocol is a paper which encourages constructive dialogue between adjacent sectors, scanning the horizon for future trends in digital engineering and developing new professions to build the future workforce. It is a natural evolution of our long-standing work in digital skills and diversity."

Jacqueline de Rojas CBE, Outgoing President, techUK

"Our engineering disciplines are fragmented within and between sectors. The Apollo Protocol is an opportunity for a 'great unification' of engineering where will see the coming together of engineering disciplines under a common purpose to design high performing system of systems and enable a truly circular and sustainable built environment."

Neil Thompson FIET, Director at Atkins, Digital Manufacturing and Performance Lead, Construction Leadership Council, Built Environment Panel Chair

"The development and adoption of digital twins, enabled by connected systems and driven by good known data to gain greater insights is already underway in manufacturing. However, as products move out of manufacturing and into the operation phase, the interoperability between twins becomes paramount. The Apollo Protocol enables a major step towards achieving this."

Austin Cook - Principal Technologist in Emerging Technologies & Systems - BAE Systems

2. Recommendations

When it comes to innovation, the manufacturing and built environment sectors often work with similar processes, only in different ways.

New products and services generally focus on sector-specific issues, resulting in path-dependent behaviours that can lead to unfit codes of practice, an inability to successfully implement at scale and other recurring issues. Unless there is a change to this silo mindset, these sectors will remain prone to these behaviours and fail to meet today's challenges of poor performance and climate change.

Each industry is currently investing in data and information management systems. Recent innovations in digital twins are enabling better understanding of the true performance of products, services and systems. If unrelated industrial sectors take an insular approach, they risk failing to accelerate the change required to meet sustainability and performance goals. Cross-sectoral challenges require cross-sectoral collaboration.

The aim of this report is to demonstrate the benefits of connecting the manufacturing and built environment sectors, supported by the technology sector. The authors also aim to contribute their collective influence into the development of cyber-physical systems and national digital twin policies, enabling wider governmental initiatives.

The Apollo Protocol: formalising communication

Our goal is to deliver the Apollo Protocol: a mechanism for formalising communication between sectors. Alongside the ambition of the National Digital Twin and *The Gemini Principles*[1] guide to the national digital twin and the information management framework that will enable it, we are establishing a prototype mechanism for developing cross-sector digital twins. It is built on *The Gemini Principles*, *the IET's Digital twins for the built environment*[2], *Vision for the built environment*[3], the AMRC's *Untangling the requirements of a digital twin*[4] and techUK's *Unlocking value across the UK's digital twin ecosystem.*[5]

The Apollo themes

Digitally, each sector is a leader in their area. A key route to making progress in communication between the sectors is to bridge the language gap. To establish the Protocol, we propose these focal points for achieving cross sector digital twins:

A single value chain - For information and data services and requirements, enabling a new paradigm for policy makers across the lifecycle of product life cycles.

Circular supply chains - Through the alignment of standards and processes, turning the built environment sector's waste and latent material into a resource for the manufacturing sector through effective, integrated digitalisation.

Optimised performance - Throughout the product lifecycle, enabled through robust and interoperable data with technology enabled information sharing.

Managed human capital - Between the sectors to ensure resources are optimally utilised and have the right learning and reskilling environments for achieving the above themes.

The Apollo Forum

We recommend the creation of The Apollo Forum as the template for establishing working groups focused on cross-sectoral digital twin interfaces. Its mission is to create and define the Apollo Protocol to bridge sectors, untangling and aligning cultural, process and technological factors.

1 The Gemini Principles, Cambridge Centre for Digital Built Britain, 2018.
2 Digital twins for the built environment, the Institution of Engineering and Technology, 2019.
3 Our vision for the built environment, Construction Innovation Hub, 2021.
4 Untangling the requirements of a digital twin, University of Sheffield AMRC, 2020.
5 Unlocking value across the UK's digital twin ecosystem, techUK, 2021.

3. Introduction

Manufacturers and built environment operators differ in their responsibilities and expertise. Manufacturers produce specific products and are not always under any obligation to make their products digitally interoperable with competitor offerings.

Built environment operators tend to install mosaic-like product assemblies from different sources, which have the inherent potential to fail to integrate into a coherent system capable of performance measurement. Construction professionals are limited by the lack of product integration and the ability to acquire and share data for a system of systems view of asset performance.

Manufacturers iterate development, focusing on the specific product performance of the provided system. It is not always in their remit to consider the performance of their product once it is integrated into a broader system (for example, a pump in a heating system). This missing factor in the design process for manufactured products is demonstrated by the performance gap in buildings: the gap between the intended and actual performance.

This is made worse by the existence of a language barrier between the sectors that creates a fragmented set of perceived value chains. It also obscures the line of view from the product development in manufacturing, through to its performance in the built environment. Addressing the language of digital twins can help to standardise digital assets, allowing for cross-market interoperability and reducing the performance gap in the built environment.

Technology is available to support both sectors with networked systems, such as the Internet of Things (IoT) and Supervisory Control and Data Acquisition (SCADA). By making the technology sector the foundation for the Apollo Protocol engagement, we can produce common ground for integrating platforms. There are also opportunities for technology suppliers with sector-specific offerings, but which may have transfer value in others: for example, a product lifecycle management system in manufacturing could be applied as a common data environment for Building Information Modelling (BIM) management systems.

The manufacturing and built environment sectors also face challenges in the form of attaining net zero and sustainability goals. The danger is that by continuing to work in silos, these sectors will run the risk of overlap and inefficiency. Working with a shared strategic direction, the sectors can establish the infrastructure required to meet these challenges.

4. Current use of digital twins

Digital twins are being developed independently in both the manufacturing and built environment sectors. While the business cases for these investments differ between the sectors, without coordination both are at risk of evolving into incompatible markets.

Manufacturing

The manufacturing sector is diverse, encompassing a wide range of different industries, technologies and activities. Its solutions require advanced levels of precision and compliance with highly controllable processes requiring a strong system of systems approach. With its increased levels of automation and data exchange, Industry 4.0 is making strides in the factory environment and extending expertise into supply chains. By 2024, more than half of supply chain organisations will be investing in advanced analytics for understanding their business, a driver of digital twins.[6] This is evidenced by clear emerging use cases, supported by the recent digital twin manufacturing framework *ISO 23247*.[7]

Manufacturing applications for digital twin technology

Product design - An engineering design application digital twin can be used to learn from products currently in operation to assist with design optimisation of next-generation assets.
Process design - Offline analytic applications using historical state of digital twins with current synchronised control applications to modify the future state, making changes to a manufacturing process in real time.
Process management - Managing data from synchronised processes during production enables identification of issues and the improvement of materials/processes by displaying and interpreting the live state of an asset in operation.
Predictive maintenance - Information analysed in real-time scheduling adaptive maintenance activities. When machine conditions are always being informed, it can lead to a reduction of unplanned downtime by as much as 30 percent.[8]

Built environment

The built environment is not a formally recognised industrial sector in economic terms but has the value of expanding the economic horizon beyond construction and into the management of built assets throughout their lifecycle. Construction-related spending represents 13 percent of all economic activity, while the built environment is responsible for 40 percent of all carbon emissions and nearly 15 percent of particulates in urban areas.[9] A leading application for digital twins in this sector is asset management systems (AMS) and the operations space. The National Digital Twin programme's climate resilience demonstrator (CReDo)[10] has infrastructure operators building interconnected twins of operational assets, such as power networks, water utilities and telecoms.

The sector has begun to develop standards for the interconnection and operation of digital twins.[11,12]

Built environment applications for digital twin technology

Citizen-centric data models - Ensuring citizen involvement in the infrastructure decision-making processes, from local planning through to impact assessment of infrastructure investments.
Retrofit of at-risk infrastructure - Enabling visibility of latent risk in existing fixed capital stock, including service operations risks, such as the digital requirements published in Dame Hackitt's *Independent review of building regulations and fire safety*.[13]
Regional resilience, response and simulation - Using connected data and organisations to enable simulation and response capabilities across interconnected infrastructure, and to test potential mitigations.

6 Gartner predicts the future of supply chain technology, April 2022.
7 ISO 23247-1:2021(en) Automation systems and integration — digital twin framework for manufacturing — Part 1: Overview and general principles.
8 Enable predictive maintenance to cut unplanned downtime up to 30%, PTC.
9 Seizing the decarbonization opportunity in construction, McKinsey, July 2021.
10 The National Digital Twin programme's Climate Resilience Demonstrator (CReDo).
11 BSI Flex 260.
12 Information Management Framework (IMF), Cambridge Centre for Digital Built Britain.
13 Independent Review of Building Regulations and Fire Safety: Hackitt review - GOV.UK (www.gov.uk).

5. Connecting the sectors

Digital twins with different definitions and methodologies are being developed in different sectors, making industry collaboration difficult. To produce a cross-sector framework, there is a requirement for standardisation. Establishing a protocol for coordinating digital twin implementations across sectors has the potential to unlock opportunities for significant benefits. There are four themes that need to be examined to connect this context:

1 Aligning the value chain	2 Circular supply chains
3 Performance optimisation	4 Human capital management

1 Aligning the value chain

Objective: to identify a single value chain for data and information management and push this new paradigm through to policy makers responsible for procurement.

Manufacturing

Manufacturers approach the value of product development to maximise efficiency of production. Value is considered in the delivery of products and services through logistics and operations, but not beyond. Supply chains are optimised to take into account the upstream value chain, but not its relationship to the built environment.

Built Environment

Value has broadened from solely economic value to encompass social and environmental factors, meaning that more data needs to be managed. As built assets have long lives, the sector needs to ensure that data is relevant and robust throughout its lifecycle. Current fragmented digital strategies prevent the realisation of a connected value chain.

Aligning the value chain: opportunities for learning

Both sectors operate within complex supply chains with heavy utilisation of SMEs, procurement requirements and standards compliance, with common barriers to a connected value chain.

To unlock previously unexploited potential, the sectors must come together to identify interfaces of a connected value chain. This can only be achieved with technology-enabled solutions, such as data insights and smart contracting, enabling a whole system of systems view of the value chain across sectors.

- Identify the cross-sector value chain for data and information management.
- Establish best practice for defining cross-sector interfaces through road mapping, supported by case studies and key performance indicators (KPIs).
- Understand and map the current and evolving ecosystem of enabling technologies.

2 Circular supply chains

Objective: to pursue circularity through the alignment of trade standards and processes; to realise the benefit of different material consumptions through new business models.

Manufacturing

In 2018, the UK commercial and industrial sectors combined produced 43.9 million tonnes of waste.[14] In 2021, 40 percent of companies were already prioritising investments in sustainable manufacturing processes.[15] Closing waste, by-product and end-of-life feedback loops is key to enable circularity.[16,17] Life cycle assessment of assets is also common for high value manufacturing with well-established standards and processes (*ISO 14040/14044*).

Built Environment

In 2018, the UK generated 67.8 million tonnes of non-hazardous construction and demolition (C&D) waste, of which 62.6 million tonnes was recovered. This represents a recovery rate of 92.3 percent.[18] The built environment is a potentially exploitable material resource for manufacturing and construction,[19] but is presently a major source of landfill. To realise this market opportunity, more information is required. Enhanced academic curricula and integration of diverse stakeholders.

Circular supply chains: opportunities for learning

Sustainability is a global challenge requiring cross-sectoral collaboration. Investment opportunities and growth are now linked to environmental, social and governance (ESG) commitments.

Although the concept of a circular economy is well established[20] the interfaces that enable circularity for adjacent industrial sectors is not clear. Using construction waste as an input to the manufacturing materials supply chain would enable cross-sector services to maintain and reuse maintainable assets.

A protocol for integrated digital twins will drive faster decarbonisation for adjacent sectors through a common exchange mechanism for relevant data. This will decouple unsustainable resource consumption from economic growth, creating new value in a circular system.

- Identify benefits to the sectors sharing data to reduce waste and enable a circular economy.
- Develop the framework for identifying information and shared data governance required by both sectors.

14 UK Statistics on waste, DEFRA, 11 May 2022.
15 2021 State of manufacturing report, fictive.
16 Manufacturing a circular economy, MAKE UK, March 2021.
17 The circular imperative, Philips.
18 Ibid. DEFRA.
19 Buildings as Material Banks.
20 Ellen Macarthur Foundation.

3 Performance optimisation

Objective: to optimise performance through the implementation of digitally transparent and interoperable supply chains.

Manufacturing

Remaining competitive in an increasingly demanding global market is key for manufacturing, requiring both prioritisation of its market position and what is needed to establish superior practices.[21] Culturally lean performance metrics drive business decisions evaluating cost, quality, dependability and flexibility.

Built Environment

Performance in the built environment has diverse requirements, with buildings often using twice as much energy as predicted.[22] One explanation is the lack of actively monitored assets.[23] The Operational Energy and Carbon Reporting Framework (OpEC)[24] integrates data requirements across the delivery lifecycle, facilitating client-side energy managers and procurement teams.

Performance optimisation: opportunities for learning

As best practice evolves, it is dependent on available information as well as the perspective of decision makers. Sectors define their own metrics and methods of working, viewing them through their own lens. Extra time in design could reap manufacturing and environmental benefits.

A cross-sector collaborative approach driven by data insights to the performance gap would address the interoperability challenge and allow performance to be explored in a fundamentally different way, with benefit to industry, society and the environment.

- Capture examples of intelligent data use between sectors and the associated performance benefits that products across the asset lifecycle could achieve.
- Encourage sharing of data between sectors and the identification of opportunities.
- Develop methodologies to explore the opportunities, such as how bringing manufacturers into the built environment design process early can front load information exchange.

4 Human capital management

Objective: to manage human capital between the sectors to ensure that competition is healthy while achieving a common goal.

Manufacturing

59 percent of companies maintain that the current education system is failing to provide the skills they require.[25] Manufacturers traditionally take a siloed approach to challenges despite evolving Industry 4.0 implementations and the cultural shift this requires for working practices. Cyber-physical infrastructure requires different mental models of working and skill requirements.[26]

Built Environment

Half of employees will need reskilling, while more than half of employers in the sector are unable to identify the roles they need to transform their workforces.[27] There is a need to bolster and retain a diverse intake of talent with the right competencies.[28] This requires greater use of apprenticeships, enhanced academic curricula and integration of diverse stakeholders.

Human capital management: opportunities for learning

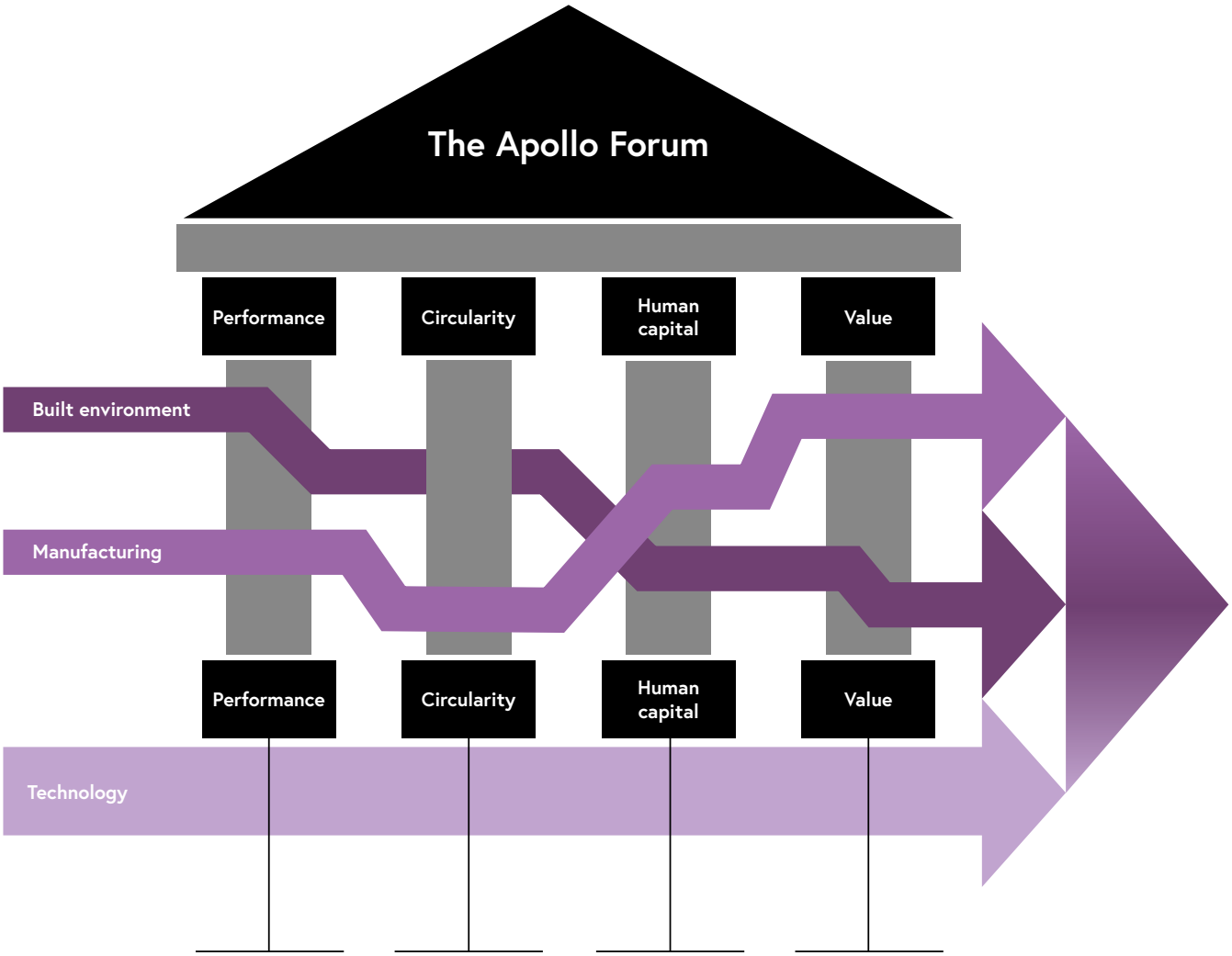
Digital skills are becoming increasingly important in decision making and the operation and governance of data management systems. Industry is not prepared for the transition from the existing paradigm of competition for skilled professionals towards integrated cross-sectoral engineering disciplines.

Effective management of an agile workforce will require appropriate incentives, decision frameworks and a consistent work culture for tech skills. Social sciences such as psychology and economics are also vital to enable both sectors to develop career paths that are resilient, flexible and attractive to talent.

- Adopt a coordinated, collaborative approach to the development of digital skills between sectors.
- Support policy for future education systems that encourage the development of T-shaped professionals - niche-topic specialists with generalist and people skills.

[21] Leachman, C., Pegels, C.C. and Kyoon Shin, S. (2005), Manufacturing performance: evaluation and determinants", International Journal of Operations and Production Management, Vol. 25 No. 9, pp. 851-874.
[22] Post occupancy review of building engineering (PROBE) studies, CIBSE, 1995-2002.
[23] Performance gap between building design and operation, Designing Buildings Wiki, January 2022.
[24] Energy and carbon reporting framework, Construction Innovation Hub, October 2021.
[25] Annual manufacturing report 2020: the search for stability.
[26] Enabling a national cyber-physical infrastructure to catalyse innovation.
[27] Skills and competencies for the National Digital Twin, Centre for Digital Built Britain.
[28] Industry Skills Plan for the UK construction sector 2021-25, Construction Leadership Council, March 2021.

We recommend the creation of The Apollo Forum as the template for establishing working groups focused on cross-sectoral digital twin interfaces. Its mission is to create and define the Apollo Protocol to bridge sectors, untangling and aligning cultural, process and technological factors. The forum is a place to bring together the views of key stakeholders in the core sectors to draw up a roadmap to address the challenges and opportunities of cross sector digital twins.



Optimise performance throughout the implementation of digitally transparent and interoperable supply chains.

Pursue circularity through the alignment of trade standards and processes, turning the built environment into a resource through effective, integrated digitisation.

Manage human capital between the sectors to ensure that competition is healthy and helps achieve a common goal.

Align the value chain and push this new paradigm through to policy makers responsible of procurement.

6. About the Apollo Forum

Apollo Protocol

The Protocol is a framework for different industrial sectors to engage with and learn from each other. This is essential for developing cross-sector initiatives effectively, such as digital twins. The framework is a set of principles that will encourage collaborative cross-sector activity, bringing together policy, standards, working practices and existing initiatives.

Inspired by the EU's eHealth Interoperability Framework[29] and the National Interoperability Framework Observatory, the Protocol will seek to become an enterprise interoperability framework[30] to encourage sharing and exchanging information.[31]

The Apollo Protocol will be available for use by any cross-sector initiative. It will be developed initially via the Apollo Forum, an exemplar engagement between manufacturing, the built environment and tech industrial sectors.

Apollo Forum

The Forum will identify a combined strategic direction and language for digital twins in manufacturing and the built environment, supported by the technology sector to achieve the potential of connected digital twins. Participants will be working on digital twins and related work in manufacturing, the built environment and technology sectors – in companies of any size – to assist policy makers working in this field.

The Forum will identify a combined strategic direction and language for digital twins in manufacturing and the built environment, supported by the technology sector to achieve the potential of connected digital twins. Participants will be working on digital twins and related work in manufacturing, the built environment and technology sectors – in companies of any size – to assist policy makers working in this field.

[29] European eHealth interoperability framework, European Union.
[30] Enterprise interoperability framework, Wikipedia.
[31] National Interoperability Framework Observatory (NIFO), European Union.

Forum operating principles

The Forum will publish a governance document setting out how decisions are made on participation, as well as roadmap and project activities. It will also include details on the processes to change the rules, strategy and purpose of the community. Key aspects of the governance document include:

Vendor-neutral governance

Facilitating learning between sectors and ensuring shared decision making, inclusiveness and accessibility.

Connected engagement

Plugging into other initiatives, to ensure facilitating not competing. Focusing on real-world problems and use cases, using and building upon the existing tools the sectors have developed. Fostering genuinely open participation.

Aligned research direction

Encouraging cross-sectoral participation in funding initiatives. Encouraging full demonstrations utilising technical interfaces between the sectors.

Collaborative management

Remaining independent, inclusive and collaborative, providing a shared vision and roadmap for cross-sector activity between organisations of all sizes. Clear language, user-centric, reduced bureaucracy.

Policy partnership

Establishing a cross-sector collaborative group to provide value to the government about known policy outcomes, international standards and industrial strategy.

Openness

Creating an environment of trust for sharing data between sectors. All findings to be published and fully accessible. Development of open-source and reusable specifications and value-driven outputs.

Forum stakeholders

This work is being created with support from organisations engaged in developing cross-sector digital twins.

Current stakeholders are listed in section 8, Acknowledgements. These stakeholder organisations will act as sponsors of the Forum and publishers of its content.

The Forum will seek to expand its stakeholder base internationally, drawing on the manufacturing, built environment and technology sectors. As the Forum matures there will be the opportunity to make connections with other cross-sectoral interfaces.

Suggested Forum activities

- Establish core group.
- Set up infrastructure and governance processes aligned with Forum principles.
- Recruit participants from all relevant sectors and policy makers.
- Establish initial working groups on the four key themes. Publish the outputs.
- Review existing work streams that can be shared cross-sector for mutual benefit. Publish the outputs.
- Produce and publish the first draft of the Apollo Protocol.
- Create, maintain and operate the protocol in an agile, open and collaborative way.
- Establish a draft measurement model for evaluating interoperability in cross-sector digital twins.
- Review progress, identify future activities.

7. Resources

The Gemini Principles, Centre for Digital Built Britain, 2018.

Digital twins for the built environment, the IET, 2019.

Common Guidelines for eHealth harmonisation and interoperability, EU4Digital, 2020.

Untangling the requirements of a digital twin, University of Sheffield AMRC, 2020.

Digitisation for construction product manufacturers: a plain language guide, the IET 2020.

Good data for the public good, the IET 2020.

Vision for the built environment, Construction Innovation Hub, 2021.

The pathway towards an information management framework: a commons for a digital built Britain, Centre for Digital Built Britain, 2020.

Unlocking value across the UK's digital twin ecosystem, techUK, 2021.

ISO 23247-1:2021 Automation systems and integration – Digital twin framework for manufacturing – Part 1: Overview and general principles, ISO, 2021.

BSI Flex 260: v1.0 2022-01 Built environment – Digital twins overview and principles – Guide, British Standards Institution 2021.

The National Digital Twin programme's climate resilience demonstrator (CReDo), 2021.

The National Interoperability Framework Observatory.

8. Acknowledgements

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The Construction Leadership Council (CLC)
Construction Innovation Hub
The Digital Twin Hub (supported by the Connected Places Catapult)
techUK
The Alan Turing Institute
The University of Sheffield Advanced Manufacturing Research Centre (AMRC)

9. About the IET

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Our mission is to inspire, inform and influence the global engineering community to advance technology and innovation for the benefit of society.

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We bring together engineers, technicians and practitioners from industry and business, from academia and research, and from government and the third sector. We are member-led, independent and impartial.

We cover engineering across industry from design and production, digital and energy to healthcare, transport and the built environment. We bring together expert practitioners from the transport industry, academia and third sector.

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