
# Digital Twin Capabilities Periodic Table

**A Digital Twin Consortium User Guide**

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The *Digital Twin Capabilities Periodic Table* (CPT for short) is an architecture- and technology-agnostic requirements-definition framework. It is aimed at organizations that want to design, develop, deploy and operate digital twins based on use case capability requirements versus the features of technology solutions.

CPT multidisciplinary teams need to create digital twins requirements specifications in large scale complex environments. The framework keeps the focus on the capability requirements of individual use cases, which can then be aggregated to determine the overall capability requirements, digital twin platforms and other technology solutions that are required to address the specific business needs.

It follows a periodic table approach with capabilities grouped or "clustered" around common characteristics. It is easy to interpret in the boardroom when explaining the business case to get funding for a digital twin project, and on the shopfloor when gathering requirements for a digital twin application. It provides visual guidance for collaboration, brainstorming and making capability requirements explicit.

End users that are investigating digital twin technology to address business transformation and other digitalization needs often ask these three questions:

- What is a digital twin?
- Why should I care?
- How do I get started?

Digital Twin Consortium's[1] (DTC) definition of a digital twin provides a comprehensive answer to the first question.

*A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.*

- *Digital twin systems transform business by accelerating holistic understanding, optimal decision-making, and effective action.*
- *Digital twins use real-time and historical data to represent the past and present and simulate predicted futures.*
- *Digital twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT/OT systems.*

The second question is addressed by the use case reference library being developed by the DTC.

It describes the problem, the impact and the way that a digital twin addresses the specific business challenge. It highlights the benefits and impact of digital twins in various use cases.

[1] *https://www.digitaltwinconsortium.org/initiatives/the-definition-of-a-digital-twin.htm*

This guide assists with the third question on how to get started with digital twins. It provides a framework for organizations that are just starting on the journey, and it provides a consistent approach as organizations scale out and increase their digital twin maturity.

# 1 REQUIREMENTS FOR THE DIGITAL TWIN CPT

## 1.1 CAPABILITY VS TECHNOLOGY

*Capability* is the ability to perform certain actions or achieve certain outcomes. The ability to drill a hole is a simple example of a capability. There are multiple use cases that require holes and each of them will have unique requirements in terms of the size, the depth or the substance that is drilled. This may be one of many capabilities required to complete a project where the hole is part of a successful solution.

The CPT is focused on technology-based capabilities but is agnostic to specific technology or product solutions. For example, machine learning capability can be provided by several technology providers, each with different products. During the assessment of vendor capabilities, the technology solution should fulfill the technological capability requirement of the business use case.

The approach used in the Digital Twins Capabilities Periodic Table to describe these capabilities follows a simple structure:

- what it is (capability name),
- what it does (cap-ability description) and
- what it means or purpose (what does it enable).

The CPT is not a reference architecture; it supports multiple architectural approaches. It highlights the capability building blocks for composable digital twins. The Digital Twin Consortium reference architecture provides recommended structures and integrations of Internet of Things (IoT), Information Technology (IT), Operational Technology (OT) and Engineering Technology (ET) products and services to form a digital twin solution. The CPT supports reference architectures that end-users may have developed using their own corporate standards, in addition to the DTC reference architecture.

## 1.2 ENABLE COMPOSABLE DIGITAL TWINS

Composable Digital Twins (CDT) is an application development approach for digital twins that is based on the composable enterprise architectural pattern. Composable applications, such as CDTs, focus on faster time to value, service-based orchestration and reusing packaged business capabilities to develop and adapt applications as business requirements evolve.

Packaged Business Capabilities (PBC) are modular combinations of technical capabilities that are presented as bundled services. These PBCs are orchestrated together through an application composition platform to deliver digital twin applications for specific use cases.

The CPT provides a consistent framework to identify the capabilities that can be grouped together to create these PBCs. Figure 1-1shows a composable Digital Twin reference model that outlines the different data types and data sources that are leveraged by PBCs to create reusable and agile Digital Twin compositions.

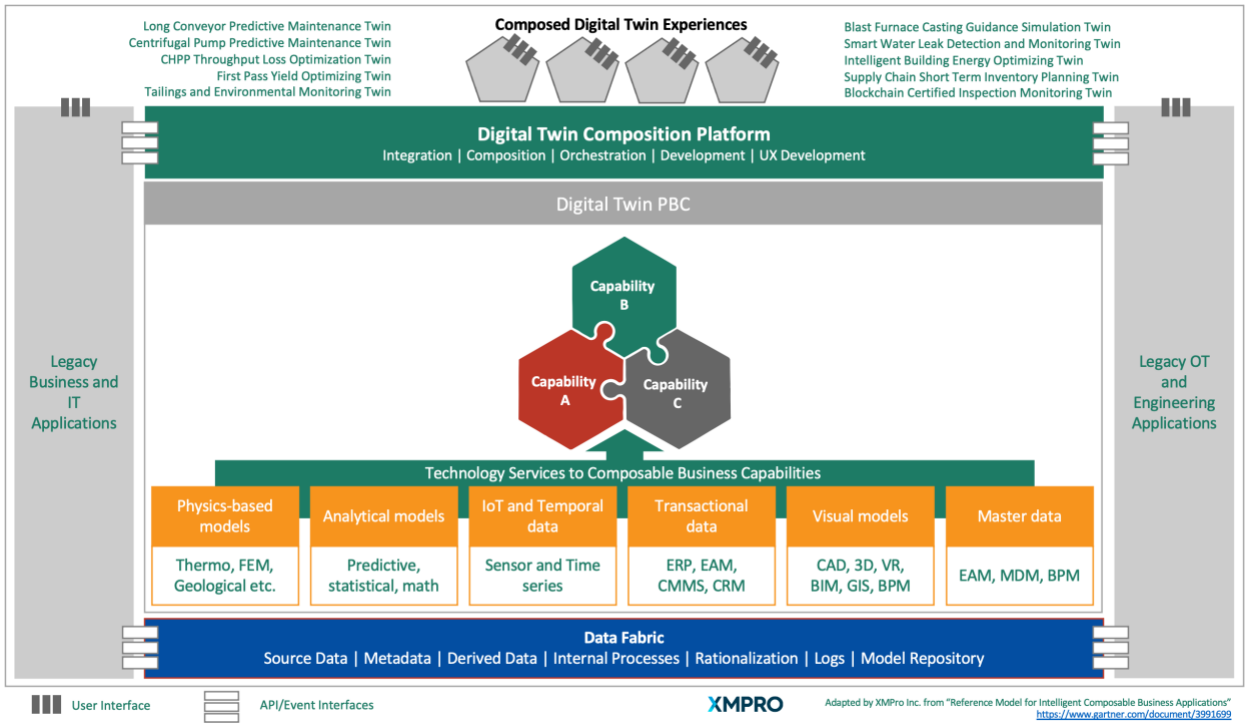


Figure 1-1: Composable Digital Twin Reference Model for discrete and system of systems digital twins.

A key characteristic of a composable digital twin is that it is typically a combination of capabilities from multiple technology vendors. Composite or system-of-systems digital twins are based on an ecosystem of capabilities rather than a single vendor.

## 1.3 Ecosystem vs Single Vendor

The smorgasbord of capabilities that are all captured in the CPT are beyond the scope of any single vendor. It requires an ecosystem of interoperable technical capabilities to address large scale, complex digital twin use cases. The CPT provides a common framework for multiple vendors to identify and present key capabilities that they provide for a digital twin solution.

This common framework is a major benefit of the CPT for an end user organization that is clarifying requirements for a digital twin. It removes the focus from vendor-specific technologies and places it on the key capabilities that are required to deliver a digital twin solution successfully. It is useful in analyzing a vendor solution to see if it is complete. It provides the opportunity to

light up the capabilities in the requirements and then overlay the capabilities in the solution to see how well they align.

### 1.4 FITS ACROSS THE DIGITAL TWINS LIFECYCLE

The CPT is applicable across the full lifecycle of the digital twin. The capabilities may differ during the different phases but identifying the key capabilities for each phase remains the same throughout the lifecycle.

Some capabilities may transfer between lifecycle phases, others may become obsolete, and others may be added. Capabilities during the design and construction phase may not all transfer to the operations and maintenance phase of an entity like a production plant. This facilitates the development of the *digital thread* as it transitions through the different lifecycle phases. As shown in Figure 1-2,, the digital twin supports the digital thread through these capabilities. The digital twin Capabilities Periodic table can also be used to identify capabilities for the digital thread.

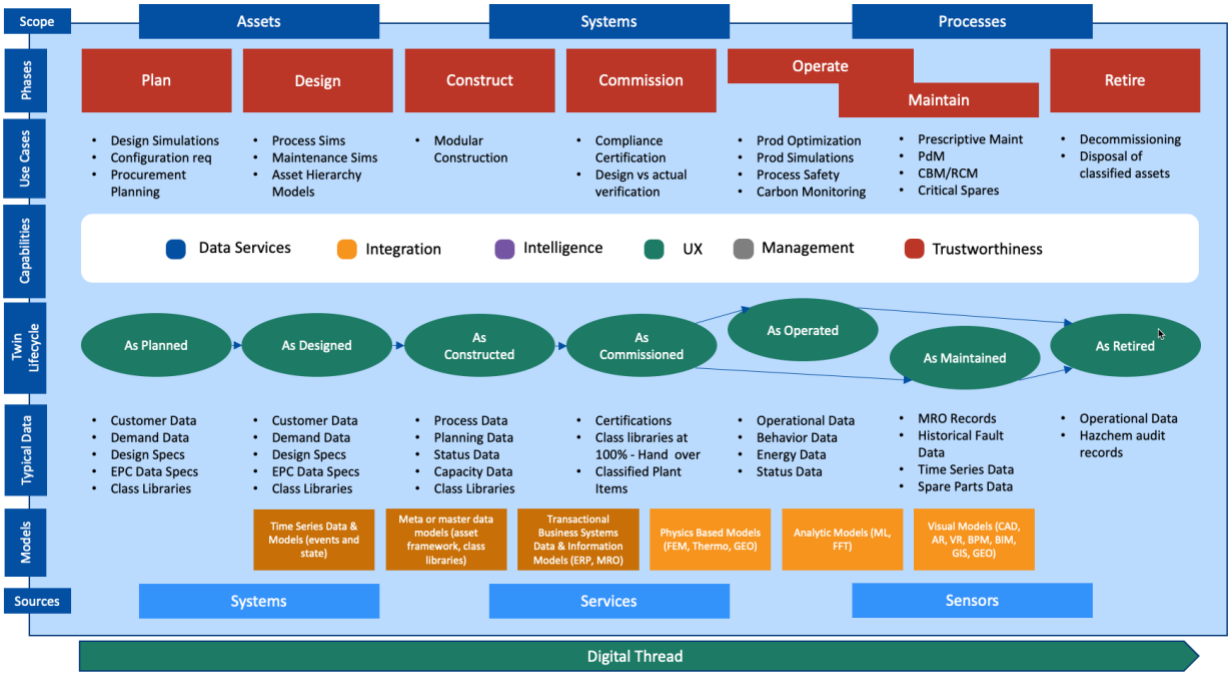


Figure 1-2: Capabilities during the digital twin and digital thread lifecycle.

The CPT provides a consistent approach for increasing capability maturity at both project and organizational levels throughout full product life cycles.

## 2 THE DIGITAL TWIN CPT

### 2.1 THE DIGITAL TWIN CPT CATEGORIES

The CPT is organized into six logical groupings, matching capabilities that have similar characteristics and application. Figure 2-1 provides context to the different categories that reflect both the digital and physical twins.

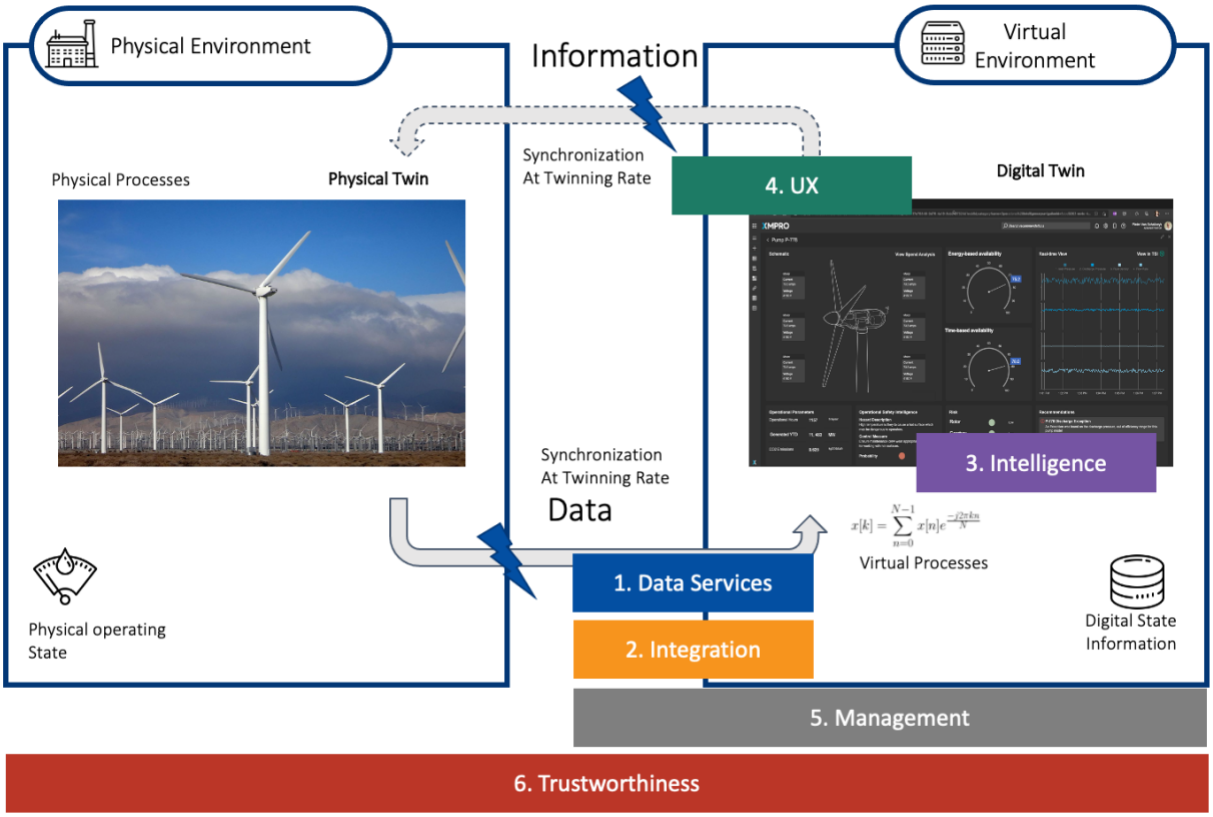


Figure 2-1: Digital twin CPT categories in physical and virtual domains.

Table 2-1 summarizes the category names and the category descriptions for the CPT.

| No | Category Name | Category Description |
|---|---|---|
| 1 | Data Services | Enables data access, ingestion and data management across the platform from the edge to the data center. It establishes the physical to virtual connection and receives data directly from equipment sensors or control systems, performs localized processing and distributes to other tiers. |
| 2 | Integration | Enables data access to existing internal and external enterprise systems and applications. Enables communication across different digital twins. |
| 3 | Intelligence | Provides an environment for the development and deployment of industrial digital twin solutions. It provides the services for data integration, basic and advanced analytics, AI, orchestration and other digital twin process capabilities. |
| 4 | UX | Provides the user with the ability to interact with digital twins and visualize its data. |
| 5 | Management | System and ecosystem management capabilities. |
| 6 | Trustworthiness | Security, privacy, safety, reliability and resilience capabilities. |

Table 2-1: Digital twins CPT category descriptions.

The six categories are used in the visual representation of the CPT and are represented in Figure 2-2.

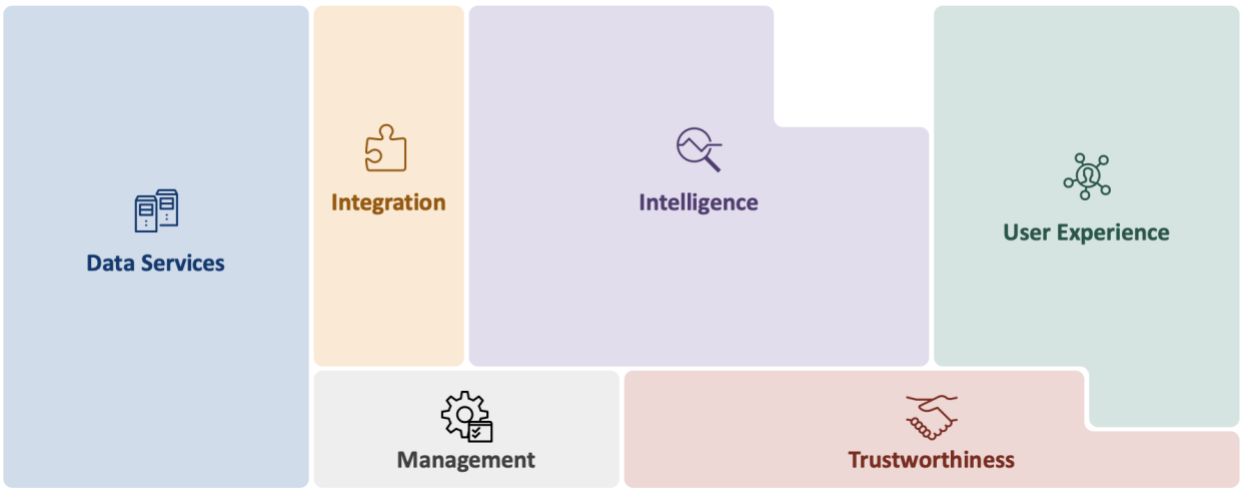


Figure 2-2: Digital twin CPT outline.

This outline provides the container for each of the 60 level 1 capabilities of the CPT.

## 2.2 THE DIGITAL TWIN CPT LEVEL 1

Level 1 represents the high level capabilities that are grouped based on the categories in Figure 2-1 and the outline presented in Figure 2-2.

Figure 2-3 provides an easy-to-use framework to describe the key capabilities required for digital twin use cases.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 Data Acquisition & Ingestion | 9 Synthetic Data Generation | 17 Enterprise System Integration | 23 Edge AI & Intelligence | 29 Prediction | | 39 Basic Visualization | 45 Dashboards |
| 2 Data Streaming | 10 Ontology Management | 18 Eng. System Integration | 24 Command & Control | 30 Machine Learning ML | | 40 Advanced Visualization | 46 Continuous Intelligence |
| 3 Data Transformation | 11 Digital Twin (DT) Model Repository | 19 OT/IoT System Integration | 25 Orchestration | 31 Artificial Intelligence AI | 35 Prescriptive Recommendations | 41 Real-time Monitoring | 47 Business Intelligence |
| 4 Data Contextualization | 12 DT Instance Repository | 20 Digital Twin Integration | 26 Alerts & Notifications | 32 Federated Learning | 36 Business Rules | 42 Entity Relationship Visualization | 48 BPM & Workflow |
| 5 Batch Processing | 13 Temporal Data Store | 21 Collab Platform Integration | 27 Reporting | 33 Simulation | 37 Distributed Ledger & Smart Contracts | 43 Augmented Reality AR | 49 Gaming Engine Visualization |
| 6 Real-time Processing | 14 Data Storage & Archive Services | 22 API Services | 28 Data Analysis & Analytics | 34 Mathematical Analytics | 38 Composition | 44 Virtual Reality VR | 50 3D Rendering |
| 7 Data PubSub Push | 15 Simulation Model Repository | 52 Device Management | 54 Event Logging | 56 Data Encryption | 58 Security | 60 Safety | 51 Gamification |
| 8 Data Aggregation | 16 AI Model Repository | 53 System Monitoring | 54 Data Governance | 57 Device Security | 59 Privacy | 61 Reliability | 62 Resilience |

Data Services  Integration  Intelligence  UX  Management  Trustworthiness

Figure 2-3: The digital twin CPT.

Each of these capabilities may be decomposed into level 2 sub-capabilities to provide more granular elements if the Digital Twin use case requires clarification.

## 2.3 THE DIGITAL TWIN CPT LEVEL 2

Future versions of the CPT may provide specific level 2 capabilities, but in the short term the level 2 capability requirements are defined case-by-case.

The machine learning capability may, for example, be decomposed into specific sub-capabilities. In certain instances, it may require a third-level breakdown to describe the specific capability that will address the needs of a specific digital twin use case.

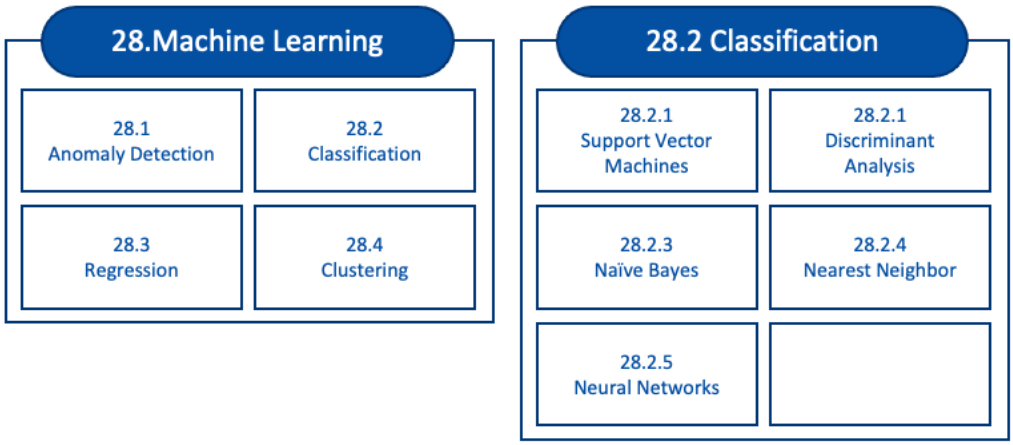


Figure 2-4: Example of Level 2 and Level 3 breakdown.

This is still at the capability level and not technology. Each of the capabilities defined at level 3 for machine learning classification can be achieved with multiple different technologies. This includes Python on Jupyter Notebooks, Azure Machine Learning, AWS Machine Learning and Google Cloud Platform, to name a few typical machine learning technology platforms.

## 2.4 CAPABILITY DEPLOYMENT CONSIDERATIONS

The requirements of a specific use case will determine the deployment environment for the different capabilities that address the use case.

Some use cases may require the digital twin capabilities at the IoT edge, while others may require processing in the data center, and in some instances hybrid deployment models may be needed. The digital twin capability specification must consider the various deployment requirements. The Industry IoT Consortium (IIC) provides technical guidance on the characteristics of distributed computing in the Industrial Internet Vocabulary Technical Report.[2]

The accompanying Excel CPT Toolkit provides identifying the required deployment environment for a specific use case. This is demonstrated in the next section on how to use the CPT.

[2] *https://www.iiconsortium.org/foundational-publications.htm*

# 3 How to Use the Digital Twin CPT

The CPT Toolkit is an Excel template that accompanies this user guide and aims at assisting requirements gathering and capability specification for a specific digital twin use case.

The Toolkit contains the template periodic table number, capability description, ability requirements and purpose. The ability and purpose descriptions for each capability may be edited at an organizational level, but we suggest you use this as the template. The specific use case capability requirements, attributes and use case application environment is then completed for each use case.

This is demonstrated by the following two use case examples for a windfarm digital twin.

## 3.1 Windfarm Use Cases Examples

Figure 3-1 shows an example of an energy prediction digital twin in a windfarm. The first few columns present the static information from the CPT and the columns marked in orange on the right represent the specific requirements of this use case. This is for illustrative purposes and will vary on the specific application of the digital twin for the end user.

| Digital Twin Ecosystem Capabilities Periodic Table | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| USE CASE | Wind Farm Energy Prediction | | | | | | | |
| | What it Is | | | | | Use Case Application | | |
| No | Digital Twin Capability | Category | Use Case Capability Requirements | Attributes | Edge | Cloud | Level | |
| 1 | Data Acquisition and Ingestion | 1. Data Services | Ingest real-time sensor readings with high frequency and low latency | 50 tags at 5 second frequency with 10kb payload per message for 10,000 wind turbines | Full | x | Advanced | |
| 2 | Data Streaming | 1. Data Services | | | x | x | Nice to have | |
| 3 | Data Transformation and Wrangling | 1. Data Services | | | x | x | | |
| 4 | Data Contextualization | 1. Data Services | | | x | x | | |
| 5 | Batch Processing | 1. Data Services | | | x | x | | |
| 6 | Real-time processing | 1. Data Services | | | x | x | | |
| 7 | Data PubSub Push | 1. Data Services | | | x | x | | |
| 8 | Data Aggregation | 1. Data Services | | | | x | | |
| 9 | Digital Twin Model Repository | 1. Data Services | Ability to store DTDL models in a central cloud storage | 10,000 digital twins models with multiple historical versions | Not Req | x | | |
| 10 | Digital Twin Instance Repository | 1. Data Services | | | | x | | |

Figure 3-1:- Example of windfarm digital twin CPT Toolkit in Excel.

In this example, the data acquisition and ingestion capability requirement are for real time sensor readings with high frequency and low latency. The specific requirement is 50 tags at a five-second frequency with a 10-kilobyte payload per message, for 10 ,000 wind turbines.

It also states that this capability is needed at the edge with potential use in a data center environment as well. End users can further choose to provide a capability level description such as basic and advanced. Each organization can create a definition for each of the levels that is suited to the capability maturity management in the organization.

Different use cases will have different CPT representations, and this is illustrated with two simple windfarm examples in Figure 3-2 and Figure 3-3.

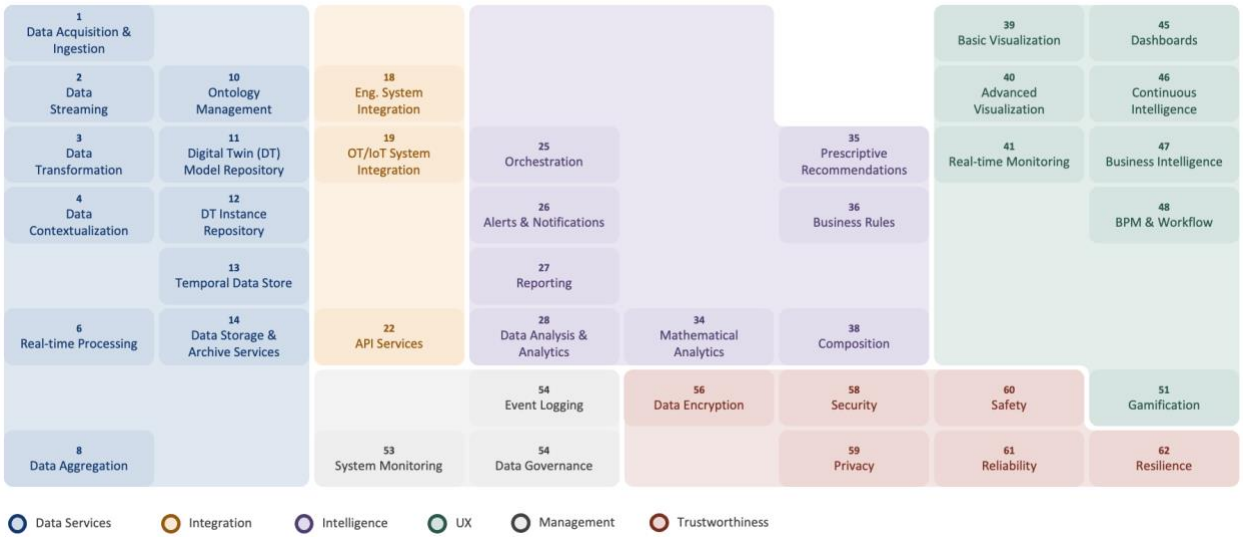


Figure 3-2: Windfarm Condition Monitoring Maintenance digital twin use case.

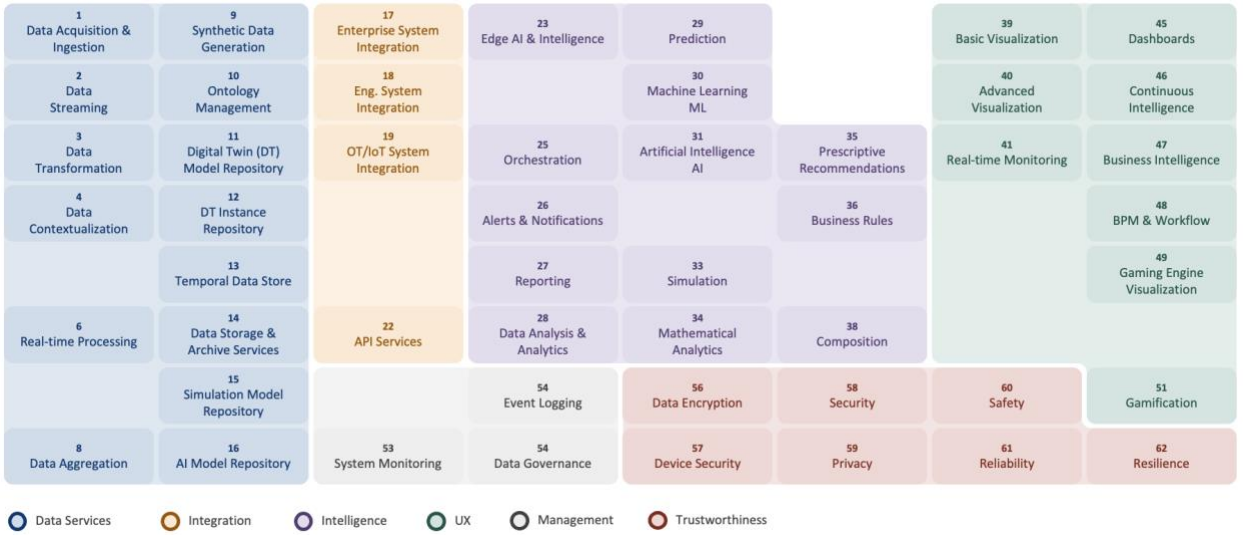


Figure 3-3: Windfarm Energy Prediction Operations digital twin use case.

The two periodic tables clearly show overlapping capabilities as well as unique requirements that are only applicable for a specific application.

## 3.2 DIGITAL TWIN CPT WORKFLOW SUMMARY

The CPT provides an overall workflow process together and communicates requirements from internal stakeholders as well as outside stakeholders such as technology solution providers.

Figure 3-4 outlines the suggested workflow, starting with using the periodic table, in collaboration meetings and presentations to familiarize stakeholders with all the potential capabilities that can be used in composing digital twins. The single page CPT image is at the right level for executive presentations. It demonstrates the specific requirements, provides clarity of business cases and can be used to show estimates for funding requirements to executives and technical managers, as in the windfarm example.


Figure 3-4: Digital twins CPT workflow summary.

The output of the Toolkit describes all the capability requirements to successfully deliver a Digital Twin use case. This can be provided to digital twin technology solution providers to propose products and services, either in isolation, or as part of a broader ecosystem. Vendor solutions can be ranked and scored against the Digital Twins CPT Toolkit.

# 4 FUTURE WORK

This user guide introduces a capability-based approach to composing digital twins. Future work will include level 2 descriptions for each of the capability elements in the Digital Twins CPT, and potentially a capability maturity model with an index that organizations can use to score progress towards more mature digital twins.

Other future work may include alignment with other DTC initiatives, including business maturity frameworks, interoperability models and reference architectures.

# Annex A

This annex describes the elements in the CPT.

## A.1 DIGITAL TWIN CPT DETAIL DESCRIPTION

| | What it Is | | What it Does | What it Means |
|---|---|---|---|---|
| **No** | **Digital Twin Capability** | **Category** | **Ability** | **Purpose** |
| 1 | Data Acquisition & Ingestion | 1. Data Services | The ability to configure and acquire data from different data sources including control system, historians, IoT sensors, smart devices, engineering system, enterprise systems, etc. | The purpose is to acquire data from the physical world, engineering technology systems, and information technology systems to support subsequent processing and insight generation. |
| 2 | Data Streaming | 1. Data Services | The ability to transfer of large volumes of data continuously and incrementally between a source and a destination without having to access all data at the same time. | The purpose is to acquire fast continuous packets of information that are changing at high speed to be able to get near real-time insights. |
| 3 | Data Transformation & Wrangling | 1. Data Services | The ability to convert data types and properties through cleaning, structuring and enriching raw data to make if suitable for further processing and analytics. | The purpose is to make data useable in digital twins. |

| | | | | |
|---|---|---|---|---|
| 4 | Data Contextualization | 1. Data Services | The ability to add language or metadata to enrich real time or transactional data. | The purpose is to combine data from different sources (such as real-time data and slower-changing contextual data) to make it suitable for subsequent processing by the digital twin. |
| 5 | Batch Processing | 1. Data Services | The ability to execute against previously collected data in bulk form. | The purpose is to provide is an efficient way of processing high volumes of data in batches or groups. |
| 6 | Real-time Processing | 1. Data Services | The ability to manage and act on the captured data with minimal latency. | The purpose is to support immediate insights from the data. |
| 7 | Data PubSub Push | 1. Data Services | The ability to package filtered data to different services based on a publish/subscribe model. | The purpose is to provide information to subscribed digital twin consumers. |
| 8 | Data Aggregation | 1. Data Services | The ability to gather raw data and express in a summary form. | The purpose is to gather data from multiple sources with the intent of combining these data sources into a summary for data analysis. |
| 9 | Synthetic Data Generation | 1. Data Services | The ability to generate synthetic data based on patterns and rules in existing sources. | The purpose is to create representative synthetic data that can used by the digital twin to train and score predictive models. |
| 10 | Ontology Management | 1. Data Services | The ability to manage knowledge graphs and ontologies. | The purpose is to enable a digital twin to interpret data directly from knowledge graphs and ontologies. |

| | | | | |
|---|---|---|---|---|
| 11 | Digital Twin Model Repository | 1. Data Services | The ability to store, manage and retrieve the metadata that describe the digital twin model. The model can include formal data names, comprehensive data definitions, proper data structures and precise data integrity rules. | The purpose is to register and manage a portfolio of digital twin models in a central repository to improve configuration management and model governance. |
| 12 | Digital Twin Instance Repository | 1. Data Services | The ability to store, manage and retrieve digital twin instance data that conforms to the requirements of the digital twin model. | The purpose is to store, manage and retrieve digital twin instance state data. |
| 13 | Temporal (Time Series) Data Store | 1. Data Services | The ability to store, organize and retrieve data relating to time instances through temporal data types, and store information relating to past, present and potentially future time. | The purpose is to store, manage and retrieve temporal (timeseries) data. |
| 14 | Data Storage & Archive Services | 1. Data Services | The ability to store, organize and retrieve data based on how frequently it will be accessed and how long it will be retained. | The purpose is to reduce the cost and effort of managing digital twin data by using hot, cold and archival data services |
| 15 | Simulation Model Repository | 1. Data Services | The ability to store, manage and retrieve the algorithmic codebase, business rules and metadata that describe a simulation model. | The purpose is to register and manage a portfolio of simulation models in a central repository to improve configuration management and model governance. |

| | | | | |
|---|---|---|---|---|
| 16 | AI Model Repository | 1. Data Services | The ability to store, manage, search and retrieve the algorithmic codebase that describe an artificial intelligence (AI) model or machine learning (ML) model. | The purpose is to register and manage a portfolio of AI and machine learning models in a central repository to improve configuration management and model governance. |
| 17 | Enterprise System Integration | 2. Integration | The ability to integrate the digital twin with existing enterprise such as ERP, EAM, CRM and CMMS. | The purpose is to integrate business applications, such as ERP, to enable data to flow between digital twin systems with ease. |
| 18 | Engineering Systems Integration | 2. Integration | The ability to integrate the digital twin with existing engineering systems such as CAD, CAM, BIM and Historians. | The purpose is to integrate business applications, such as CAD, to enable data to flow between digital twin systems with ease. |
| 19 | OT/IoT System Integration | 2. Integration | The ability to integrate directly with control systems and IOT devices/sensors and SCADA. | The purpose is to integrate business applications, such as SCADA, to enable data to flow between digital twin systems with ease. |
| 20 | Digital Twin Integration | 2. Integration | The ability to integrate or access information from existing digital twin instances. | The purpose is to integrate digital twin applications with one another to enable interoperable digital twins. |
| 21 | Collaboration Platform Integration | 2. Integration | The ability for the digital twin to interface with platforms like Yammer, Jabber, Teams and Slack. | The purpose is to integrate collaboration platforms to provide digital twin users with a conversational user interface. |

| | | | | |
|---|---|---|---|---|
| 22 | API Services | 2. Integration | The ability for the digital twin to publish APIs to external, partner and internal developers to access data and services. | The purpose is to simplify digital twin development by allowing data to integrate data with the endpoint. |
| 23 | Edge AI & Intelligence | 3. Intelligence | The ability to make decisions at the device level based on real -time data, distribution, and federation of analytics at the edge instead of transporting the data to the cloud to perform analytics. | The purpose is to make real-time decisions at the edge. |
| 24 | Command & Control | 3. Intelligence | The ability to execute upon work instructions without human interaction. Control would be limited to IoT devices and non-plant controls. | The purpose is to support future smart IoT devices with centralized management. |
| 25 | Orchestration | 3. Intelligence | The ability to coordinate the automated configuration, management and coordination of systems, applications, digital twins and services. | The purpose it to manage complex tasks and workflows between different systems, applications, digital twins or systems of digital twins easily. |
| 26 | Alerts & Notification | 3. Intelligence | The ability to display and manage alerts, messages, message queues, triggers and notifications. | The purpose is to trigger actions that may require intervention to the ongoing processes. |
| 27 | Reporting | 3. Intelligence | The ability to generate configurable and customizable reports to get insights into the data. | The purpose is to get insights into the data that can be useful for various stakeholders in the system as well as for regulatory compliance. |

| | | | | |
|---|---|---|---|---|
| 28 | Data Analysis & Analytics | 3. Intelligence | The ability to analyze data through charts, tables and dashboards; to fetch data between dates and filter data based on various criteria. The analysis of data, typically large sets of business data, using mathematics, statistics and software with an objective to draw conclusions. | The purpose is to understand past trends from historical data. |
| 29 | Prediction | 3. Intelligence | The ability to estimate that a specified event will happen in the future or will be a consequence of other events. | The purpose is to use historical data, engineering, and analytical models to predict events before they occur. |
| 30 | Machine Learning (ML) | 3. Intelligence | The ability of computer algorithms to improve a digital twin automatically through experience. The algorithms build a mathematical model based on training data, to make predictions or decisions without being explicitly programmed to do so. It is seen as a subset of artificial intelligence. | The purpose is to enable the digital twin and digital twin systems to learn from data, identify patterns and make decisions with minimal human intervention. |

| | | | | |
|---|---|---|---|---|
| 31 | Artificial Intelligence | 3. Intelligence | The ability for a system to perform actions and take decisions like humans. AI would include machine learning, natural language processing, knowledge modelling and representation, reasoning, inferencing etc. It is based on the capacity of a computer to perform operations analogous to learning and decision making in humans, as by an expert system, a program for CAD or CAM or a program for the perception and recognition of shapes in computer vision systems. | The purpose is to enable a digital twin or a digital twin system to take actions and decisions similar to humans. |
| 32 | Federated Learning | 3. Intelligence | The ability to train an algorithm across multiple decentralized digital twin edge devices or servers holding local data samples, without exchanging their data samples. | The purpose is to enable multiple actors to build a common, robust machine learning model without sharing data, thus addressing critical issues such as data privacy, data security, data access rights and access to heterogeneous data. |
| 33 | Simulation | 3. Intelligence | The ability to create an approximate imitation of a process or a system using past historical information, physical models, video, audio and animation. What-if-scenarios. | The purpose is to imitate the behavior of a physical system in the digital twin before applying to the physical world. Training operations and maintenance teams on simulated digital twins is another purpose of simulation. |

| | | | | |
|---|---|---|---|---|
| 34 | Mathematical Analytics (Engineering Calculations) | 3. Intelligence | The ability to perform mathematical and statistical calculations to enable physics-based and other mathematical models. | The purpose is to enable the use of physics models and mathematics calculations in digital twin analytics. |
| 35 | Prescriptive Recommendations | 3. Intelligence | The ability to create prescriptive recommendations based on business rules and AI logic to suggest the best next actions to take when a pre-determined event happens. | The purpose is to enable digital twins to provide guidance based on a combination of analytics, business rules and workflow to create actions and deliver business outcomes. |
| 36 | Business Rules | 3. Intelligence | The ability to create, manage and use business rules that influence the digital twin behavior throughout its lifecycle. | The purpose is to enable digital twins to provide and manage business rules that influence a digital twin's behavior. |
| 37 | Distributed Ledger & Smart Contracts | 3. Intelligence | The ability to use distributed ledgers for digital twin applications that require immutable data for digital twin instances, transactions and automation (smart contracts). | The purpose is to enable digital twins to interact in an automated, trustworthy and responsible manner with systems that support smart contracts and provide a full, immutable transaction record. |
| 38 | Composition | 3. Intelligence | The ability to use a modular digital twin application development approach to compose and recompose digital twin services that deliver use case specific outcomes rapidly. | The purpose is to compose or recompose digital twins from a set of packaged, reusable business capabilities (PBCs) to reduce time to value, duplication and support citizen development of digital twins. |

| | | | | |
|---|---|---|---|---|
| 39 | Basic Visualization | 4. UX | The ability to visualize data through simple charts, graphs, simple dashboards, tables, hierarchical and basic 3D views of the assets graphically or parametrically (that is, through parameters and values). | The purpose is to help people understand the significance of data by placing it in a visual context. |
| 40 | Advanced Visualization | 4. UX | The ability to visualize data through complex charts and graphs, dashboards fetching raw and process data from multiple systems, complex 3D models and animations, visualizations with overlayed data from different systems graphically or parametrically (that is, through parameters and values). | The purpose is to help people understand the significance of data by placing it in a visual context. |
| 41 | Real-time Monitoring | 4. UX | The ability to present and interact with continuously updated information streaming at zero or low latency. | The purpose is to help make decisions that are of consequence to real-time. |
| 42 | Entity Relationship Visualization | 4. UX | The ability to present digital twin entities and their hierarchical or graph-based relationships interactively. | The purpose is to help business users navigate and interact with complex entity (asset) hierarchies in a user-friendly manner. |

| | | | | |
|---|---|---|---|---|
| 43 | Augmented Reality (AR) | 4. UX | The ability to provide an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information such as visual, auditory or haptic environments. | The purpose is to realize an improved, immersive and interactive experience. |
| 44 | Virtual Reality (VR) | 4. UX | The ability to provide a simulated experience that can be similar to, or completely different from, the real world. | The purpose is to realize an improved, immersive, and interactive experience. |
| 45 | Dashboards | 4. UX | The ability to provide a graphical user interface that provides at-a-glance views of key performance indicators relevant to a particular objective or business process. | The purpose is to enable various personas in operations, technology, and business to understand the current or past state of a system visually. |
| 46 | Continuous Intelligence | 4. UX | The ability to analyze data in flight (signals) to derive insights and actions in a business user-focused visual interface. | The purpose is to have various personas in operations, technology, and business to make informed real-time decisions. |
| 47 | Business Intelligence | 4. UX | The ability to analyze stored data (records) to derive insights and actions in a business user focused visual interface. | The purpose is to have various personas in operations, technology, and business to make informed real-time decisions. |
| 48 | Business Process Management & Workflow | 4. UX | The ability to execute a sequence of actions as a process flow to achieve specific business outcomes. | The purpose is to have effective, repeatable actions that deliver the business outcomes of the digital twin. |

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| 49 | Gaming Engine Visualization | 4. UX | The ability to create immersive virtual worlds and interactive experiences with gaming engine technology. | The purpose it to enable digital twins in a digital metaverse where users interact with the digital twin highly interactively. |
| 50 | 3D rendering | 4. UX | The ability to render 3D visualizations from point cloud data sets generated by LiDAR and other scanning technologies. | The purpose is to interact with large point cloud and 3D datasets in a user-friendly manner. |
| 51 | Gamification | 4. UX | The ability to enable game playing in digital twin interactions. | The purpose is to facilitate gamification elements such as points scoring, badges and competition in the user experience and interactive engagement of a digital twin. |
| 52 | Device Management | 5. Management | The ability to provision and authenticate, configure, maintain, monitor and diagnose connected IoT devices operating as part of digital twin environment. | The purpose of (IoT) device management is to provide and support the spectrum of functional capabilities of the devices and sensors. |
| 53 | System Monitoring & Alerting | 5. Management | The ability to observe digital twin systems, applications, and services by collecting, analyzing and acting on their health data to maximize their availability and performance. | The purpose of system monitoring is to provide and support the whole spectrum of digital twin systems, applications and services. |

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| 54 | Logging | 5. Management | The ability to record events and transactions; to access user data and their transactions to understand and trace the activities occurring in a digital twin system. | The purpose of event logging is to provide records that enable event activities to be traced within a digital twin system. |
| 55 | Data Governance | 5. Management | The ability to manage the availability, usability, integrity and security of the data in digital twin systems, based on internal data standards and policies that control data usage. | The purpose is to ensure that data is consistent and trustworthy and doesn't get misused. |
| 56 | Data Encryption | 6.Trustworthiness | The ability to convert digital twin data from a readable format into an encoded format that can be used to transfer data securely. It includes the ability to decrypt the data to read or process the data once it reaches its destination. | The purpose of data encryption is to protect digital data confidentiality as it is stored in a digital twin system, accessed and transmitted. |
| 57 | Device Security | 6.Trustworthiness | The ability to enforce authenticated and authorized access to IoT device data through identity management, role-based access, encryption and policies. | The purpose is to control access to device data by having the appropriate privileges and enforcement framework for users and programs. |

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| 58 | Security | 6.Trustworthiness | The ability to protected digital twins from unintended or unauthorized access, change or destruction. Security concerns equipment, systems and information, ensuring availability, integrity and confidentiality of information. | The purpose is to ensure a digital twin is protected from unintended or authorized access, change or destruction. |
| 59 | Privacy | 6.Trustworthiness | The ability to enable the rights of individuals that interact with digital twins to control or influence what information related to them may be collected and stored and by whom and to whom that information may be disclosed. | The purpose of privacy is to ensure the rights of individuals with regards to data collection, storage and use is respected and enforced. |
| 60 | Safety | 6.Trustworthiness | The ability to operate digital twins without causing unacceptable risk of physical injury or damage to the health of people, either directly, or indirectly as a result of damage to property or to the environment. | The purpose is to ensure a digital twin is operating safely without causing an unacceptable risk to safety. |
| 61 | Reliability | 6.Trustworthiness | The ability of a digital twin system or component to perform its required functions under stated conditions for a specified period. This includes expected levels of performance, QoS, functional availability and accuracy. | The purpose is to ensure a digital twin is able to operate and maintain an acceptable level of service as continuously as possible. |

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| 62 | Resilience | 6.Trustworthiness | The ability of a digital twin system or component to maintain an acceptable level of service in the face of disruption. This includes the ability to recover lost capacity in a timely manner (using a more-or-less automated procedure) or to reassign workloads and functions. | The purpose is to ensure a digital twin is able to operate and maintain an acceptable level of service when disrupted. |

## AUTHORS & LEGAL NOTICE



This document is a work product of the Digital Twin Consortium Natural Resources Working Group, co-chaired by Pieter van Schalkwyk (XMPro), and John Reynolds (Agile Fractal Grid).

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