Building Industrial Digital Twins

Design, develop, and deploy digital twin solutions for real-world industries using Azure Digital Twins

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Foreword by Dan Isaacs, CTO – Digital Twin Consortium

Preface

You can download the example code files for this book from GitHub at `https://github.com/PacktPublishing/Building-Industrial-Digital-Twin.` If there's an update to the code, it will be updated in the GitHub repository.

Chapter 1

Links

Pareto principle: https://bit.ly/DTPareto8020

Link to the Excel file for Business impact and technical feasibility assessment :https://bit.ly/DTPriority

Figures:

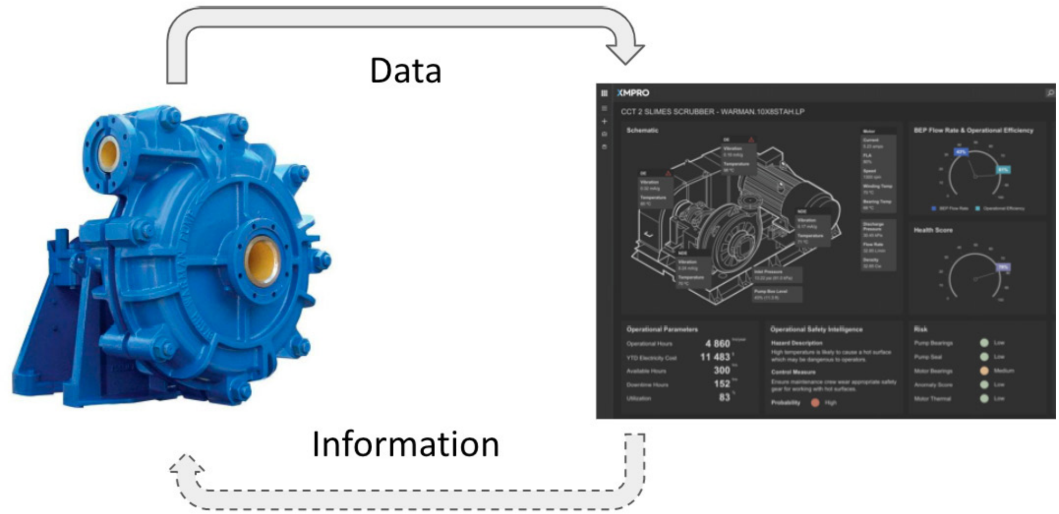

Figure 1.1 – Physical and virtual products combined to create a Digital Twin

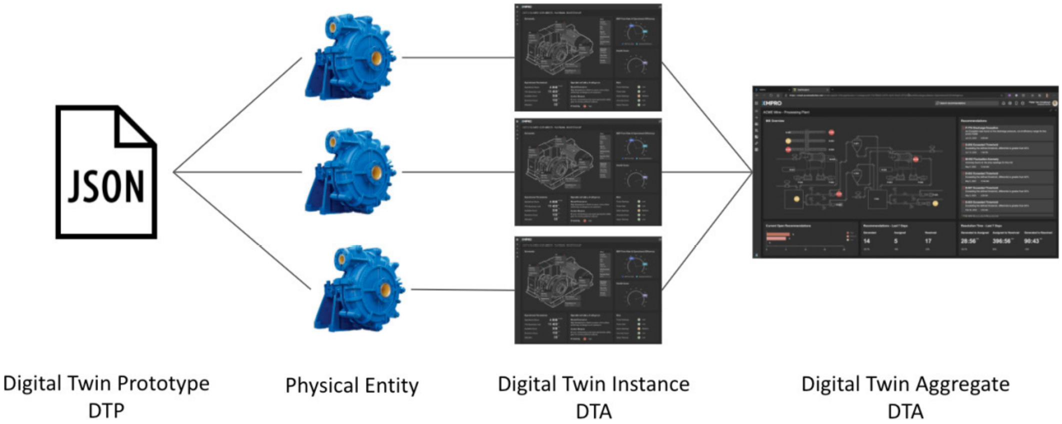

Figure 1.2 – Relationships between Digital Twin concepts

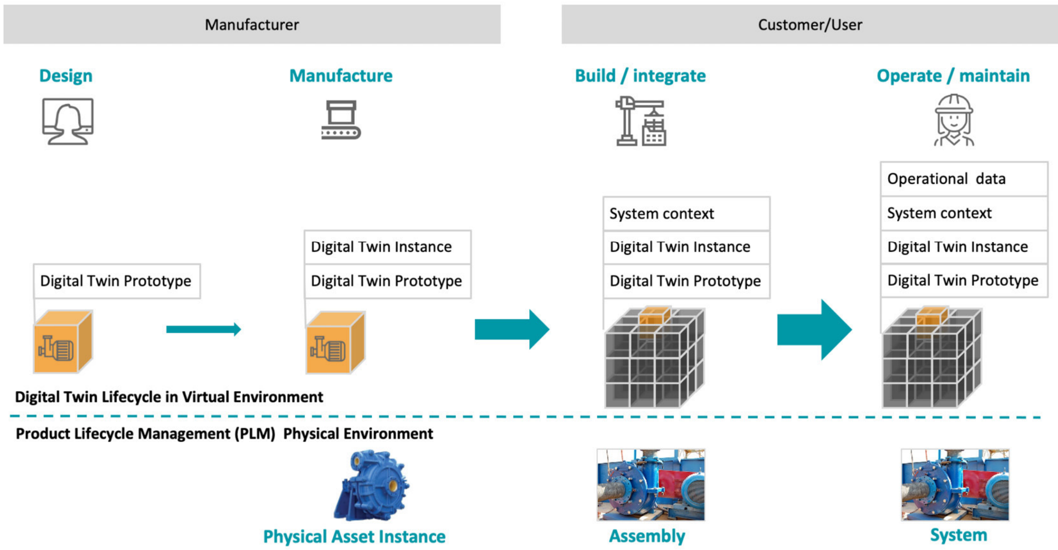

Figure 1.3 – Digital Twin and product life cycle relationship

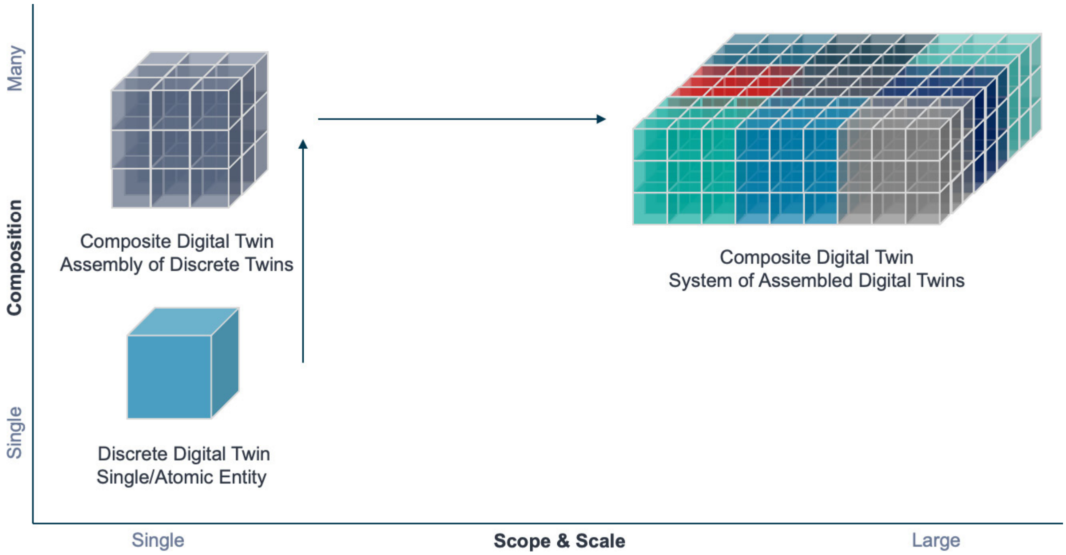

Figure 1.4 – Discrete and composite Digital Twin relationship

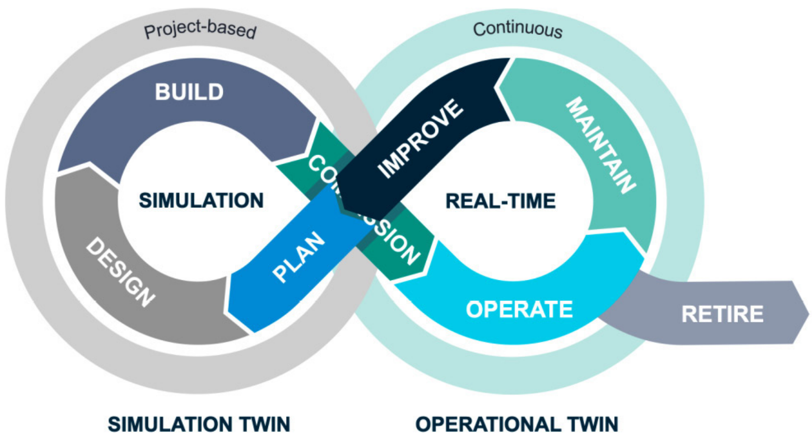

Figure 1.5 – Simulation and operational Digital Twin types

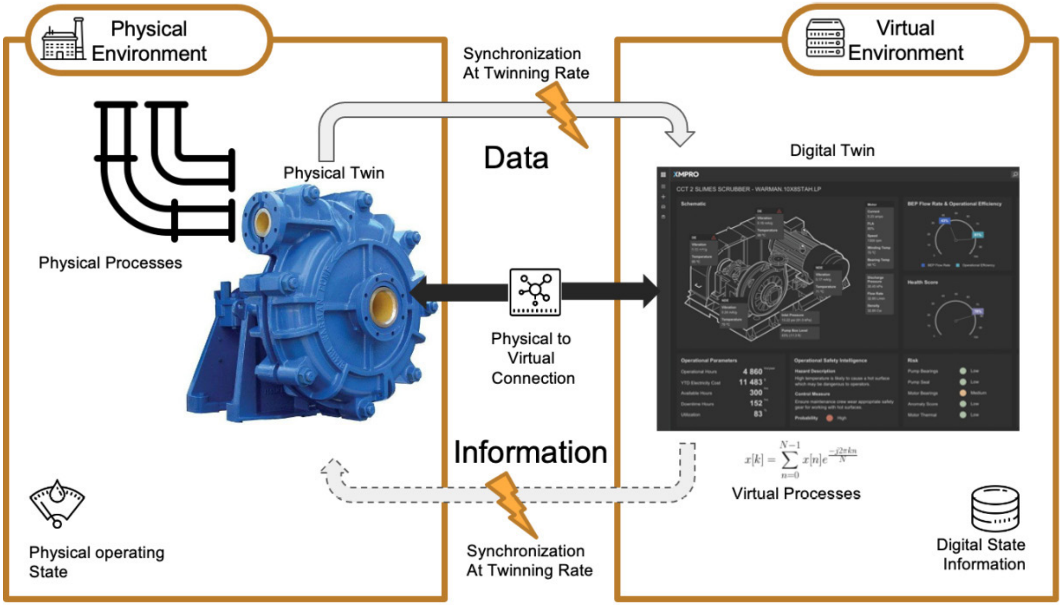

Figure 1.6 – Digital Twin characteristics

Characteristic	Description
Physical Entity (Physical Twin)	"An entity is an item that has recognizably distinct existence, e.g., a person, an organization, a device, a subsystem or a group of such items" ISO/IEC 24760-1:2011
Physical Environment	The real-world environment that the Physical Twin exist in (factory, oil platform, hospital, nature reserve, etc.)
Virtual Entity (Virtual Twin)	The virtual Digital Twin prototype (DTP) and instance(s) synchronized with the physical entity at a twinning rate
Virtual Environment	The technology-based environment that the virtual Twin exists in
Synchronization (twinning)	Synchronization or updating the state of the physical twin and virtual twin
Twinning Rate	The rate or frequency at which synchronization happens
State	The values of all the parameters of both the physical and virtual Twins in its environments
Physical to Virtual Connection (bi-directional)	The communications and data connections or processes used to establish this synchronization of the state at the prescribed twinning rate
Physical Processes	The processes in the real-world environment that will change or impact the state of the physical twin
Virtual Processes	The processes in the virtual environment (such as analytics or physics-based calculations) That will change or impact the state of the virtual twin

Table 1.7 – Key characteristics

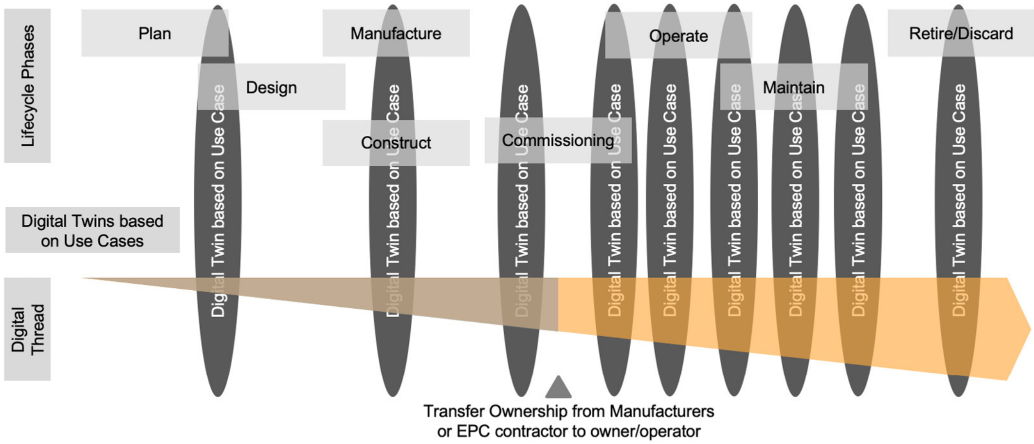

Figure 1.8 – Digital Twin versus Digital Thread

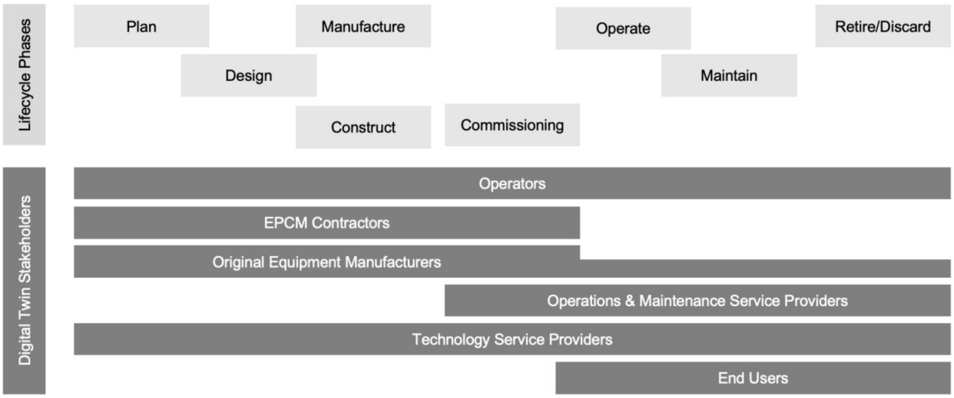

Figure 1.9 – Key stakeholders during the life cycle of an entity

Increase Revenue	• Improved Productivity • Increased machine uptime • Monetizing digital information and services (business model innovation)
Reduce Cost	• Reduced machine or equipment failures • Optimized inventory and better supply chain management • Reduce rework and improved quality
Improve Customer and Employee Experience	• Provide real-time situational awareness to customers and business users • Provide decision support through simulation, analytics augmented and virtual reality, and business rules embedded in the Digital Twin • Provide holistic or 360-degree visualization of an asset and its operating environment
Improve Compliance and Reduce Risk	• Monitor real-time compliance on Health, Safety, and Environment • Improve transparency on operational use and maintenance of assets, specifically for classified equipment such as pressure vessels and pressure relief valves. (Insurance and asset integrity inspection services) • Automate compliance with Operational Excellence for business KPIs and balanced scorecards.

Table 1.10 – The business impact of Digital Twins

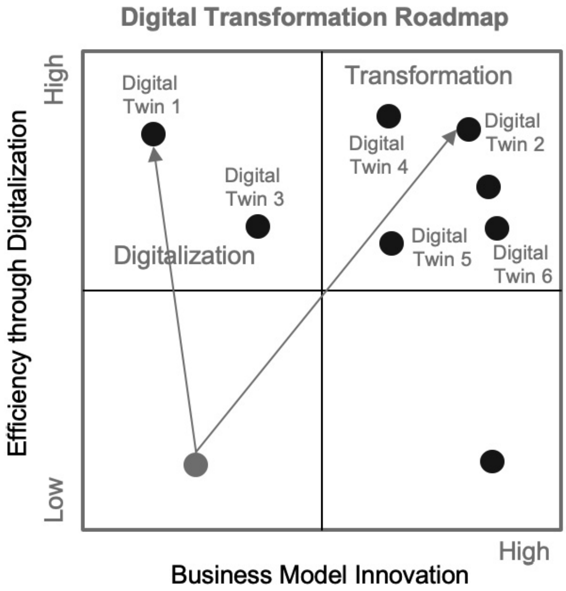

Figure 1.11 – Digital transformation versus digitalization

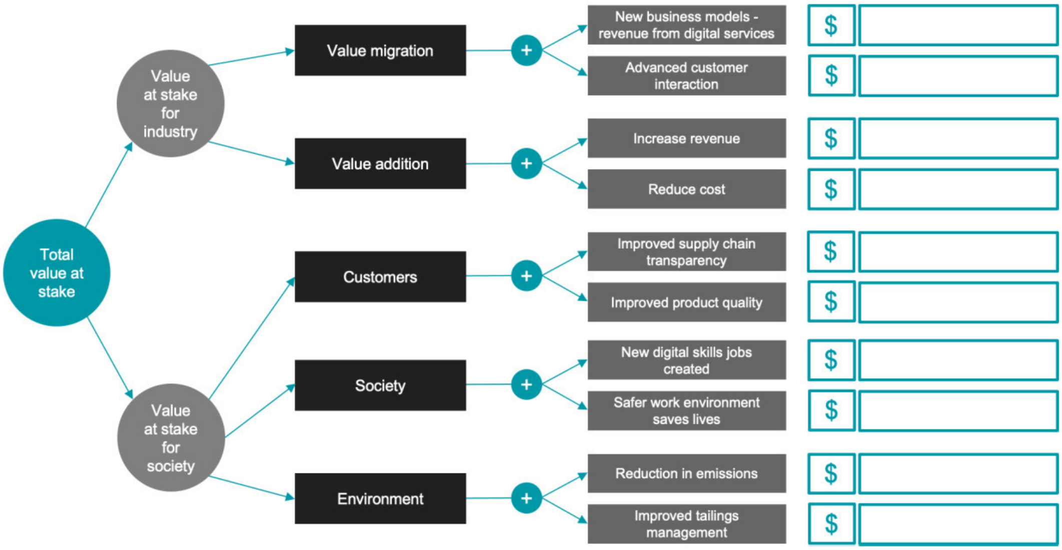

Figure 1.12 – Example of a value at stake analysis for a Digital Twin

> **Note**
>
> The preceding diagram has been adapted from https://reports.weforum.org/digital-transformation/introducing-value-at-stake-a-new-analytical-tool-for-understanding-digitalization/. The single-page view of the value at stake for a Digital Twin, shown in the preceding diagram, provides a simple yet powerful way to describe a Digital Twin's value proposition.

XMPRO **Business Value Assessment**

		Business Impact					Economic	Technical Feasibility				
#	Use Case/Scenario	Safety	Downtime	Throughput	Quality	Cost	Value/year	Automation	IT Systems	Analytics	Environment	Project
1	Use Case 1	Medium	High	High	High	High	> $10m	High	High	Medium	High	High
2	Use Case 2	Low	Low	Medium	customer satisf	High	> $10m	High	High	Low	High	High
3	Use Case 3	Low	Low	Low	Low	Low	> $1m	High	High	Low	High	High
4	Use Case 4	Low	Low	Low	Low	Low	> $1m	High	High	Low	High	High
5	Use Case 5	Low	Medium	High	Low	Medium	> $10m	Medium	High	Low	High	High
6	Use Case 6	Medium	Medium	Medium	Medium	Medium	> $1m	High	High	High	High	High
7	Use Case 7	Low	Medium	Medium	Medium	Low	> $1m	High	High	High	High	High
8	Use Case 8	Medium	Medium	Medium	Medium	Medium	> $10m	High	High	High	High	High
9	Use Case 9	Medium	High	High	High	High	> $1m	High	High	High	High	High
10	Use Case 10	High	Medium	Low	High	Low	> $1m	Medium	Medium	Medium	High	High

Figure 1.13 – Business impact and technical feasibility assessment

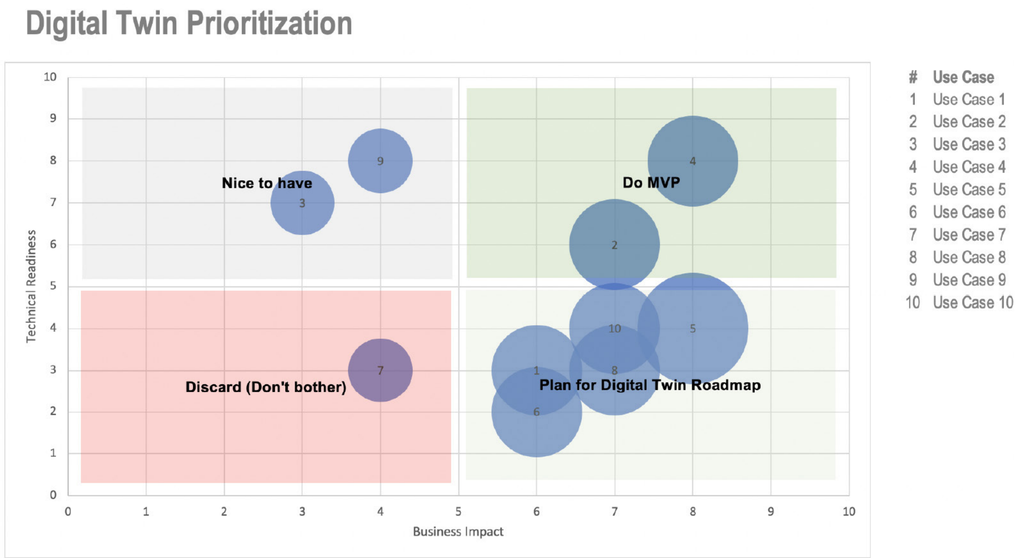

Figure 1.14 – Digital Twin prioritization matrix

Chapter 2

Links

Twin2Twin (T2T) ecosystem: https://www.hcltech.com/blogs/twin-2twin-new-paradigm-enterprise-digital-transformation

Oracle Cloud marketplace: https://cloudmarketplace.oracle.com/marketplace/oci.

Virtual Singapore: https://www.youtube.com/watch?v=QnLyy0owGL0&feature=youtu.be

What does AOG mean? The Causes and Costs of a Grounded Aircraft: https://www.proponent.com/causes-costs-behind-grounded-aircraft/

Taneco and ChemTech create "digital twin" of refinery: https://www.hydrocarbonprocessing.com/news/2018/06/taneco-and-chemtech-create-digital-twin-of-refinery

Digital twin for refinery-wide emission and efficiency monitoring: https://www.worldofchemicals.com/media/digital-twin-for-refinery-wide-emission-and-efficiency-monitoring/4697.html

Medtech firms get personal with digital twins using the pacemaker: https://www.reuters.com/article/us-healthcare-medical-technology-ai-insi/medtech-firms-get-personal-with-digital-twins-idUSKCN1LG0S0

Gartner says IoT technology is two to five years from "transformational" impact (Hype Cycle): https://www.supplychainquarterly.com/articles/3877-gartner-says-iot-technology-is-two-to-five-years-from-transformational-impact

Develop new economic and business models that deliver maximum value from digital twins: https://www.gartner.com/smarterwithgartner/prepare-for-the-impact-of-digital-twins

Siemens Digital Industries Software: https://www.sw.siemens.com/

Futurithmic: https://www.futurithmic.com/2020/04/14/how-digital-twins-driving-future-of-engineering/

THE DIGITAL INDUSTRIAL COMPANY: https://www.ge.com/digital/sites/default/files/download_assets/What-is-a-digital-industrial-company-infographic.pdf

The Oracle IoT Digital Twin Framework: (https://docs.oracle.com/en/cloud/paas/iot-cloud/iotgs/iot-digital-twin-framework.html)

The Azure Digital Twin: (https://azure.microsoft.com/en-us/services/digital-twins/)

IBM Digital Twin Exchange: (https://www.ibm.com/internet-of-things/trending/digital-twin/ or https://digitaltwinexchange.ibm.com/)

Ansys Twin Builder: (https://www.ansys.com/products/systems/ansys-twin-builder)

GE's Predix Platform: (https://www.ge.com/digital/applications/digital-twin)

Figures

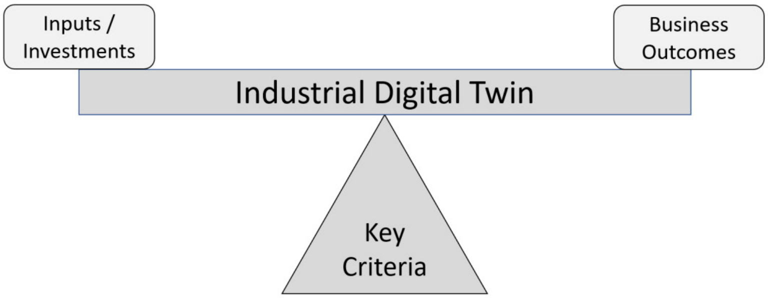

Figure 2.1 – Evaluation of the business benefits of the Industrial Digital Twin

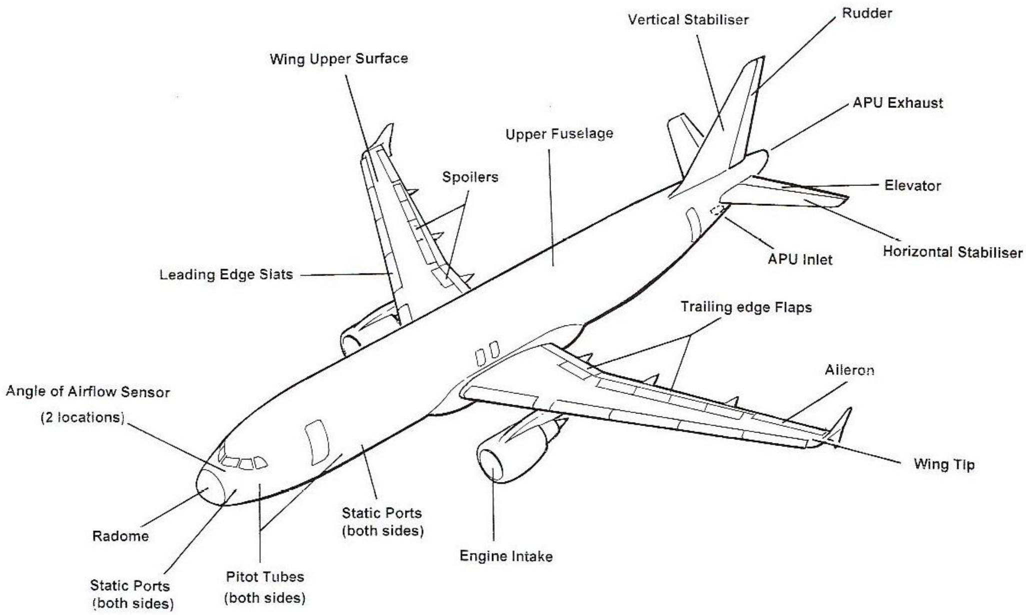

Figure 2.2 – The major parts of an aircraft

Upstream Industry
- Mining and Drilling
- Oil Production
- Natural gas

Midstream Industry
- Transportation
- Storage

Downstream Industry
- Refining
- Distribution

Figure 2.3 – The three segments of the oil and gas industry

Figure 2.4 – A petroleum refinery

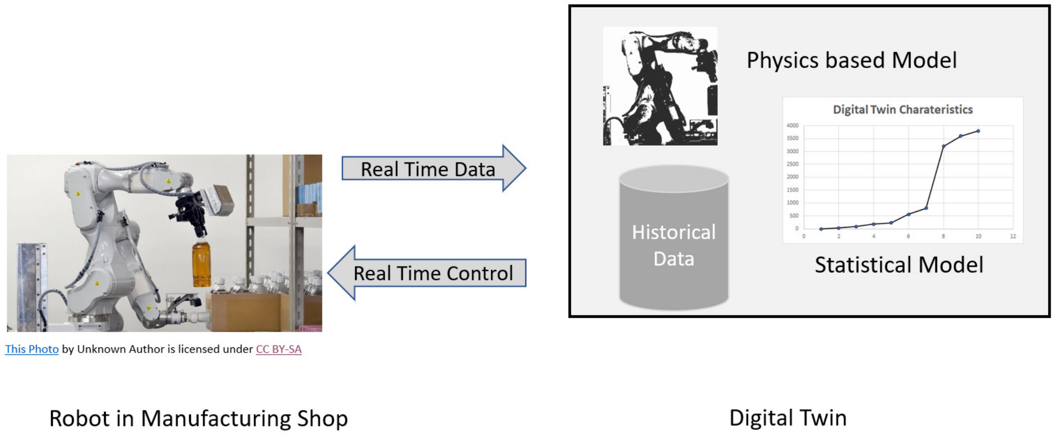

Figure 2.5 – The Digital Twin of a manufacturing robot

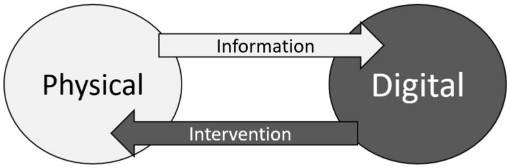

Figure 2.6 – A feedback loop of the physical asset and Digital Twin

Figure 2.7 – The supply chain process

Note

Image source: `https://geobrava.wordpress.com/2019/04/16/how-ai-innovation-transforms-supply-chain-planning/`

Figure 2.8 – OTA updates to the car

Chapter 3

Links:

Case study of the Digital Twin of an aircraft's landing gear is available here: https://www.ge.com/digital/customers/predictive-insights-aid-aircraft-landing-gear-performance

Boeing CEO Talks 'Digital Twin' Era of Aviation: https://www.aviationtoday.com/2018/09/14/boeing-ceo-talks-digital-twin-era-aviation/

Digital twin-based offerings sold as new revenues including to defense customers: https://www.machinedesign.com/automation-iiot/article/21139448/full-throttle-digital-twins-boost-airworthiness-in-legacy-airplanes

Dasault Systems: Digital twin technology generates the insights to drive growth post-pandemic: https://www.3ds.com/3dexperience/cloud/digital-transformation/digital-twin-technology

Bentley Systems | Newsroom:https://www.bentley.com/en/about-us/news/2019/october/22/bentley-systems-introduces-assetwise-digital-twin-services

Medtronic's Digital Twin Supports Their Ability To Respond In The Pandemic: https://www.forbes.com/sites/stevebanker/2020/06/19/medtronics-digital-twin-supports-their-ability-to-respond-in-the-pandemic/?sh=d4819b6857ee

The next era of public sector digital transformation: https://www.challenge.org/insights/the-next-era-of-public-sector-digital-transformation/

Why the Public Sector should Look to Digital Twins for Better Policy Making: https://www.digitalurbantwins.com/post/why-the-public-sector-should-look-to-digital-twins-for-better-policy-making

Navy using 'digital twins' to speed innovation to the fleet: https://federalnewsnetwork.com/federal-insights/2020/05/navy-using-digital-twins-to-speed-innovation-to-the-fleet/

SAP has talked about its customers Kaeser Kompressoren and Netzsch using a Digital Twin here: https://www.sap.com/products/supply-chain-management/digital-twin.html.

XMPRO: https://xmpro.com/digital-twins-the-ultimate-guide/

iGeneration – Digital Twin on Azure (see https://azuremarketplace.microsoft.com/en-us/marketplace/apps/adfolks.igenerations-implement?tab=Overview)

Asset Performance Management – L&T Technology Services (see https://azuremarketplace.microsoft.com/en-us/marketplace/apps/ltts.rapm_asset_performance_management?tab=overview)

Digital twin market: https://deloitte.wsj.com/cio/2020/06/23/digital-twins-bridging-the-physical-and-digital

Engineering technology: https://thansyn.com/why-cios-must-better-engage-with-engineering-technologists-to-leverage-digital-twins/

Federal Aviation Administration (FAA) handbook: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook/media/10_afh_ch8.pdf

AirAsia's low-cost high-efficiency approach to sustainability: https://climatechange-theneweconomy.com/aviation-airasia

Agile maifesto values and principles are described here: https://www.visual-paradigm.com/scrum/agile-manifesto-and-agile-principles/

The use of the Agile methodology in the context of Digital Twins, by Siemens and Accenture, is described here: https://blogs.sw.siemens.com/thought-leadership/2018/01/26/using-agile-processes-and-digital-twin-technology.

We suggest you view the video shared on this Siemens blog page, from the Digital Twin Summit (see https://youtu.be/ETTlTq88oHU).

Western Digital Corporation (WDC) described their 12-week-long Digital Twin experimentation here: https://blog.westerndigital.com/digital-twins-optimize-robot-manufacturing-ops/.

More details about artifacts and Agile rituals can be found here: https://www.atlassian.com/agile/scrum/artifacts

Figures

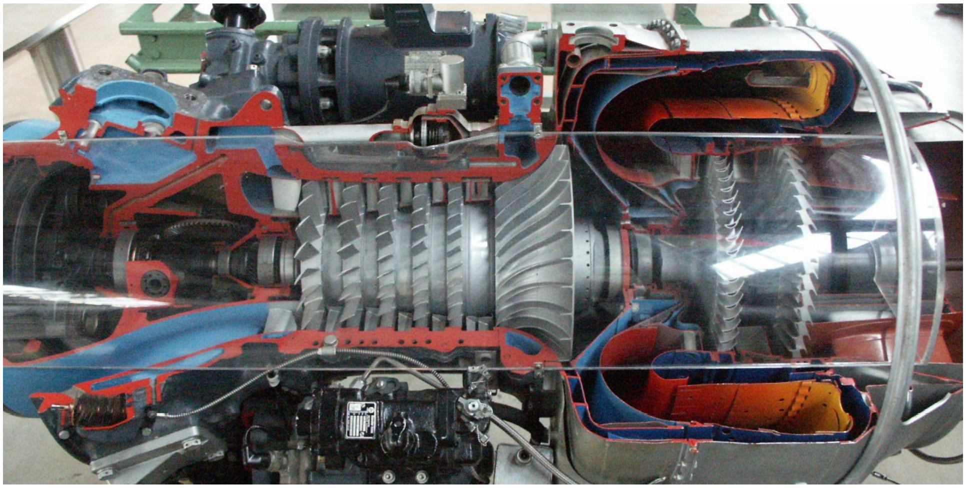

Figure 3.1 – Gas generator

Note

Image source: http://commons.wikimedia.org/wiki/File:Turboprop_T-53.jpg

Figure 3.2 – Electric power plant

Note

Image source: https://commons.wikimedia.org/wiki/File:Turboprop_T-53.jpg

Figure 3.3 – Rolls-Royce aircraft engine and landing gear

Note

Image source: https://www.aeronef.net/2011/12/boeing-777-300-with-rolls-royces-jet.html

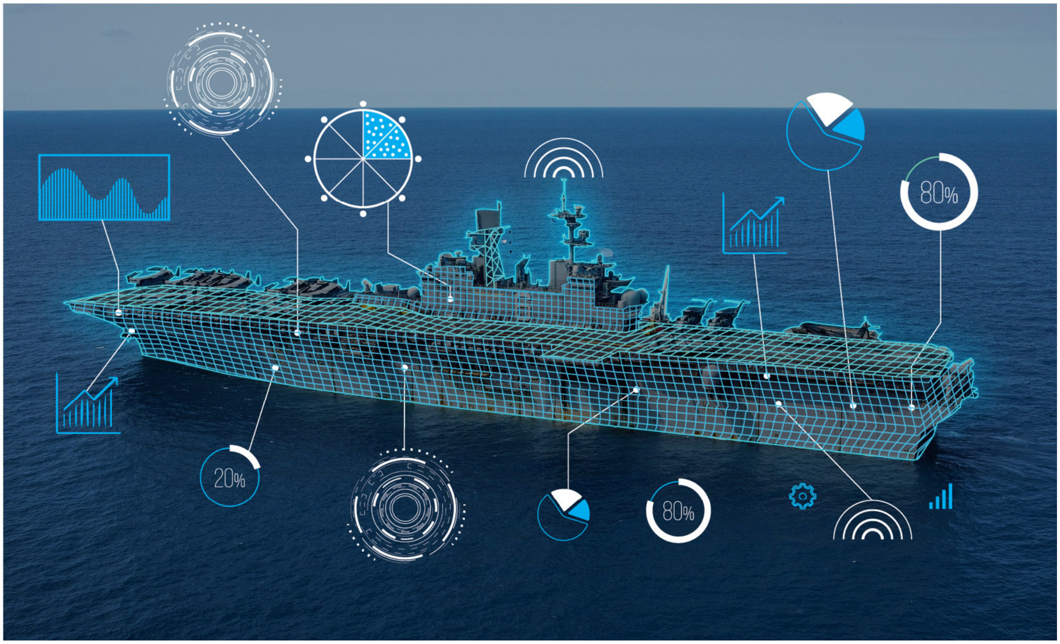

Figure 3.4 – Digital twin of a navy ship

RACI Matrix Definitions

R	Who is Responsible	Team or person assigned to do the work
A	Who is Accountable	Team or person who makes the final decision and has the ultimate ownership
C	Who is Consulted	Team or person who must be consulted before a decision or action
I	Who is Informed	Team or person who must be informed about a decision or action

Figure 3.5 – Description of the RACI matrix

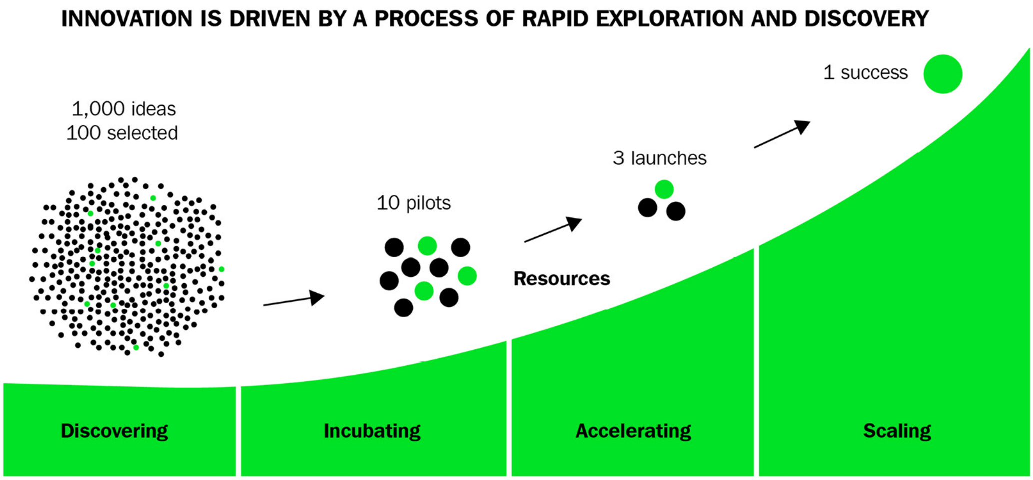

Figure 3.6 – Rapid exploration and discovery of the Digital Twin candidate

Figure 3.7 – Agile Manifesto

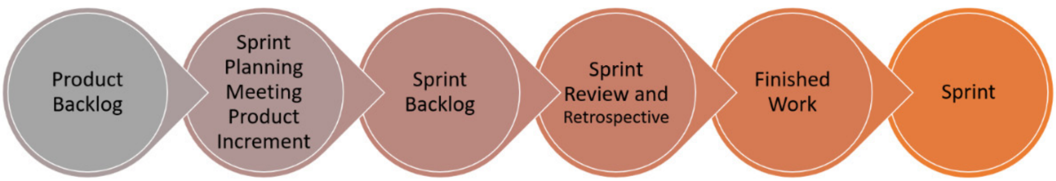

Figure 3.8 – Scrum methodology

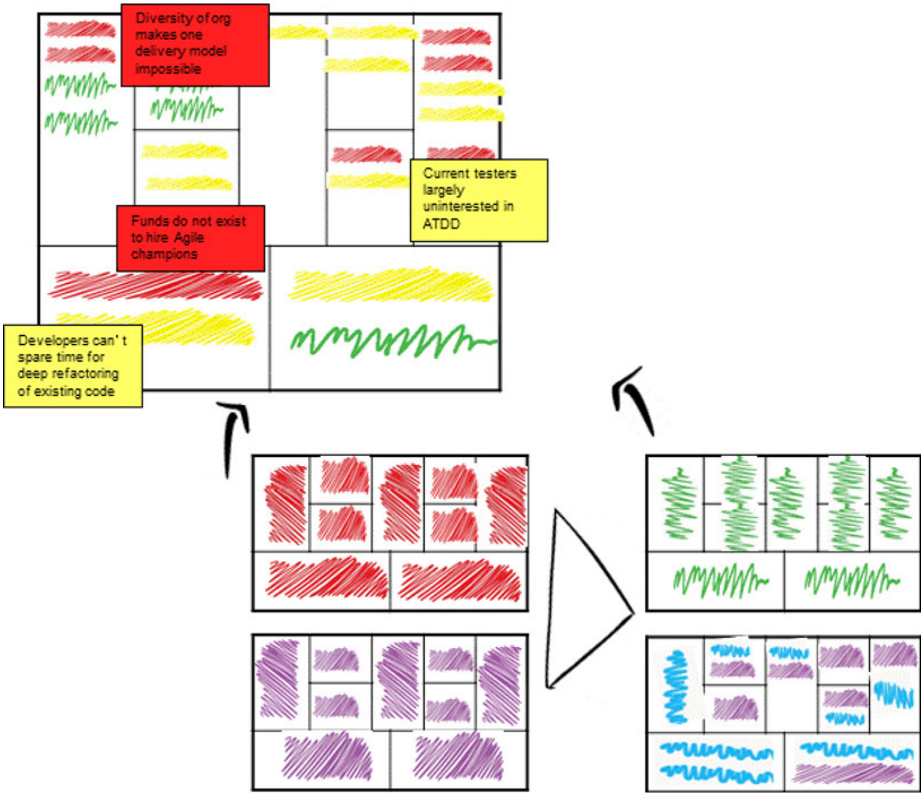

Figure 3.9 – Scrum information radiator

Note

Image source: http://agileconsulting.blogspot.com/2013/09/agile-transformation-cadence-model_495.html

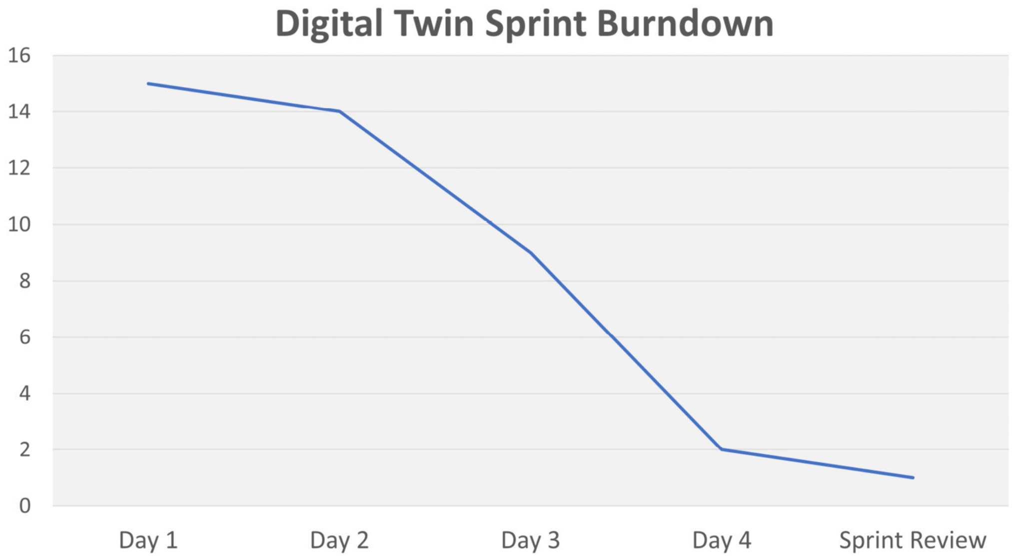

Figure 3.10 – Electronic Scrum board for the Agile methodology

> **Note**
>
> Image source: http://phdesign.com.au/general/excel-templates-for-scrum-product-and-sprint-backlogs/

Tables

Criteria	Twin of Engine, E	Twin of Gas Generator, G	Twin of Generic Gas Generator
First customer/user	Yes	Yes	Not yet
Reusability of twin	Low	Possible for other generators	High
Productivity/ efficiency use case	Yes	Yes	No – external only
New digital revenues	Possible	Possible	Yes
Investment	Moderate	Moderate	High

Table 3.1: Comparison of the three scenarios

	CDO/CTO	LOB Leader	Architect	Developer
Digital Twin Ideas	RA	C	I	
Validating the Idea	A	RA	C	
Prototype	R		RA	C
Test/Validate	I		A	R
Production/Market Readiness	R	A	C	I

Table 3.2

	Nature of Digital Twin	Owner/Users	Use Case	CIO's Role
1	Physical properties model	Plant engineers, product designers	Plant maintenance Accelerated prototyping of new products	Provide High-Performance Computing (HPC) and Product Life Cycle Management (PLM) capabilities
2	Electrical properties model	Facilities in charge, electrical engineer	Reduce power consumption	Data center strategy
3	Chemical or thermodynamic properties model	Plant engineer, process engineer	Alternative product and process	Integration of simulation and production systems
4	Process operations model	Process operations engineer	Faster problem resolution in operations and improved efficiency	Tie disparate systems together, such as ERP, MES, and plant operations
5	Reliability model	Maintenance engineers	Reduced maintenance costs and higher uptime	Tie together maintenance systems and time series data
6	Economic model	CFO/finance team	Better economic performance	Integrate the financial planning and profitability systems

Table 3.3

Company	Size	Role	Job Description
Tesla	4,800	Senior virtual commissioning engineer	Tesla is seeking a highly motivated engineer for a Senior Virtual Commissioning Engineer position that focuses on developing code as well as testing and simulation for digital manufacturing equipment and its sub-assemblies. This position concentrates specifically on industrial Virtual Commissioning, Digital Twin integration, Industrial PC/PLC software simulation/emulation, code development using Structured Text/object-oriented programming and automatic testing.

Company	Size	Role	Job Description
Nokia	98,000	Mirror X Bells Labs summer intern	Robots, mixed reality devices, infrastructure and other sensors will provide the proximal sensing necessary to create a Mirror World/ Digital Twin of the Physical world - in real time. Such a Digital Twin will be a key element in the digitalization of enterprises.
Idaho National Lab	2,200	Digital twin research scientist	Idaho National Laboratory's (INL) Digital and Software Engineering group within the Energy, Environment, Science and Technology Directorate is seeking forward-thinking, professionals interested in exploring a technical career at INL as a Digital Twin Research Scientist.
Johnson & Johnson	1,30,000	Post-doctoral scientist	The Postdoctoral Scientist will be responsible for leading a collaborative project to build a Digital Twin model of Janssen's upstream platform process. The goal of the project is to create an accurate, genome-based model that will serve as a digital representation of large scale-production reactors, and to use the model to guide upstream process development from cell line selection through the production bioreactor.
PTC	6,000	IoT and AR sales regional director	PTC technology helps companies to quickly unlock the value now being created at the convergence of the physical and digital worlds through the IoT, AR, 3D Printing, Digital Twin, and Industrie 4.0.
Autodesk	10,000	Support program manager	Come join the Autodesk Tandem™ team at Autodesk! Our mission is to create Digital Twin technology and solutions that will transform how buildings are designed, built, and operated.

Company	Size	Role	Job Description
Principal Power	2,600	Senior Naval architect	Global Performance engineering and analysis work relating to Digital Twins such as: scaled model test design and planning, verification, and validation of Digital Twin software versus numerical models and asset performance.
Rivian	100	Senior virtual engineer	Define a road map to enable delivery of a full Digital Twin and automation to keep the digital model up to date.
Bright Machines	330	Senior software engineer – 3D graphics	You will be joining a team of software engineers who are currently building a Digital Twin for Bright Machines' microfactories. At Bright Machines we're building Digital Twin software that serves as a virtual 3D environment where our users design, program, debug and test microfactories – an environment where mistakes are cheap and iterations are fast.
IBM	3,46,000	Digital Twin Architect	Leading the design and delivery of Digital Twin solutions for our clients, Providing technical leadership to clients on how Digital Twin, AR and IoT solutions can transform their business and operations, Presenting IBM's Digital Twin Point of View to C-level client executives, Providing technical leadership to presales and proposal teams, Developing IBM intellectual property and technical eminence in Digital Twin and IoT.

Table 3.5

Chapter 4

Links

Why the Lean Start-Up Changes Everything: https://hbr.org/2013/05/why-the-lean-start-up-changes-everything

XMPRO, Lean Digital Twin: Part 1: https://xmpro.com/lean-digital-twin-part-1/

The template for the canvas is available to download at https://bit.ly/idt-ldtc

Two notable projects in this area are the Asset Administration Shell (AAS), developed by Plattform Industrie 4.0 (https://bit.ly/idt-aas), and the Digital Twin Definition Language (DTDL), which is sponsored as an open source initiative by Microsoft (https://bit.ly/idt-dtdl).

Working Group „Reference Architectures, Standards and Norms: (https://bit.ly/idt-wgI40)

Details of the Asset Administration Shell: https://bit.ly/idt-zvei-aas

AAS Explorer source code :https://bit.ly/idt-aasx

Other Digital Twin enabling technology vendor examples can be found at http://www.i40-aas.de.

Technical information on the open source implementation of DTDL and the six classes is available at: https://bit.ly/idt-dtdlv2

Visit https://bit.ly/idt-adts for more information on Azure Digital Twins.

The Digital Twin knowledge graph in Azure Digital Twins can be visualized with Azure Digital Twins Explorer: https://bit.ly/idt-dtdlx

A description of this example is available at:https://bit.ly/idt-dtdlx

Alleantia (alleantia.com)

Particle (particle.io)

Microsoft (microsoft.com)

Relayr (relayr.io)

Thingworx (ptc.com)

Avolution (avolutionsoftware.com)

Boxarr (boxarr.com)

iGrafx (igrafx.com)

QPR (qpr.com)

XMPro (xmpro.com)

ANSYS (ansys.com)

C3.ai (c3.ai)

OSIsoft (osisoft.com)

Sight Machine (sightmachine.com)

Uptake (uptake.com)

AVEVA (aveva.com)

Bentley (bentley.com)

GE Digital (ge.com)

IBM (ibm.com)

Oracle (oracle.com)

SAP (sap.com)

Siemens (siemens.com)

Figures

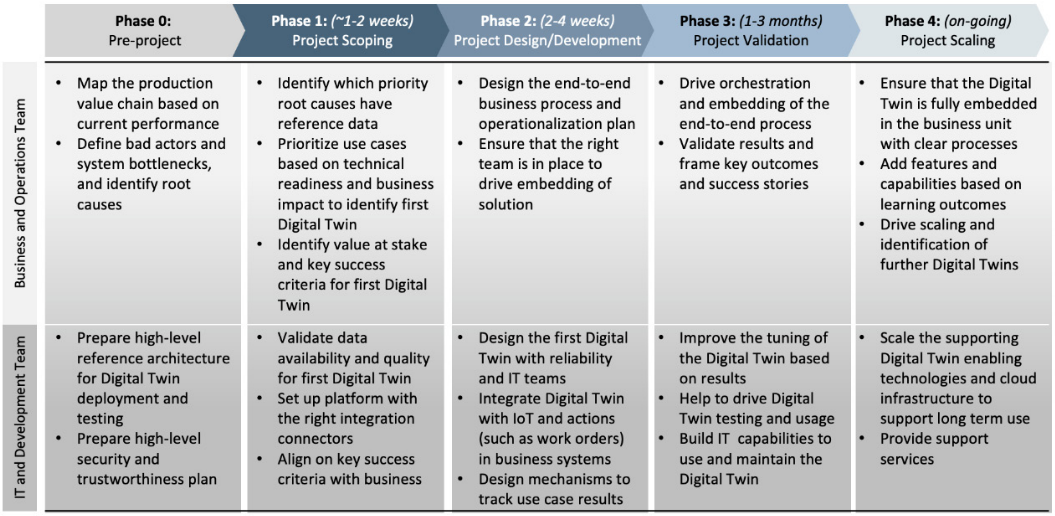

Figure 4.1 – Project planning framework for a predictive maintenance Digital Twin

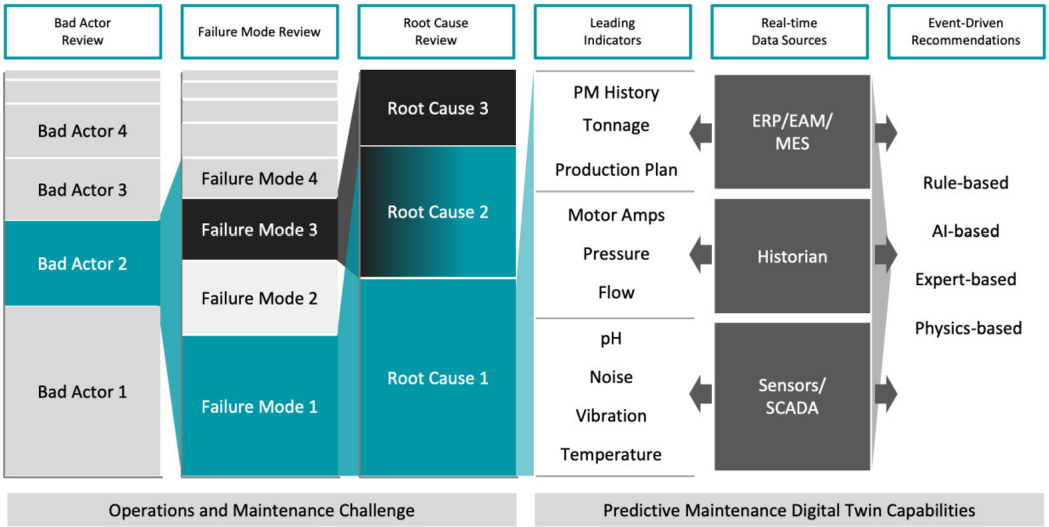

Figure 4.2 – Project planning framework for the predictive maintenance Digital Twin

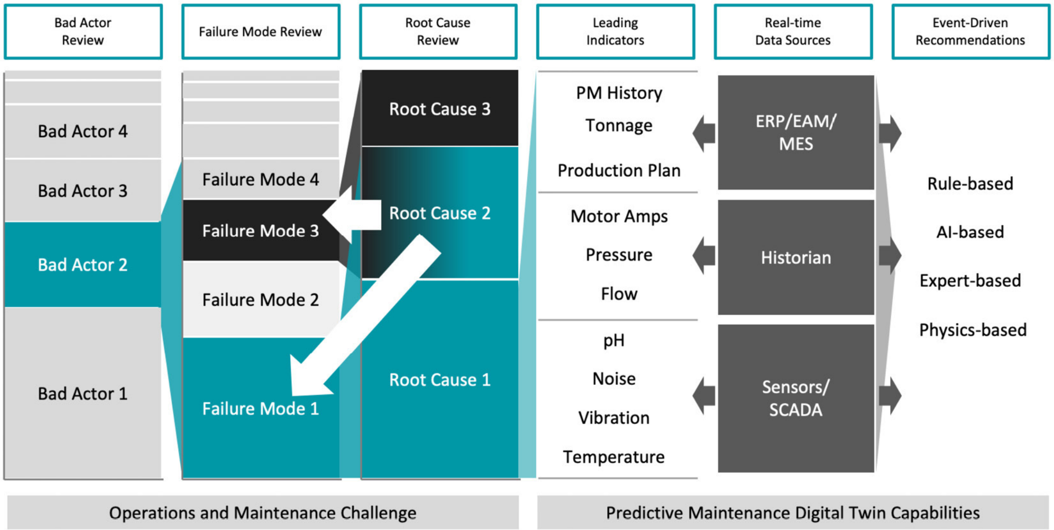

Figure 4.3 – Relationship of root causes and failure modes

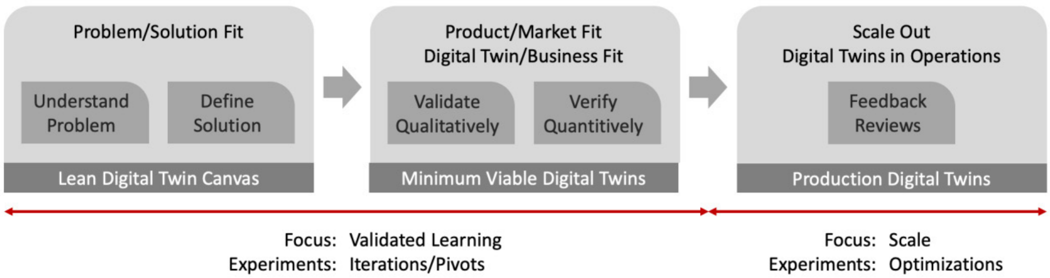

Figure 4.4 – Moving from the Problem/Solution to the Digital Twin/Business Fit

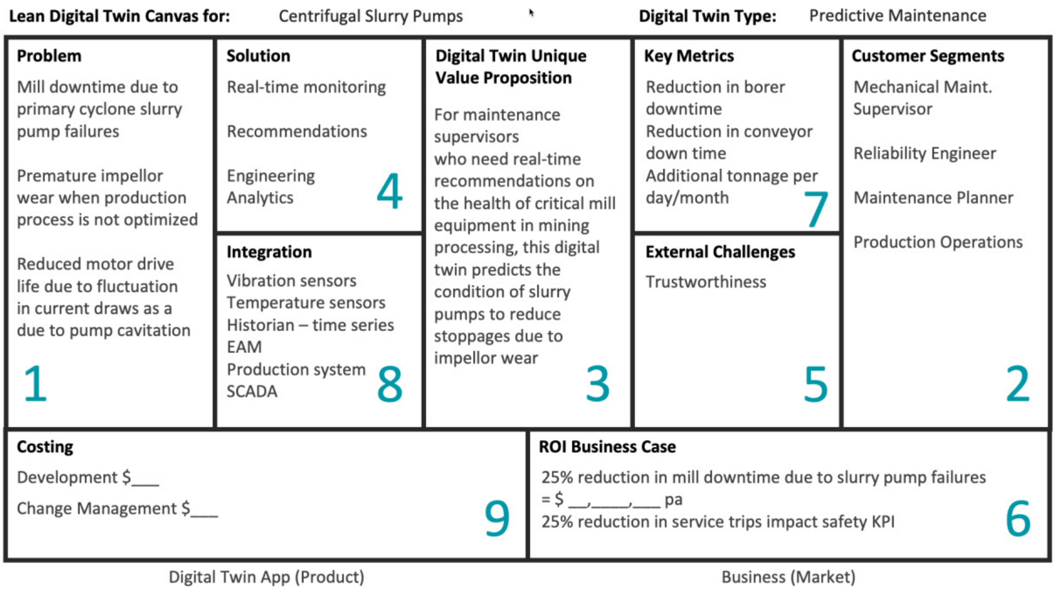

Figure 4.5 – The lean Digital Twin canvas for the slurry pump predictive maintenance Digital Twin

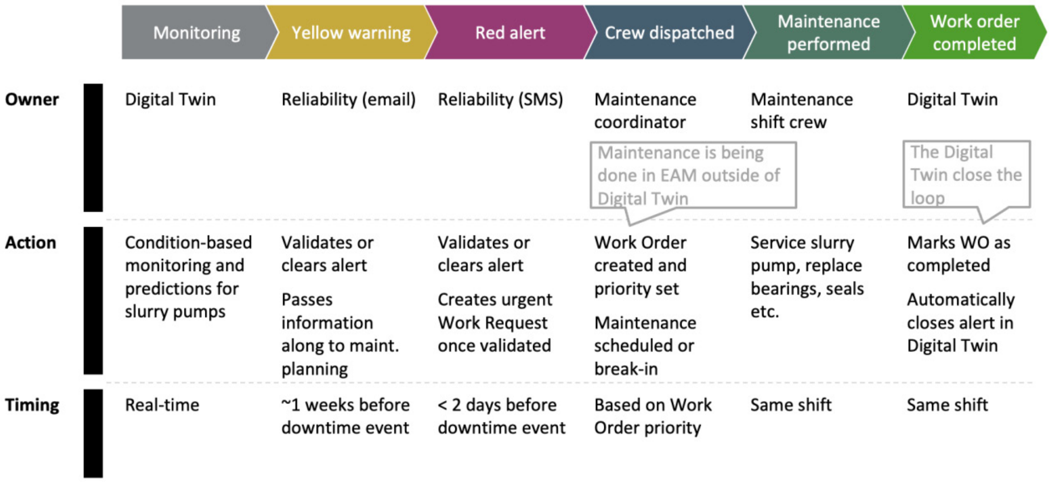

Figure 4.6 – Example of business process changes based on Digital Twin inputs

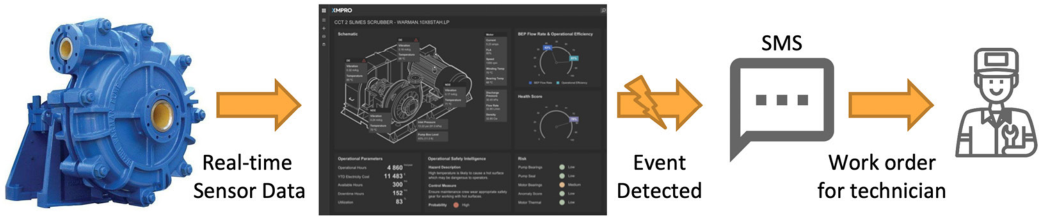

Figure 4.7 – End-to-end business process initiated by a Digital Twin of a pump

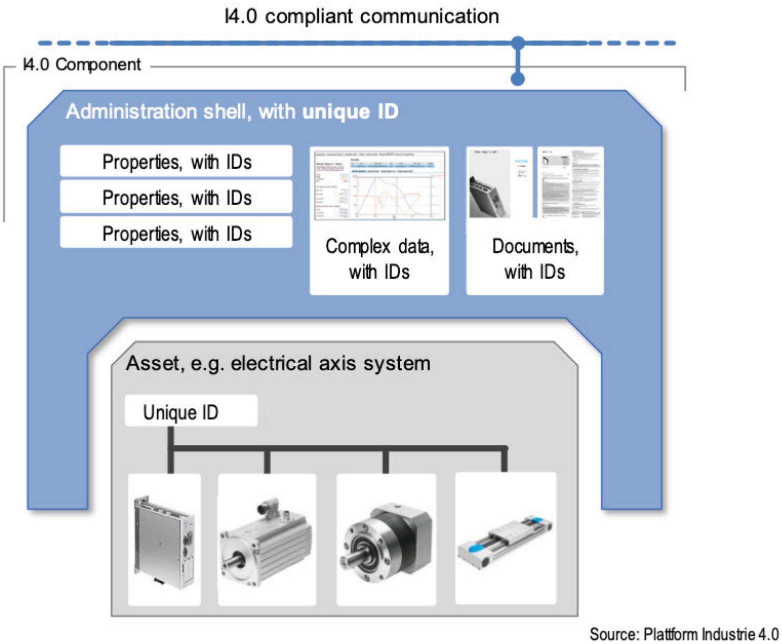

Figure 4.8 – High-level metamodel of AAS: https://bit.ly/idt-zvei-aas

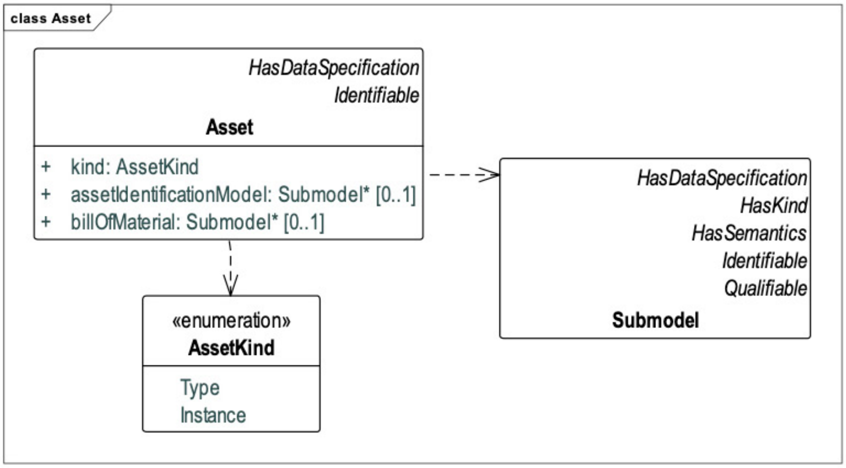

Figure 4.9 – Metamodel of an asset in the AAS structure

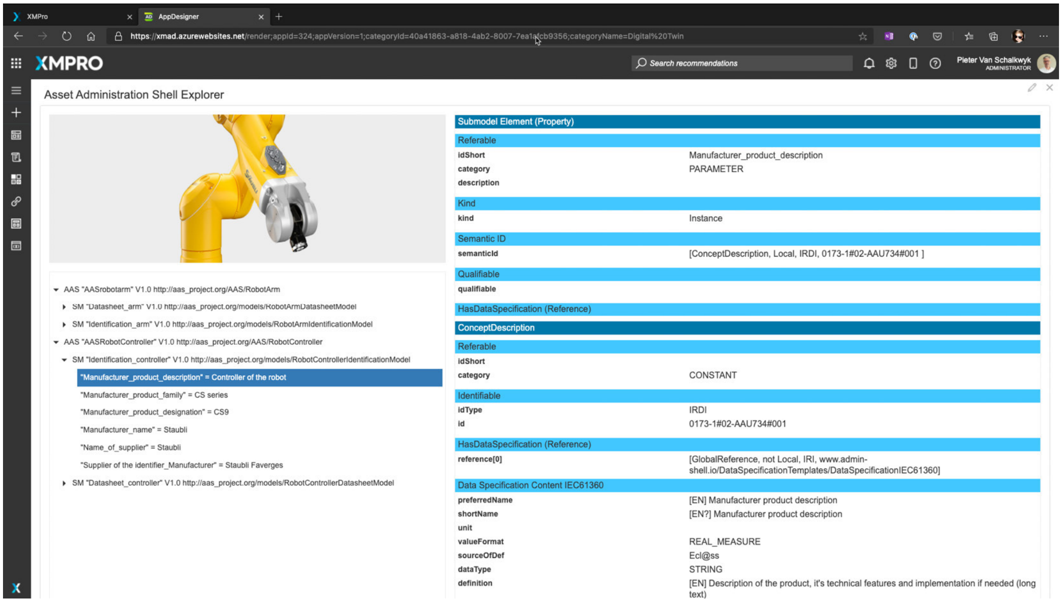

Figure 4.10 – Example of a robotic arm Digital Twin in the AAS definition for a smart factory

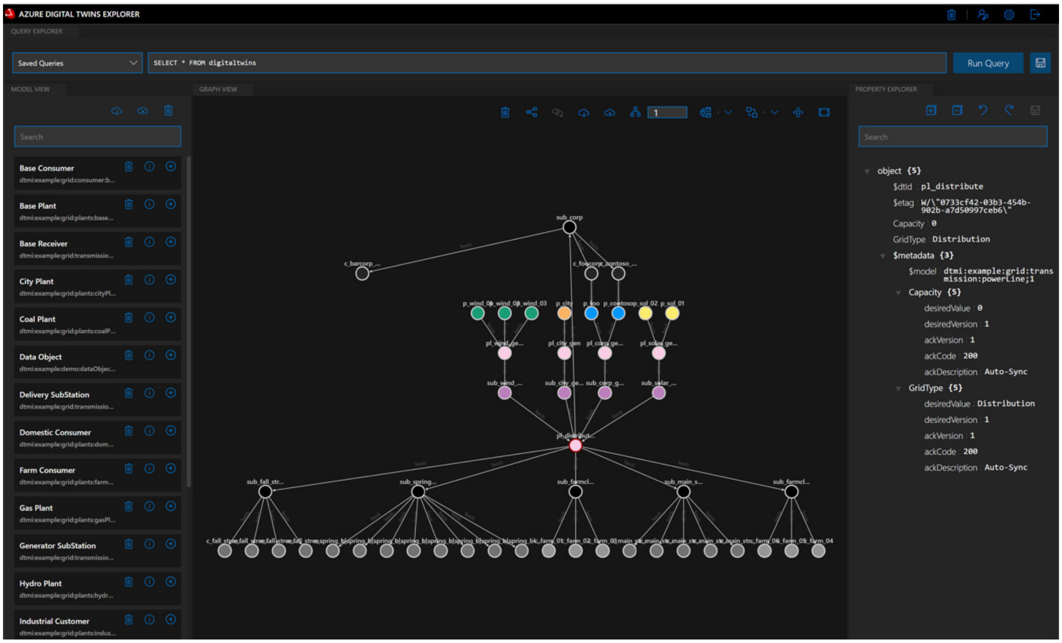

Figure 4.11 – DTDL-based Digital Twin graph in the Azure Digital Twins service

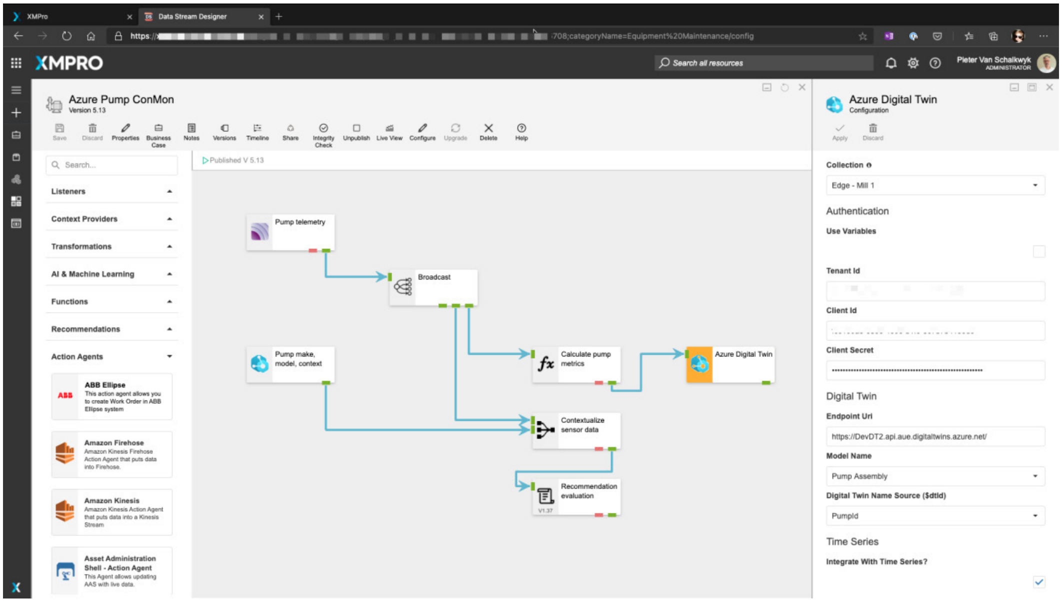

Figure 4.12 – DTDL-based Digital Twin graph in the Azure Digital Twins service

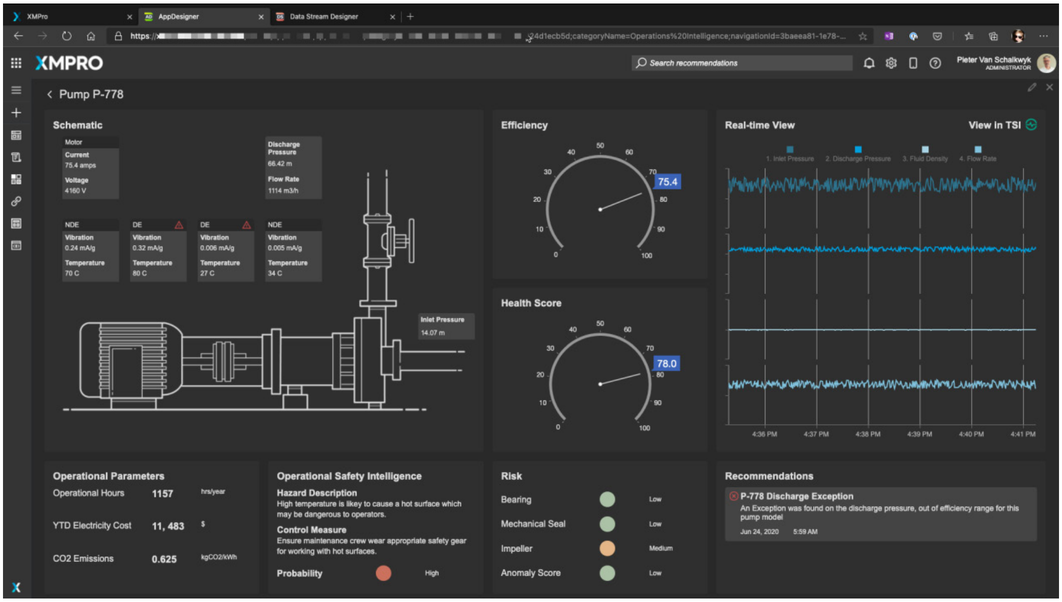

Figure 4.13 – DTDL-based Digital Twin graph in the Azure Digital Twins service

Code

Code 4.1:

This snippet of XML code shows the structure of defining the asset and its component or sub-model hierarchy in a machine-readable format:

```
. . .
<aas:assetAdministrationShells>
    <aas:assetAdministrationShell>
      <aas:idShort>ExampleMotor</aas:idShort>
      <aas:category>CONSTANT</aas:category>
      <aas:identification idType=”URI”>http://customer.
com/        aas/9175_7013_7091_9168</aas:identification>
      <aas:assetRef>
        <aas:keys>
          <aas:key type=”Asset”
local=”true”            idType=”URI”>http://customer.com/assets/
KHBVZJSQKIY            </aas:key>
        </aas:keys>
```

```
      </aas:assetRef>
      <aas:submodelRefs>
        <aas:submodelRef>
          <aas:keys>
            <aas:key type="Submodel"
local="true"             idType="URI">http://i40.customer.
com/             type/1/1/1A7B62B529F19152</aas:key>
          </aas:keys>
        </aas:submodelRef>
      </aas:submodelRefs>
      <aas:conceptDictionaries />
    </aas:assetAdministrationShell>
  </aas:assetAdministrationShells>
. . .
```

Code 4.2:

Here is a DTDL JSON example that describes some of the properties of the centrifugal slurry pump:

```
{
     "@id": "dtmi:com:XMPro:PumpAssembly;1",
     "@type": "Interface",
     "@context": "dtmi:dtdl:context;2",
     "displayName": "Pump Assembly",
     "contents":[
          {
           "@type": "Property",
            "name": "Description",
            "schema": "string"
          },
          {
            "@type": "Property",
            "name": "PumpType",
            "schema": "string"
          },
          {
            "@type": "Property",
```

```
              "name": "MotorRatedPower",
              "schema": "double"
            },
            {
                "@type": more types and properties here
            }
       ]
 }
```

Chapter 5

Links:

Germany gears up to test 20MW wind turbines: https://reneweconomy.com.au/germany-gears-up-to-test-20mw-wind-turbines-79007

Wake effect: https://www.wind-energy-the-facts.org/wake-effect.html#).

Device Shadow service: https://docs.aws.amazon.com/iot/latest/developerguide/iot-device-shadows.html.

Hexagon Digital Reality (HxDR) platform : https://aws.amazon.com/blogs/industries/hxdr-transforming-geospatial-data-in-the-cloud-with-aws-and-hexagon-leica-geosystems/

Vertex: https://aws.amazon.com/iot/solutions/VertexDigitalTwin/).

Bosch IoT Things on AWS:https://aws.amazon.com/marketplace/pp/BoschIO-GmbH-Bosch-IoT-Things/B07DTJK8MV).

Oracle's Fusion Cloud Internet of Things IoT Intelligent Applications: https://www.oracle.com/internet-of-things/

For more details on Oracle Digital Twin implementation, see https://docs.oracle.com/en/cloud/paas/iot-cloud/iotgs/oracle-iot-digital-twin-implementation.html.

ThingWorkx IoT Deployment: http://bit.ly/idt-3thingworx

The ADT documentation is at http://bit.ly/idt-azuredocs

ADT Explorer (http://bit.ly/idt-adtexplorer)

Figures

Figure 5.1 – HAWT

Figure 5.2 – Offshore wind farm

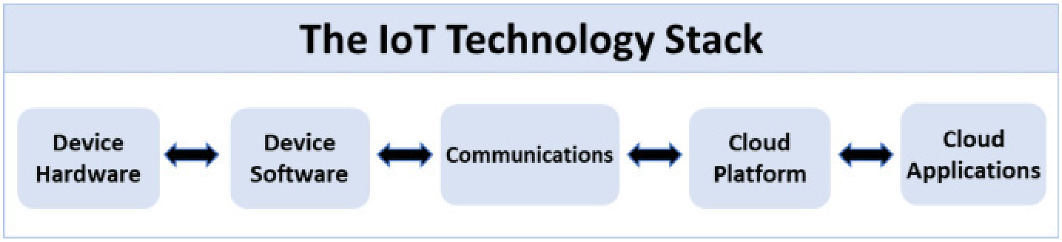

Figure 5.3 – The IoT technology stack

> **Note**
>
> Image citation: Abunahla, H., Gadhafi, R., Mohammad, B. et al. *Integrated graphene oxide resistive element in tunable RF filters*. Sci Rep 10, 13128 (2020). https://doi.org/10.1038/s41598-020-70041-x

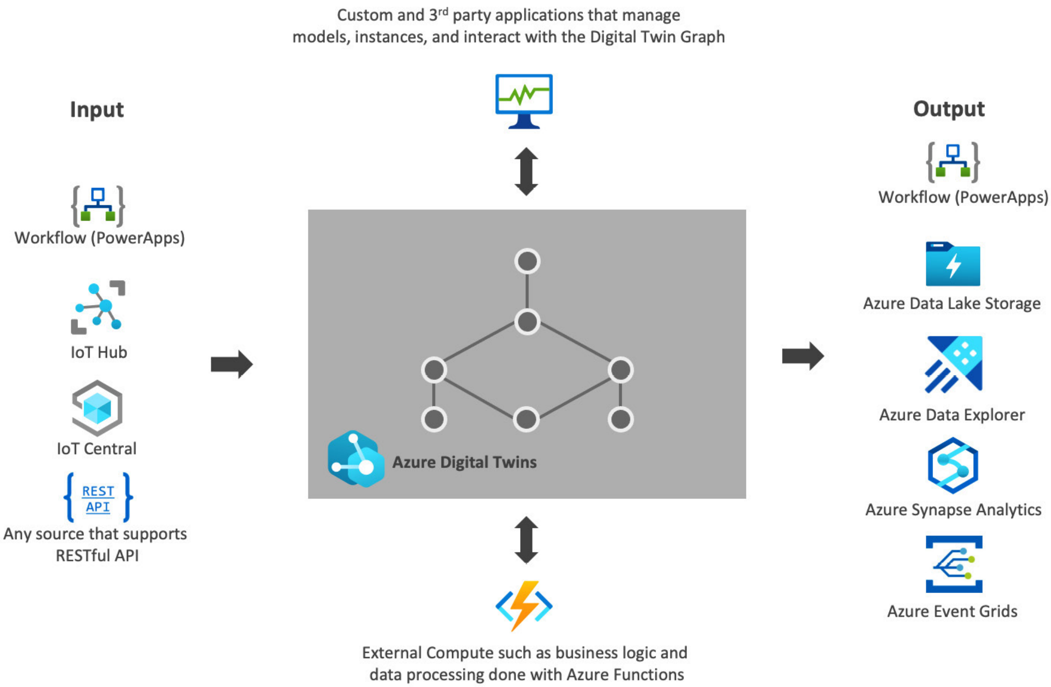

Figure 5.4 – Microsoft ADT in an Azure IoT platform

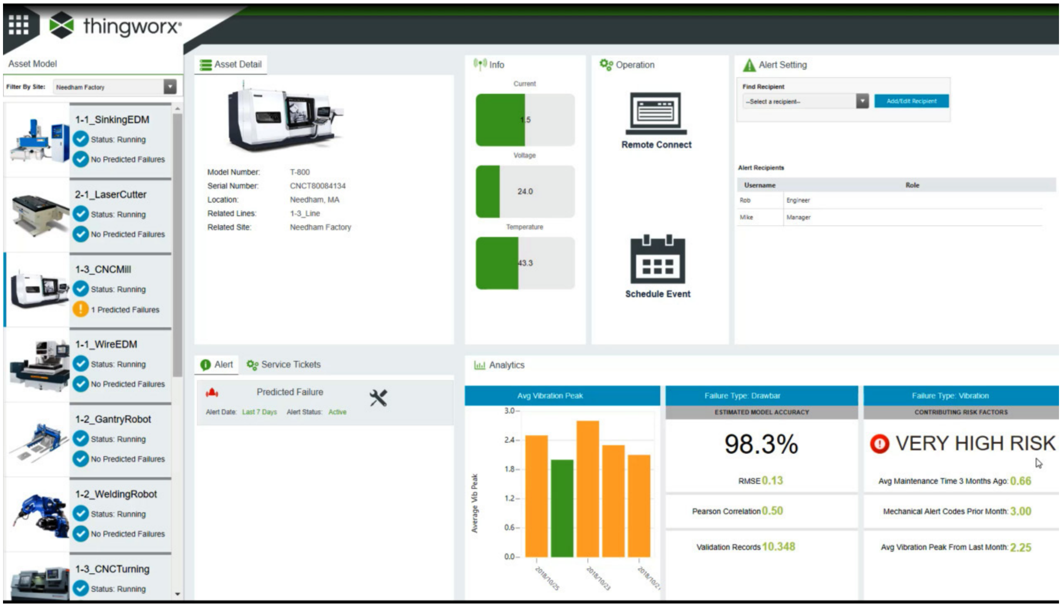

Figure 5.5 – PTC ThingWorx example Digital Twin (courtesy of http://bit.ly/idt-thingworx)

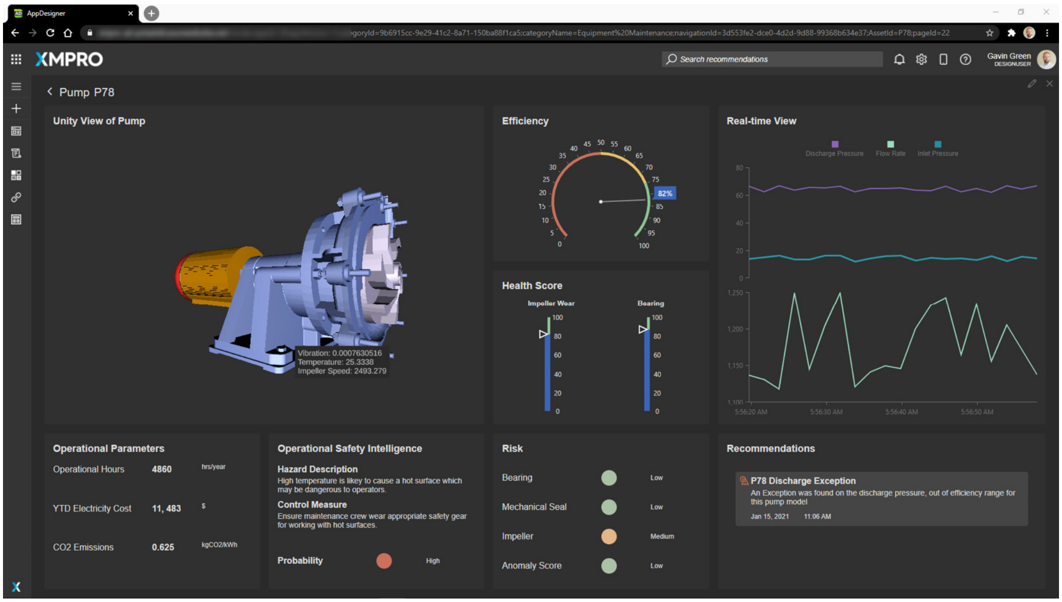

Figure 5.6 – XMPro sample Digital Twin (courtesy of XMPro Inc.)

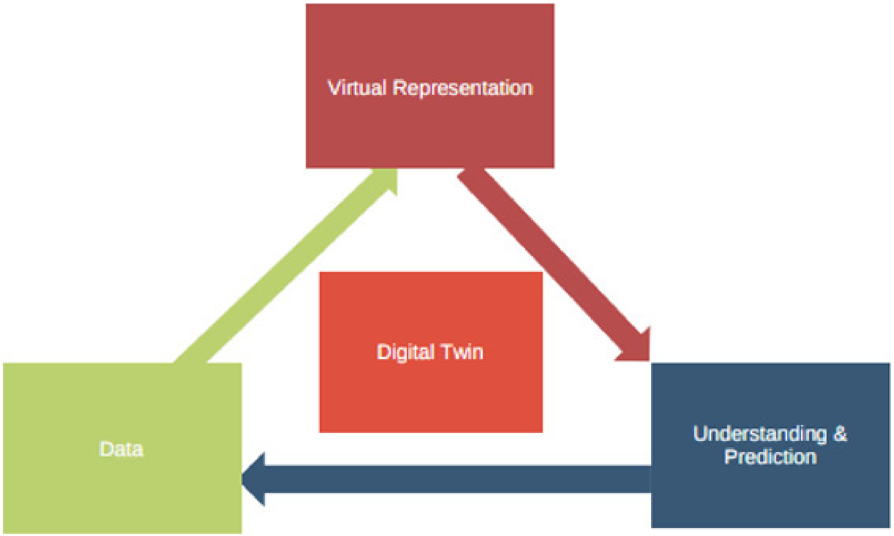

Figure 5.25 – Business problem for the Digital Twin

Note

Image source: Technology Media Telecommunications (TMT), GeoActive Group: `https://blog.geoactivegroup.com/2020/07/digital-twin-apps-in-industrial-markets.html`

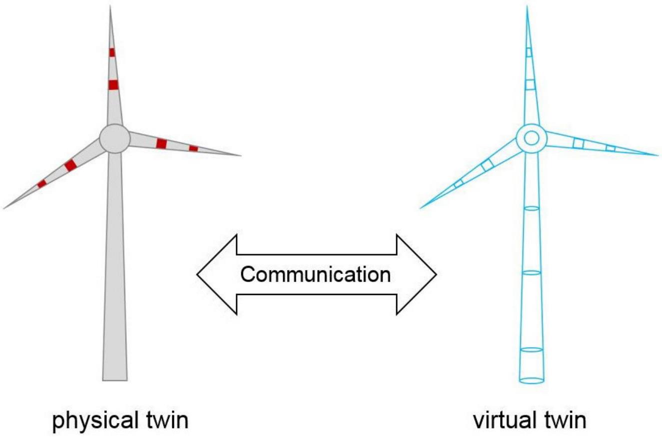

Figure 5.26 – Distilling the business problem to evolve the solution architecture

> **Note**
>
> Image source: http://dx.doi.org/10.18775/ijied.1849-7551-7020.2015.52.2006

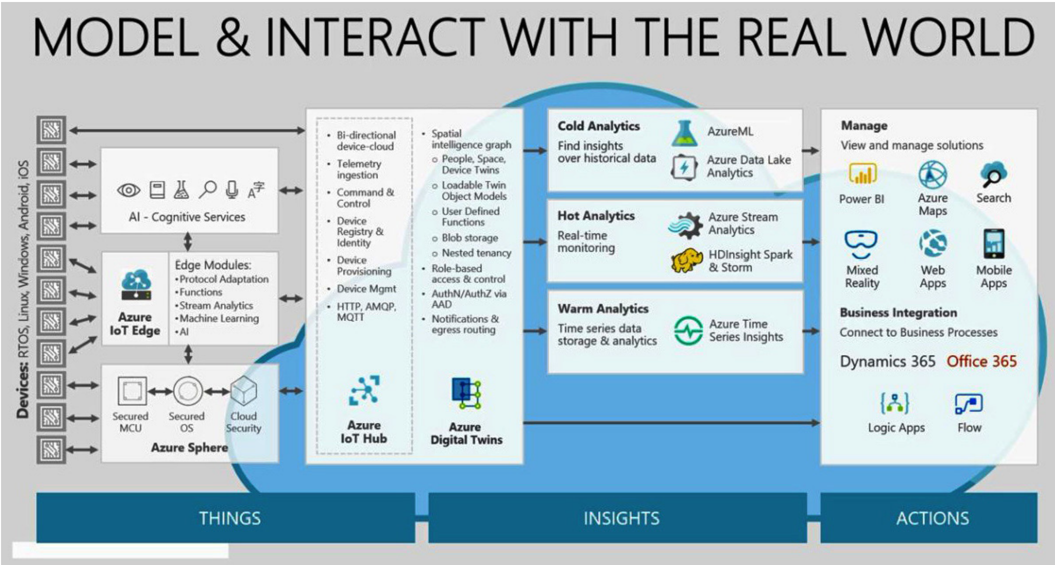

Figure 5.27 – Evolving the solution architecture using Microsoft ADT

> **Note**
>
> Image source: https://schwabencode.com/blog/2020/03/10/Device-Twins-vs-Digital-Twins-Azure-IoT

Configuration and setup of Microsoft ADT

Before we can configure our first Digital Twin in Microsoft ADT, we must set up the cloud infrastructure and account on Microsoft Azure. Microsoft provides detailed setup instructions for Azure administrators, but we will start from the perspective of a non-corporate user that wants to set up a free account to build a first digital-twin prototype. The ADT documentation is at `http://bit.ly/idt-azuredocs`.

The first step is to create a free Azure account that will host your ADT service and any other IoT and analytics services that you will need for your first Digital Twin. See the following screenshot for an overview of how to do this:

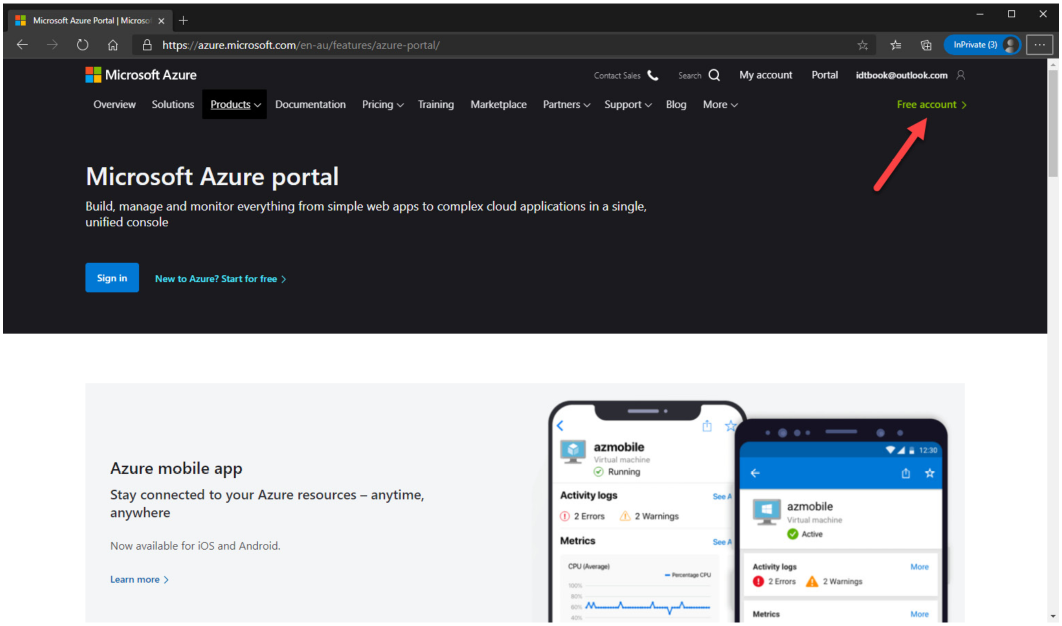

Figure 5.7 – Microsoft Azure portal UI

Once you've created an account, you will be directed to the Azure service portal. This is the central management environment for all Azure services, including ADT, Azure databases, IoT services, and all the other products that Microsoft provides in its Azure product range.

ADT is a PaaS solution that provides the infrastructure to create and use Digital Twins. It is a development environment for Digital Twins that is focused on developers to code Digital Twins. It is not an end user-focused application with a UI for business users to configure Digital Twins. It will require other Azure services in your Azure account to perform these actions.

ADT can be configured through the web-based Azure Portal or in a command line through the Azure command-line interface (Azure CLI). Both approaches are documented in the official Microsoft documentation at `http://bit.ly/idt-azuredocs`. We will describe the portal configuration approach at a high level for the purpose of the book.

The configuration and setup of ADT and the supporting app service to code against is done in five main steps, as illustrated in the following diagram:

Figure 5.8 – Microsoft ADT resource and application configuration

The first step is to set up an Azure account. Microsoft provides a free account option at the time of writing the book. The second step is to create an ADT resource or service in the Azure account that you've created. The third step is to give yourself user and data access to the ADT resource you created. You can also give others access to your ADT service during this step. The ADT resource that you created requires an Azure app resource to be able to code against the ADT service. We configure the app resource during the fourth step. Finally, in the fifth step, we give the app resource access and permissions to the ADT service.

You can see an overview of this in the following screenshot:

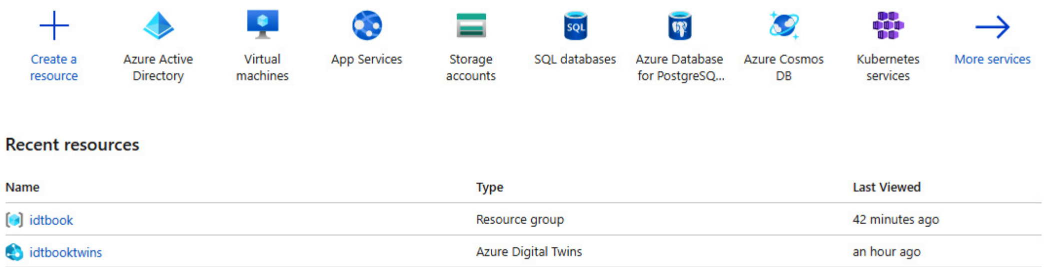

Figure 5.9 – Microsoft Azure portal UI

The UI shown in *Figure 5.9* indicates that you have successfully created your free Azure account and shows a list of services available at the time of writing this book. The next step in our process is to create a new service for ADT. Select the + Create a resource option. A range of existing resources should show, and in the event that ADT is not on the display, you can easily search for it in the search bar, as shown in the following screenshot:

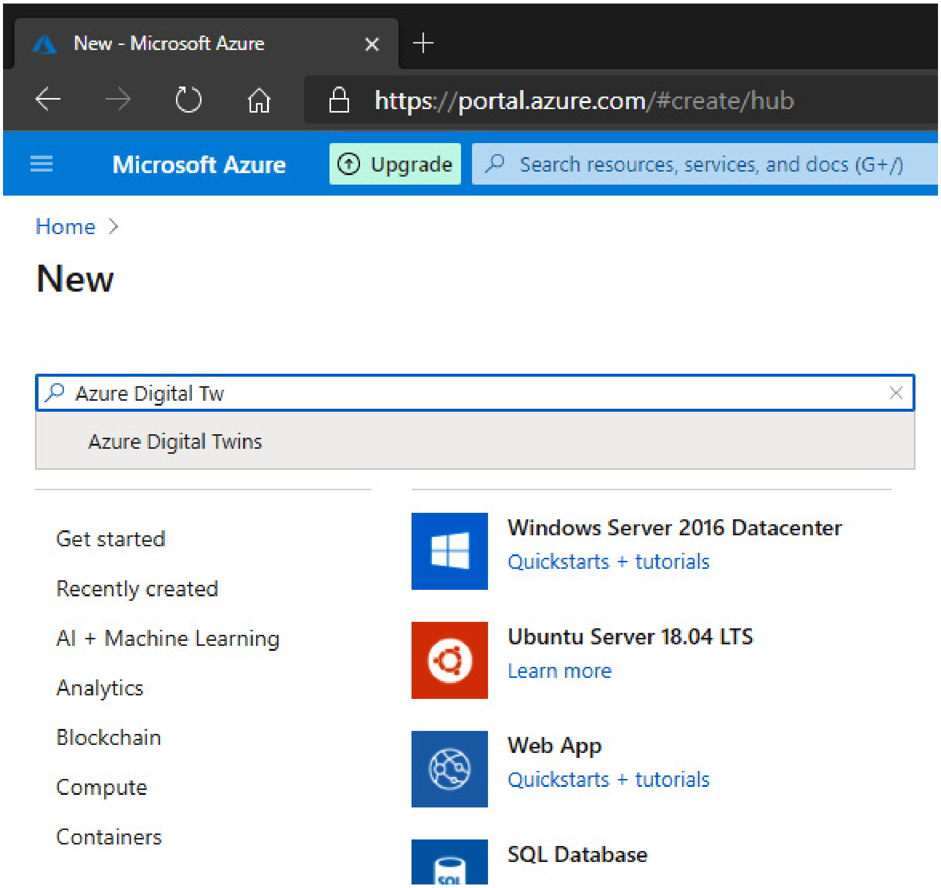

Figure 5.10 – Creating a new Azure resource

Once you've located the ADT resource, click on the Create button to start the process of configuring the resource.

Creating the resource has two main components—the first is to choose a subscription that the resource will run in, and the second part is to choose a hosting location and a name for the ADT resource or service.

The following screenshot shows the subscription options, and it is a good practice to name the resource group in an easily identifiable way. For the purposes of building your first Digital Twin, we recommend that you create a resource group for your digital-twin application. You can think of a resource group as a container that holds related resources for an Azure solution. For later reference in the book, we called the resource group `digitaltwinbook`:

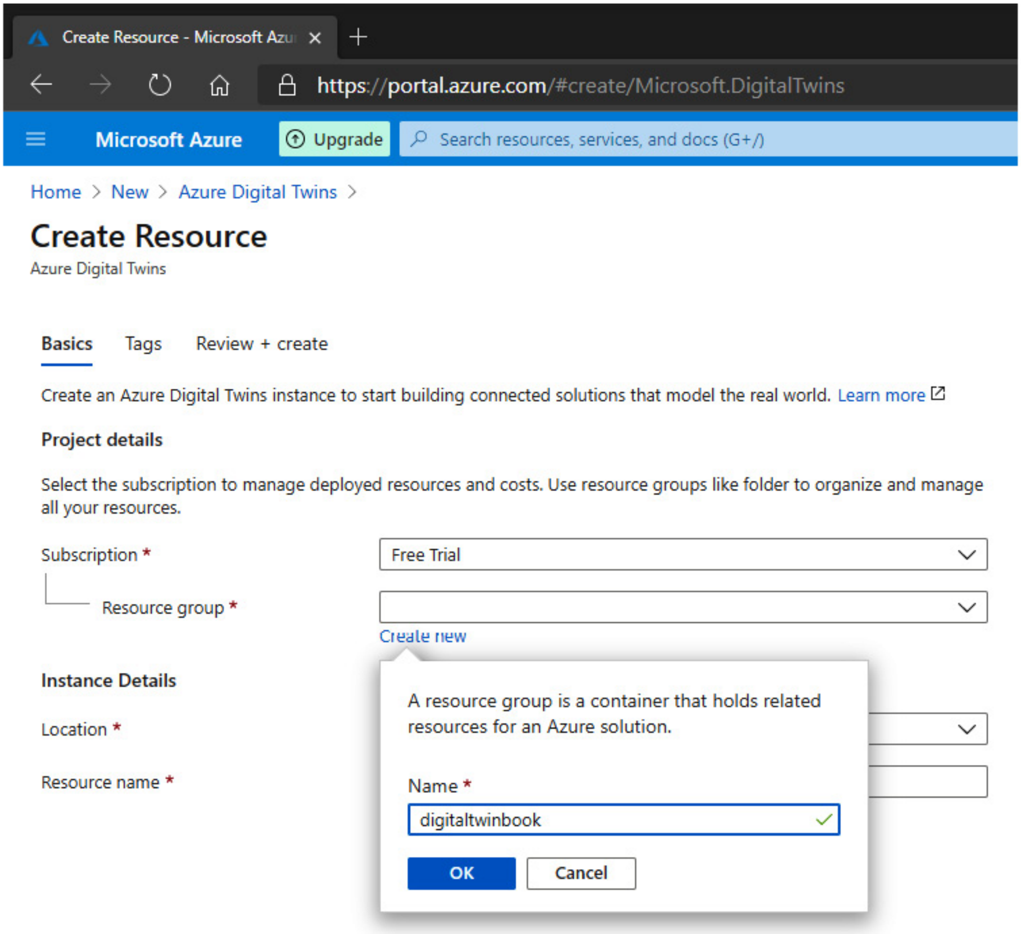

Figure 5.11 – Creating an Azure resource subscription

The second part of the process to create an Azure subscription is to choose a hosting location and name the resources. Hosting locations that provide ADT resources are available from the drop-down list. The decision of a location is most often based on your geographical proximity, to reduce latency. Privacy and data considerations may, however, prescribe your choice if you are in the European Union (EU), for example.

The following screenshot shows the location and name that we chose to use for the Digital Twin that we will configure in *Chapter 6*, *Building the Digital Twin Prototype*. Clicking on the Review + create button will give you the option to review all the settings before the ADT resource is finally created in your chosen subscription and preferred location:

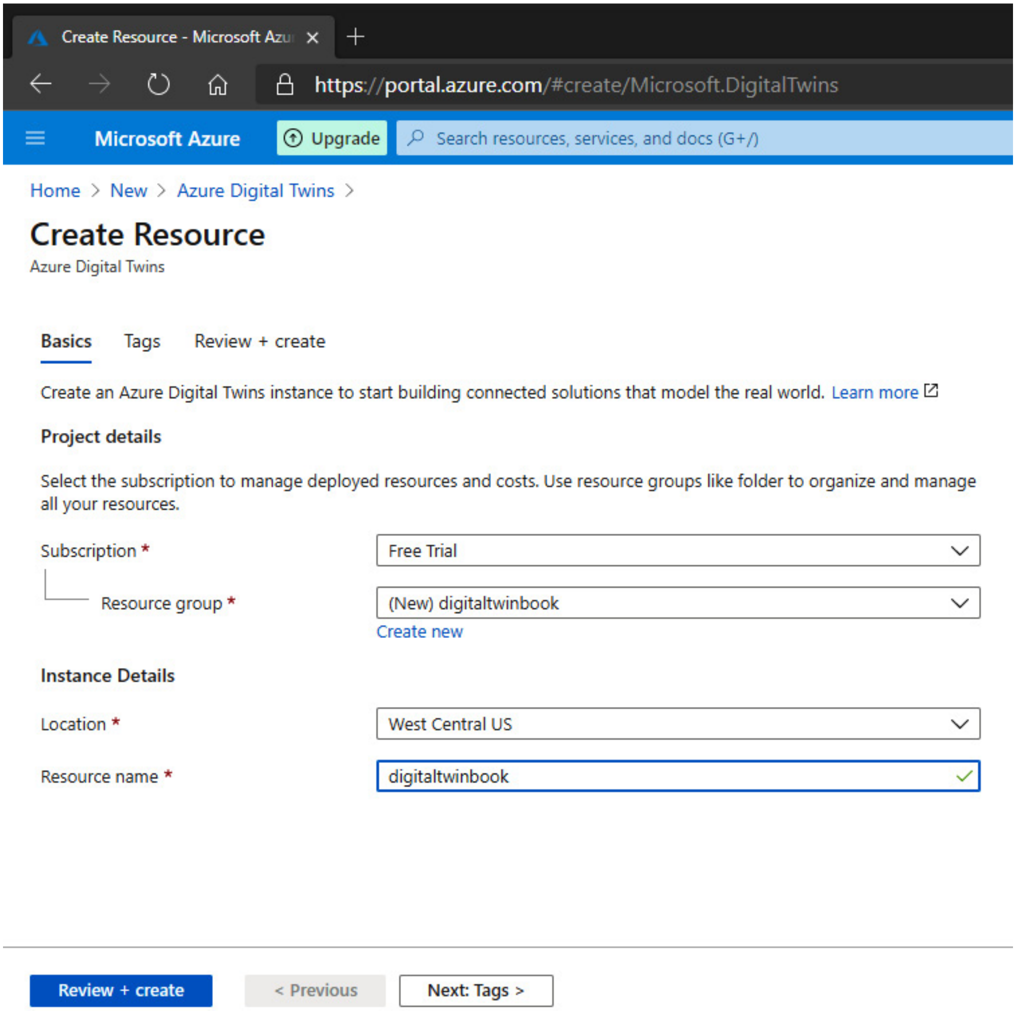

Figure 5.12 – Choose the Azure resource location and name

All the ADT resource information is available in the portal view, as shown in *Figure 5.13*. This concludes the first two steps shown in *Figure 5.8*. The third step is the user access configuration to enable you to access the digital-twin resource when you create your first Digital Twin in *Chapter 6*, *Building the Digital Twin Prototype*.

Next, we see the successful creation of an ADT resource in the following screenshot:

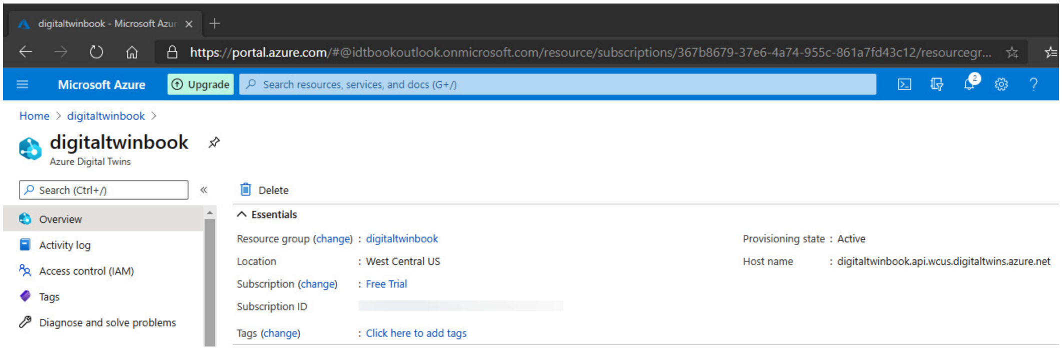

Figure 5.13 – Successful creation of an ADT resource

Select the Access control (IAM) option from the left menu and click on Add role assignments to open the configuration pane. This will enable you to give your user and credentials access to the digital-twin resource. *Figure 5.14* shows the UI at the time of writing the book.

It is important to set your own login user as the data owner for the digital-twin resource when you set this up in a personal or free account. There may be other governance requirements if you are doing this in your organization's Azure subscription or tenant; however, we recommend that you do the initial prototype in a free account.

You can see an overview of the UI here:

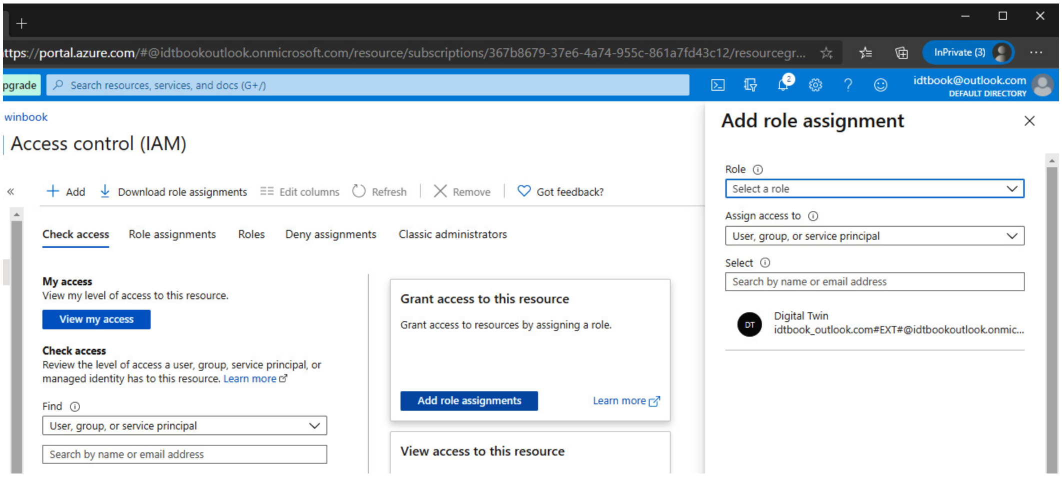

Figure 5.14 – Setting up user access permissions to an ADT resource

Select Azure Digital Twins Data Owner from the available options in the Role dropdown on the right-hand side of the screen. This option will give you full access and ownership to all the capabilities of the ADT resource, as shown in *Figure 5.15*.

The Assign access to option can be left at the default User, group, or service principal setting. Select or type in an Azure free account username in the Select drop-down field.

Your user will appear as an icon below the drop-down fields. Select your user and save the access rights with the Save button on the page, as illustrated in the following screenshot:

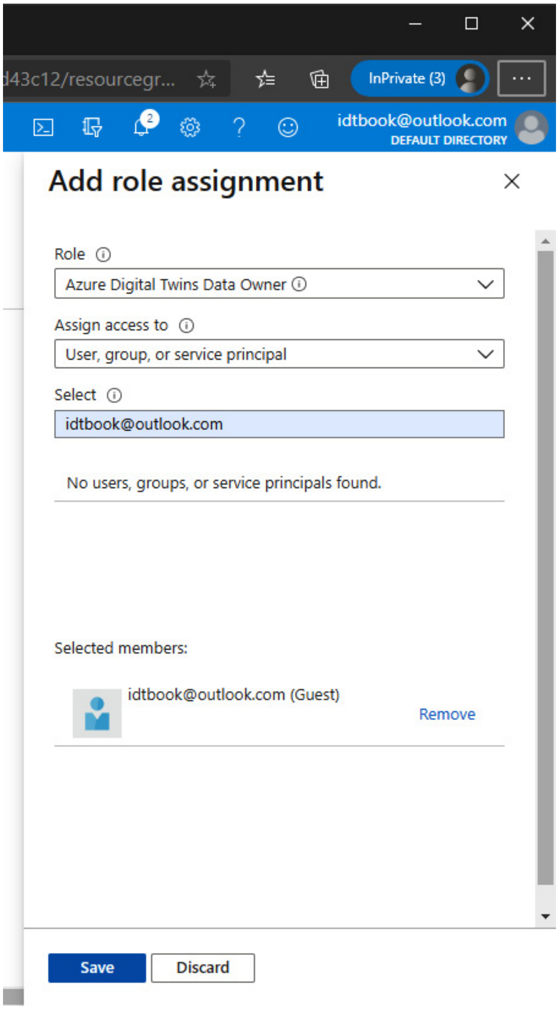

Figure 5.15 – Creating a role assignment for your user in ADT

You have now successfully given your user account access, and this concludes the third step of *Figure 5.8*. Now, have a look at the following screenshot:

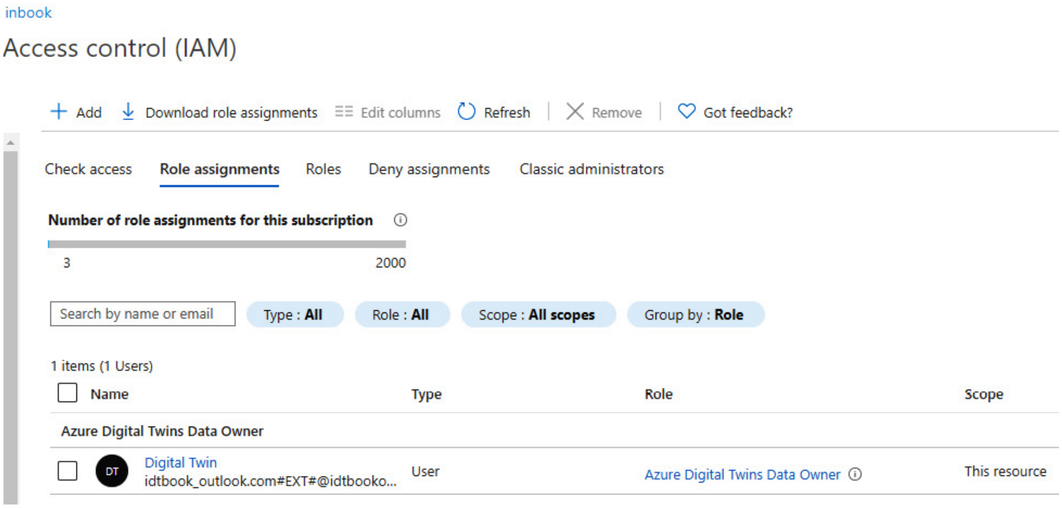

Figure 5.16 – User access successfully assigned in ADT

The fourth step in *Figure 5.8* is to create an Azure app that will be able to interact with the digital-twin service.

It is common practice to interact with an ADT instance through an application such as ADT Explorer (`http://bit.ly/idt-adtexplorer`) or your own custom application. These applications need to authenticate themselves to the ADT service by using Azure Active Directory (Azure AD). This means that you need to create an Azure app service in *step 4* of the process in *Figure 5.8*. Once this is complete, the new app servers will be given access and permissions to the Digital Twin, similar to the user access in the previous step.

This is done from the main page of your Azure portal instance or by choosing Azure Active Directory from the menu on the left on the screen, as shown in the following screenshot:

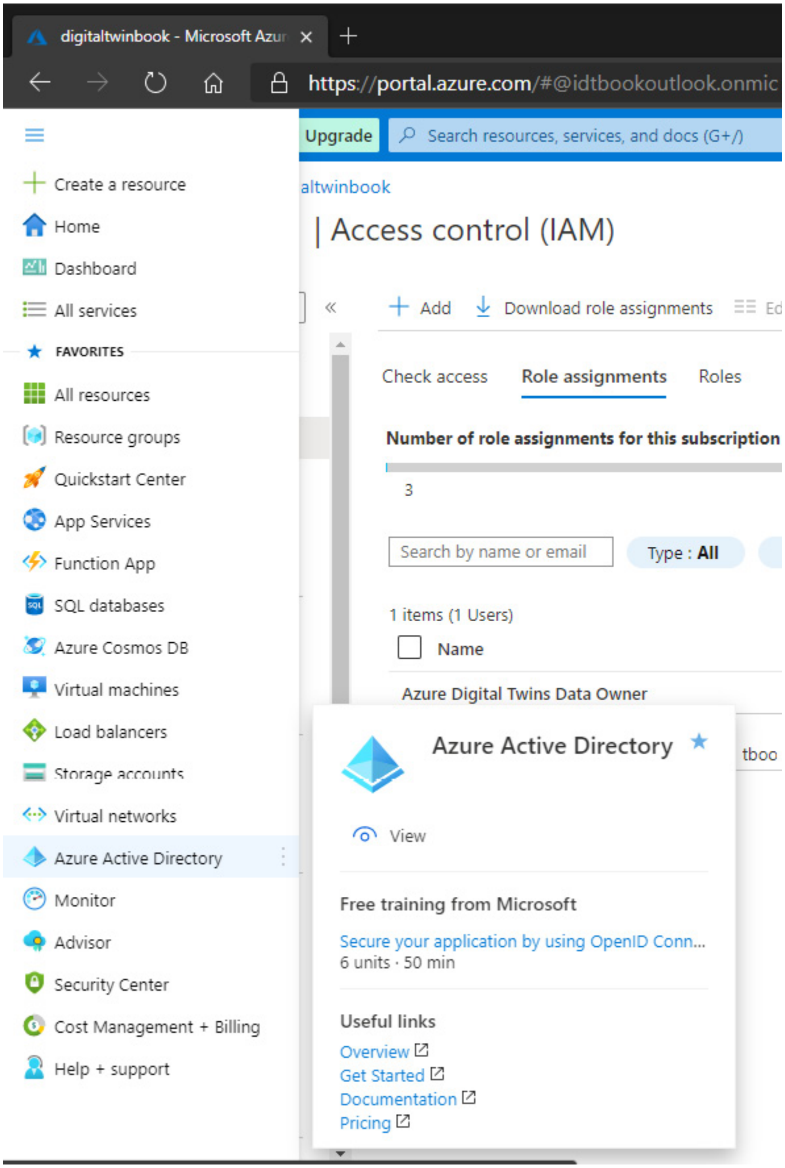

Figure 5.17 – Creating a new Azure AD resource

A screen with app registration options similar to those shown in the following screenshot provides an option to create and manage new applications on Azure. Choose + New registration to start the wizard shown in *Figure 5.19*:

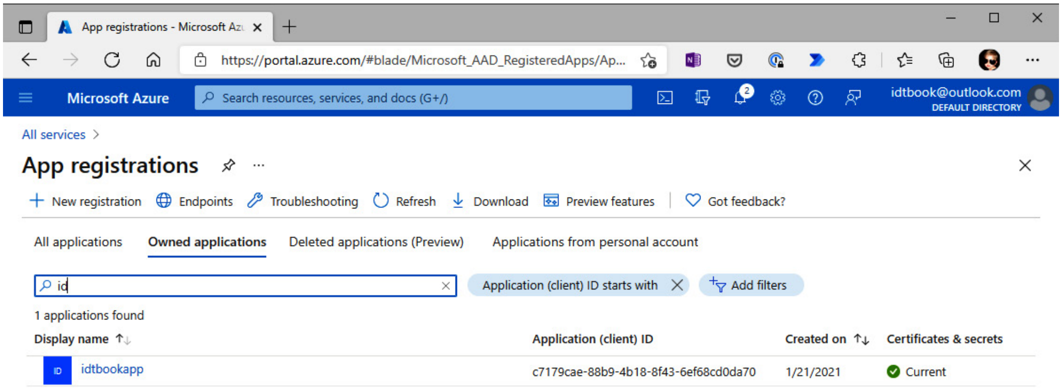

Figure 5.18 – App registrations in Azure AD

Create a recognizable name for your app and continue to register the application with the default settings by clicking on the Register button, as illustrated in the following screenshot:

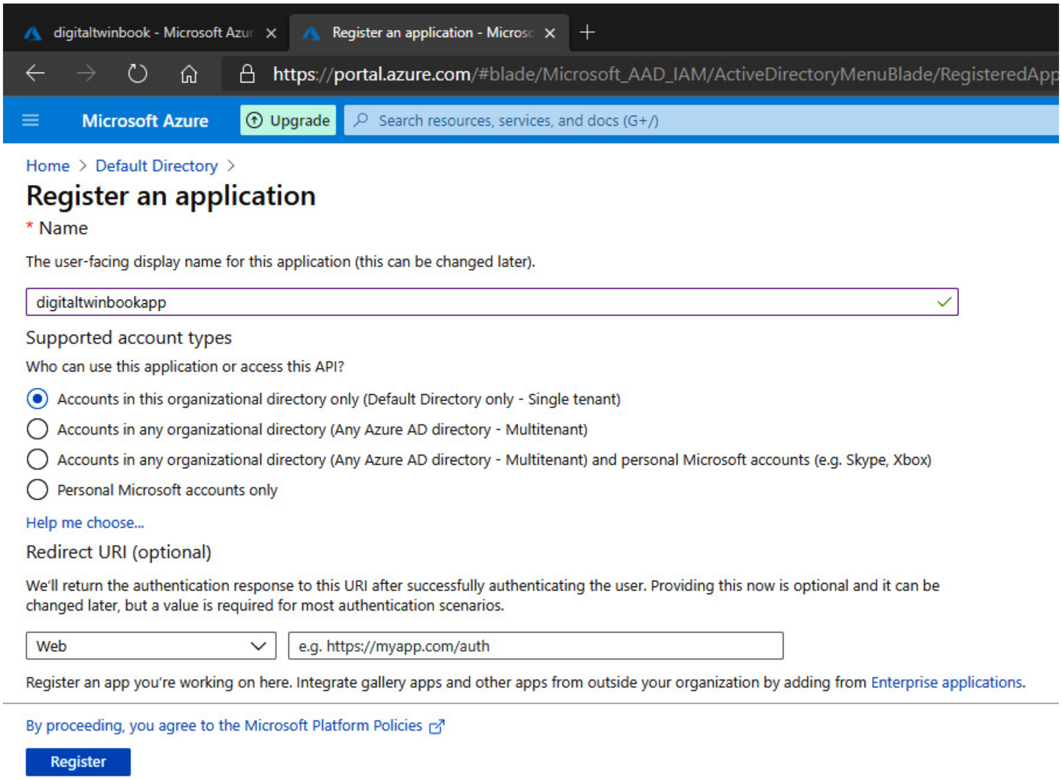

Figure 5.19 – App registration configuration wizard in Azure AD

You have now successfully completed *step 4* in *Figure 5.8*, as demonstrated in the following screenshot:

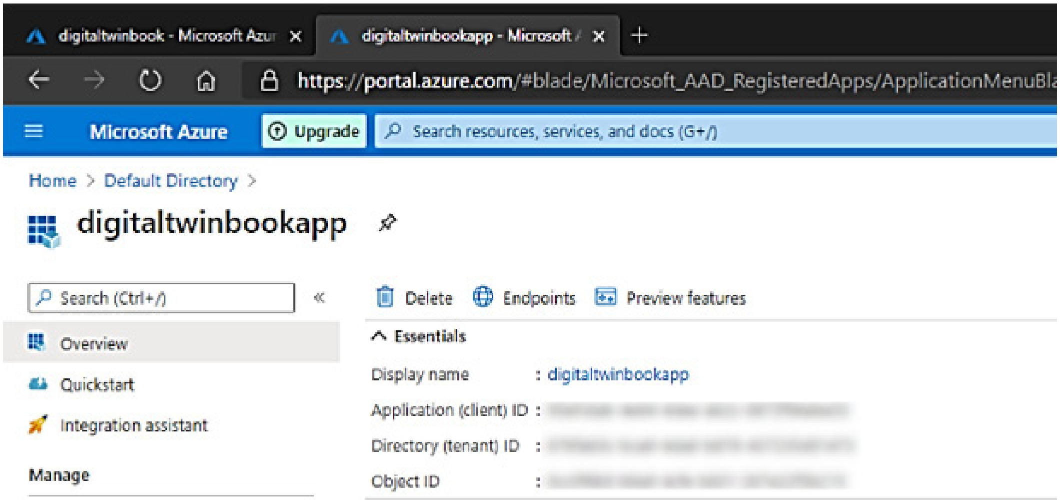

Figure 5.20 – User access successfully assigned in ADT

You now have an ADT and application resource group in your account, similar to that shown in *Figure 5.21*.

The final step in *Figure 5.8* will give your new application resource access to ADT resources. This is similar to the previous step, where we gave you user access. In this instance, we want to give the application the right to read and write information from your ADT resource. We follow a similar approach, but instead of the user account, we will select the new application service that you created, as illustrated in the following screenshot:

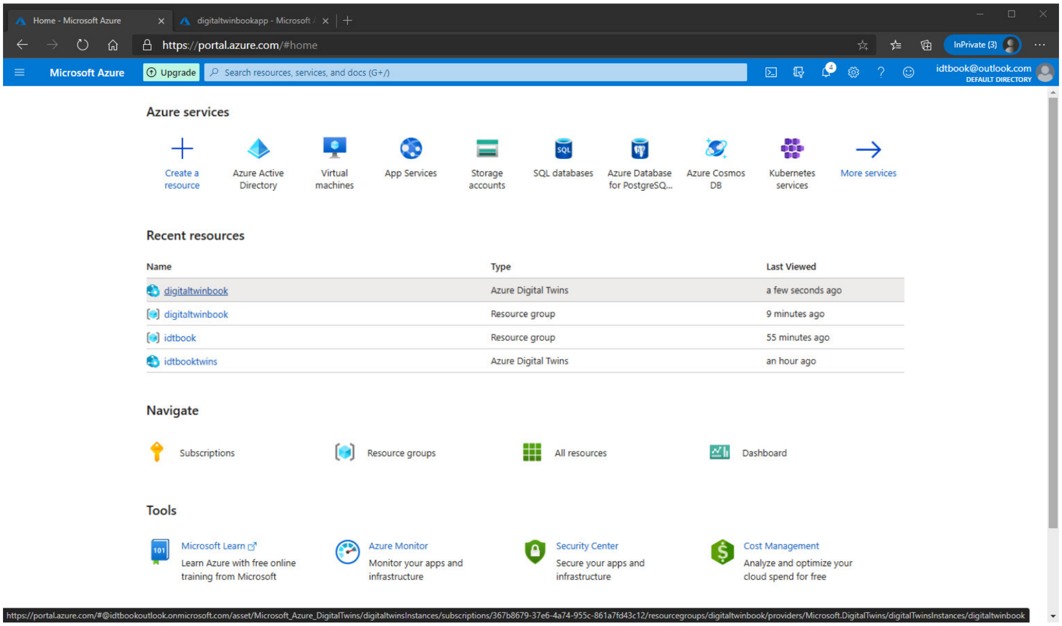

Figure 5.21 – ADT and application resource in your Azure account

Start by clicking on the ADT service on your Azure portal account. In our example, it is the `digitaltwinbook` ADT resource shown in *Figure 5.9*.

Select Access control (IAM) from the menu on the left and proceed with the role assignment, similar to *step 3* of *Figure 5.8*, as illustrated in the following screenshot:

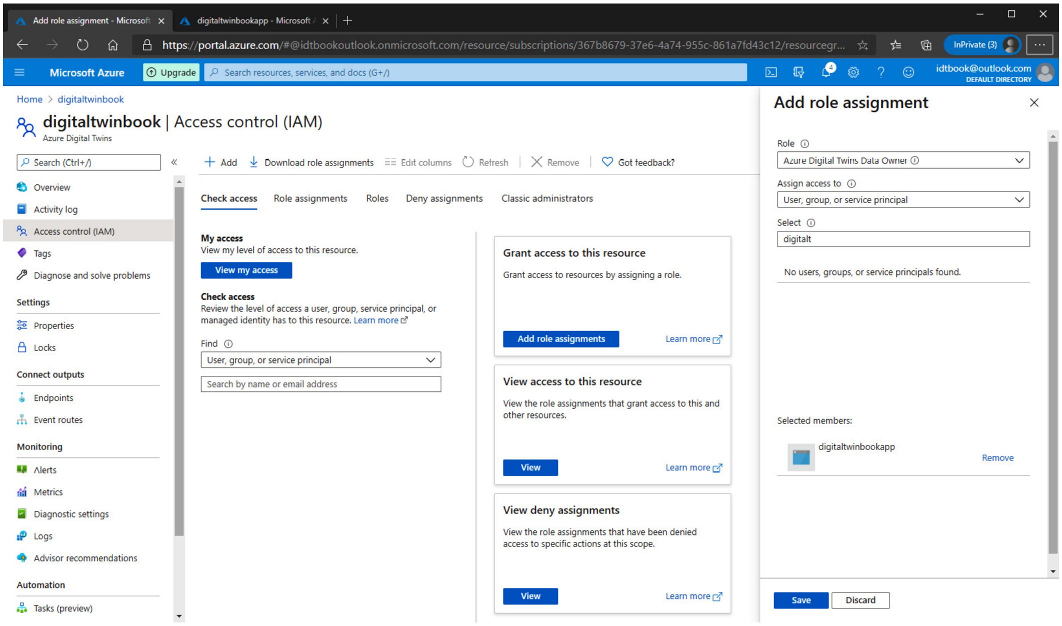

Figure 5.22 – Configuring app access to the ADT resource

We recommend that you assign a data owner role to your application for this application to interact with the digital-twin resource. Select the application instead of your user role in the Select dropdown. You may have to type in the name of your application in the search bar if it doesn't appear in the default list.

Check the API permissions of your app to see whether the Microsoft Graph API appears. This API is used by ADT Explorer. If it is visible, this means that you have successfully completed the last step in the configuration of your ADT service process, as illustrated in the following screenshot:

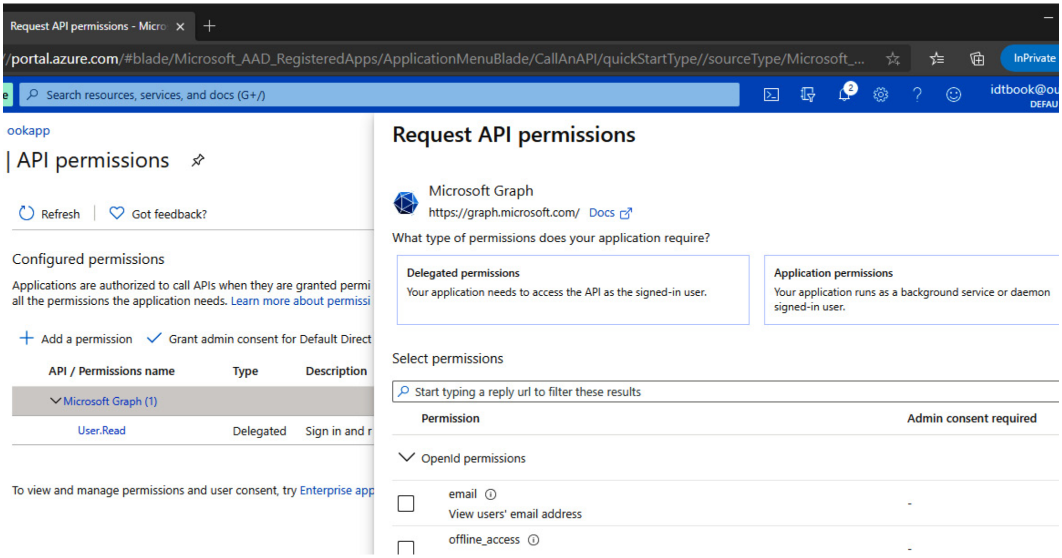

Figure 5.23 – Application access to ADT resource successfully completed

This concludes the configuration of the ADT environment in a free Azure account. We started by creating a free Azure account, creating an ADT resource, and gave our Azure account user access to the ADT service. To interact with our ADT resource, we also created an Azure app with access to the ADT service.

We now have the ability to create our first Digital Twin on the ADT platform. There are, however, two other configuration processes that you may want to follow to install ADT Explorer and Azure TSI.

ADT Explorer is an example application that enables you to view your Digital Twin in a graph-like visualization. ADT Explorer is not an officially supported product by Microsoft at the time of writing the book, even though it is recommended by Microsoft. The sample application as well as source code and installation instructions can be downloaded from GitHub (`http://bit.ly/idt-adtexplorergit`).

The hostname for ADT will be required by ADT Explorer during the configuration to ensure that it is connecting to and visualizing the correct digital-twin service. You will find the Uniform Resource Locator (URL) in the properties of your ADT service in the Azure portal, as shown in the following screenshot:

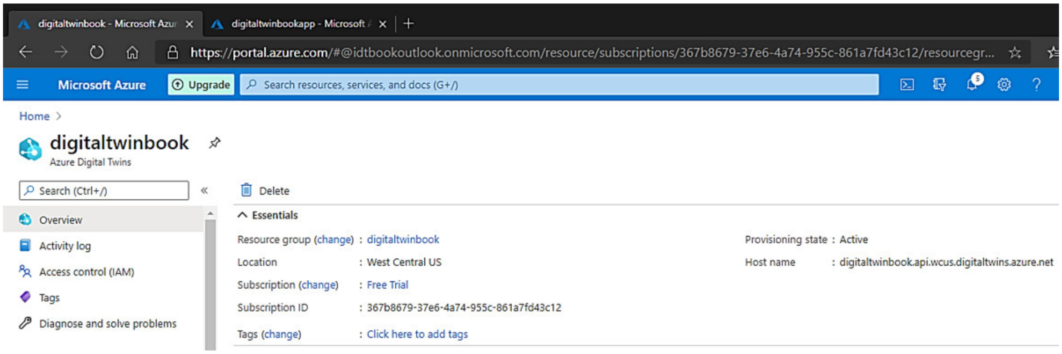

Figure 5.24 – ADT host URL

Configuring Azure TSI is not required at this stage, but it will be used later to store temporal data for our first digital-twin prototype. Installation instructions are available at `http://bit.ly/idt-azuretsi`.

Chapter 6

Technical requirements

In this chapter, we will configure your first Digital Twin prototype. There are sample JSON-based DTDL files for the wind farm example that we use. You can find the code files for this chapter on GitHub at `https://github.com/PacktPublishing/Building-Industrial-Digital-Twin.`

Links

Corrosion Risks and Mitigation Strategies for Offshore Wind Turbine Foundations: `https://www.materialsperformance.com/articles/material-selection-design/2016/03/corrosion-risks-and-mitigation-strategies-for-offshore-wind-turbine-foundations`

Digital Twins Definition Language-based RealEstateCore ontology for smart buildings (`http://bit.ly/idt-buildingontology`),

Azure Digital Twins Documentation: `https://learn.microsoft.com/en-us/azure/digital-twins/`

The ADT Explorer sample application, source code, and installation instructions can be downloaded from GitHub (`http://bit.ly/idt-adtexplorergit`).

Biggest wind farms: `https://www.power-technology.com/features/feature-biggest-wind-farms-in-the-world-texas`

The Azure Digital Twins APIs and SDKs are well documented at `http://bit.ly/idt-adtapisdk`

A detailed list of API operations is available at `http://bit.ly/idt-apioperations` and it is maintained by Microsoft as new operations are added.

Microsoft provides a full tutorial to code a client app at `http://bit.ly/idt-tutorialapp` for developers who want to create Azure Digital Twins applications with real-time telemetry data.

Microsoft tutorial on updating a map service from Azure Digital Twins: `http://bit.ly/idt-connectmaps`

Willow Inc: https://www.willowinc.com/posts/under-the-hood-willowtwin-x-azure-digital-twins/

Gartner Forecasts Worldwide Low-Code Development Technologies Market to Grow 23% in 2021: https://www.gartner.com/en/newsroom/press-releases/2021-02-15-gartner-forecasts-worldwide-low-code-development-technologies-market-to-grow-23-percent-in-2021

Oracle APEX Low Code: https://apex.oracle.com/en/platform/low-code/

XMPRO provides a free 120 days trial license for readers of this book at https://xmpro.com/idtbooktrial

Cost of Wind farm maintenance globally (see https://www.shell.com/business-customers/lubricants-for-business/sector-expertise/power-industry/wind-power/true-cost-of-wind-turbine-maintenance.html

Figures

Figure 6.1 shows the conceptual view of the Digital Twin of a wind turbine, from the perspective of an industrial user, who will be the beneficiary of the twin.

Figure 6.1 – A conceptual view of the Digital Twin of wind turbines

Note

Image source: Digitalisation in power generation driving performance. Available at: https://www.powerengineeringint.com/digitalization/digitalisation-in-power-generation-driving-performance/

Figure 6.2 – Wind turbines in southern California, USA

Note

Image source: https://commons.wikimedia.org/wiki/File:Wind_turbines_in_southern_California_2016.jpg

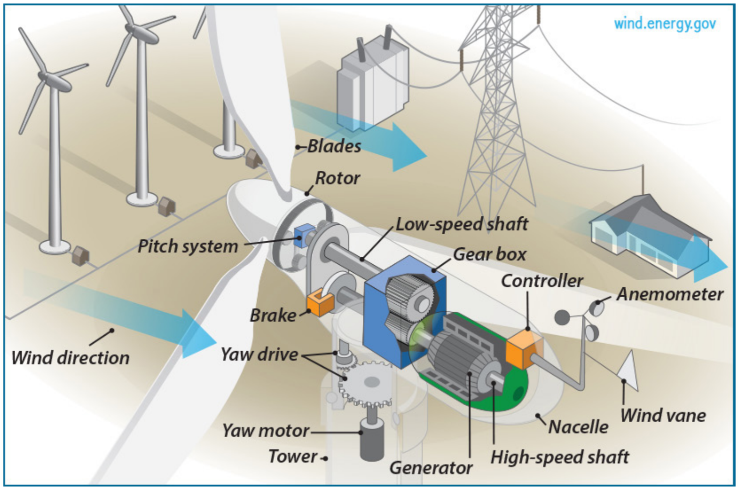

Figure 6.3 – Inside a typical wind turbine

Note

Image source: US Department of Energy: `https://www.energy.gov/eere/wind/inside-wind-turbine`

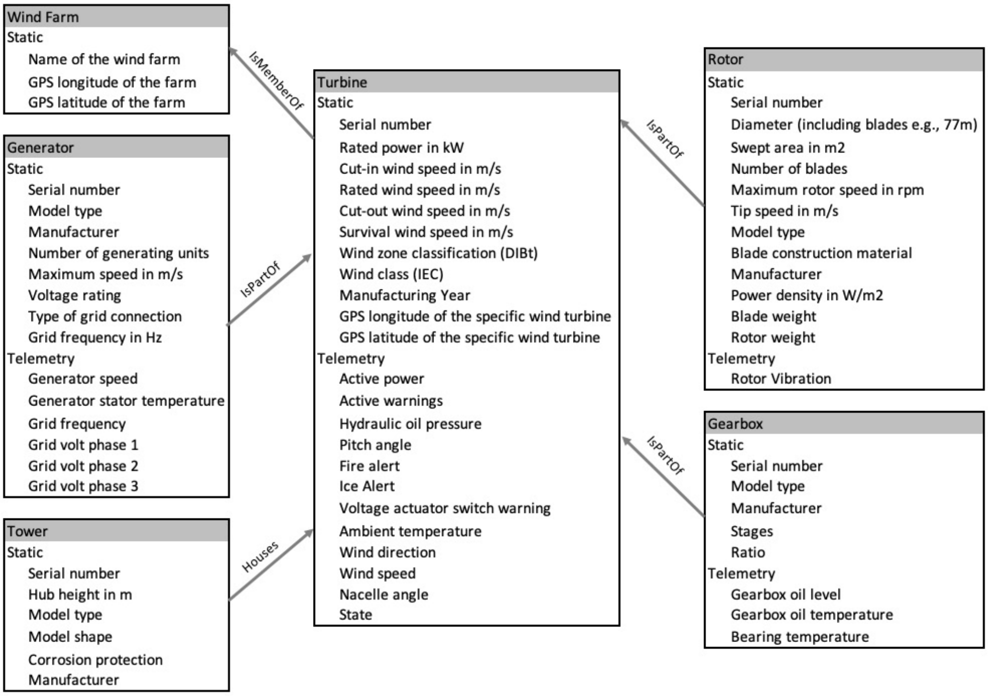

Figure 6.4 – Simple data model for our wind turbine solution

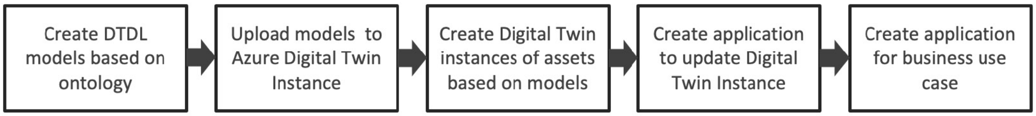

Figure 6.5 – Process to create and use a Digital Twin

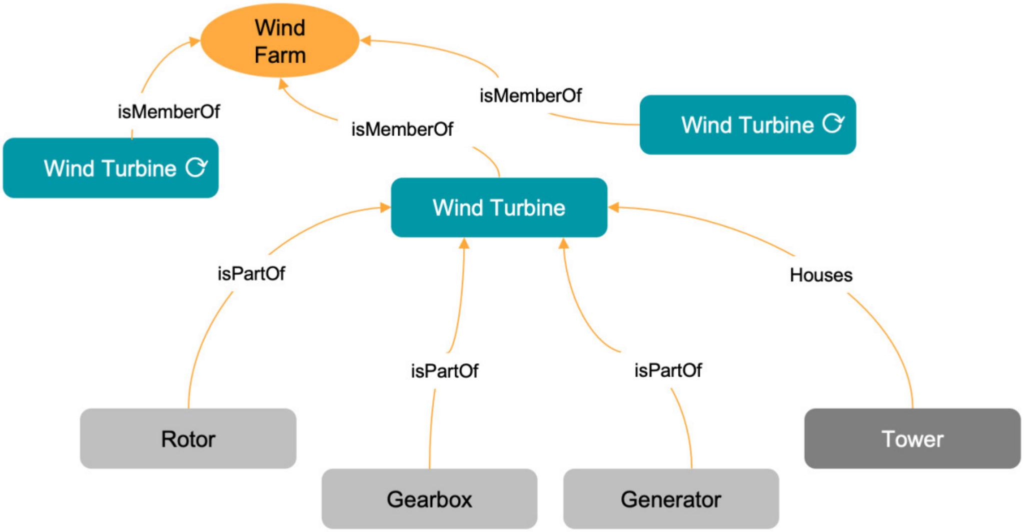

Figure 6.6 – Proposed wind farm and wind turbine Digital Twin

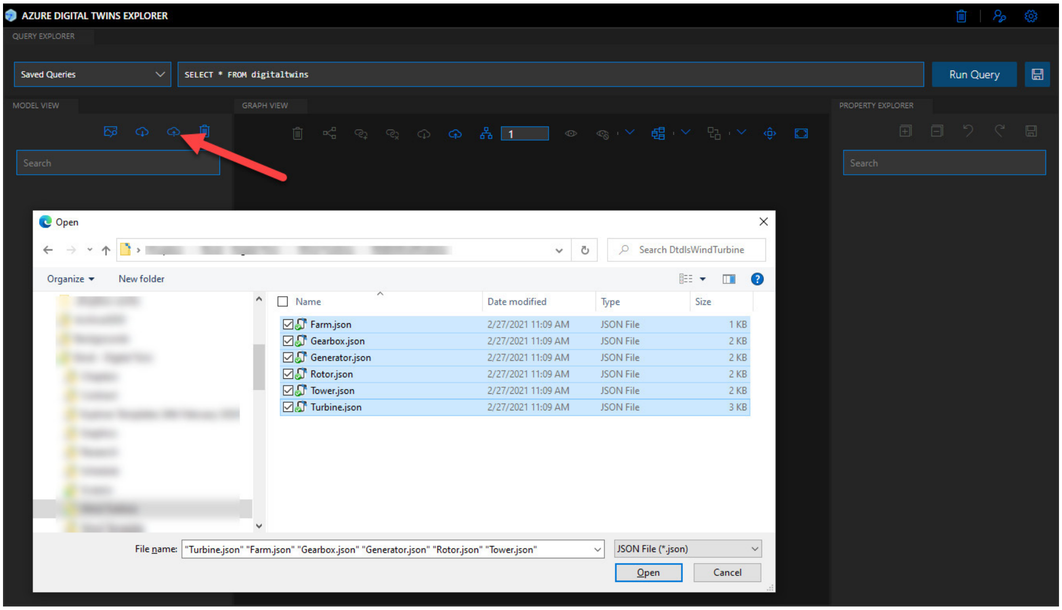

Figure 6.9 – Upload DTDL JSON files with Azure Digital Twins Explorer

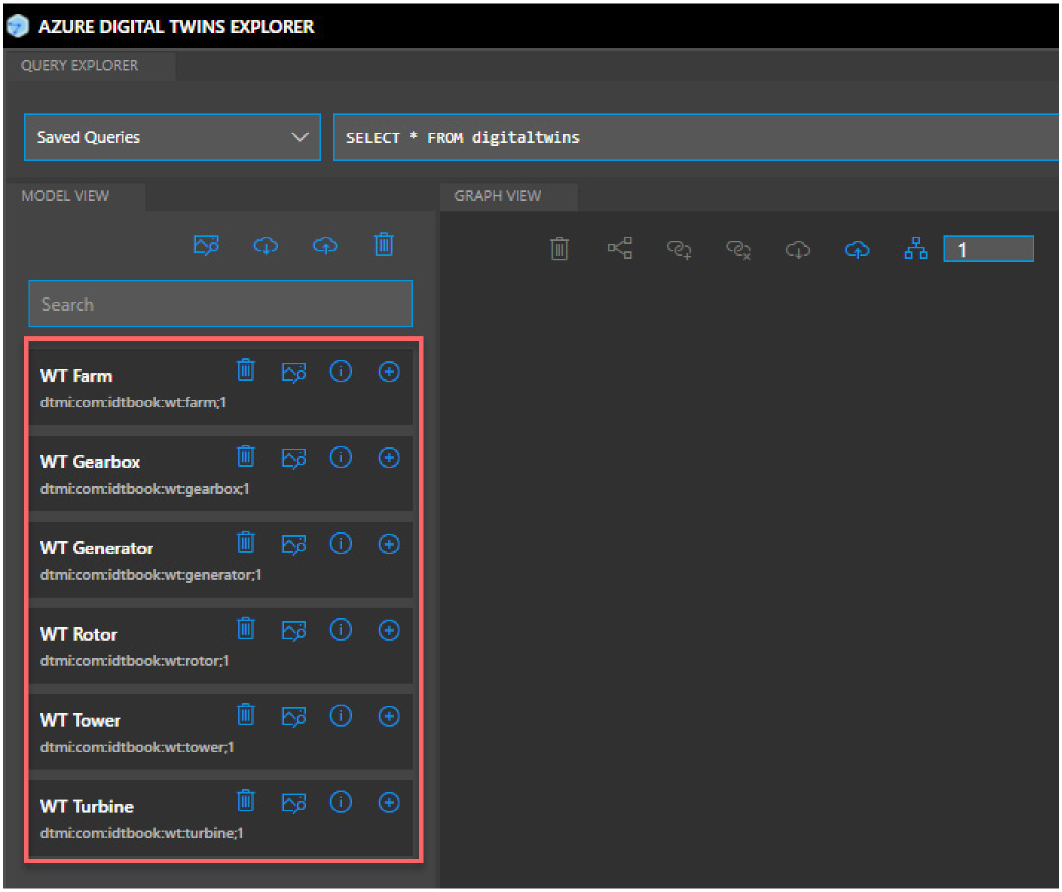

Figure 6.10 – DTDL models available for use in Azure Digital Twins

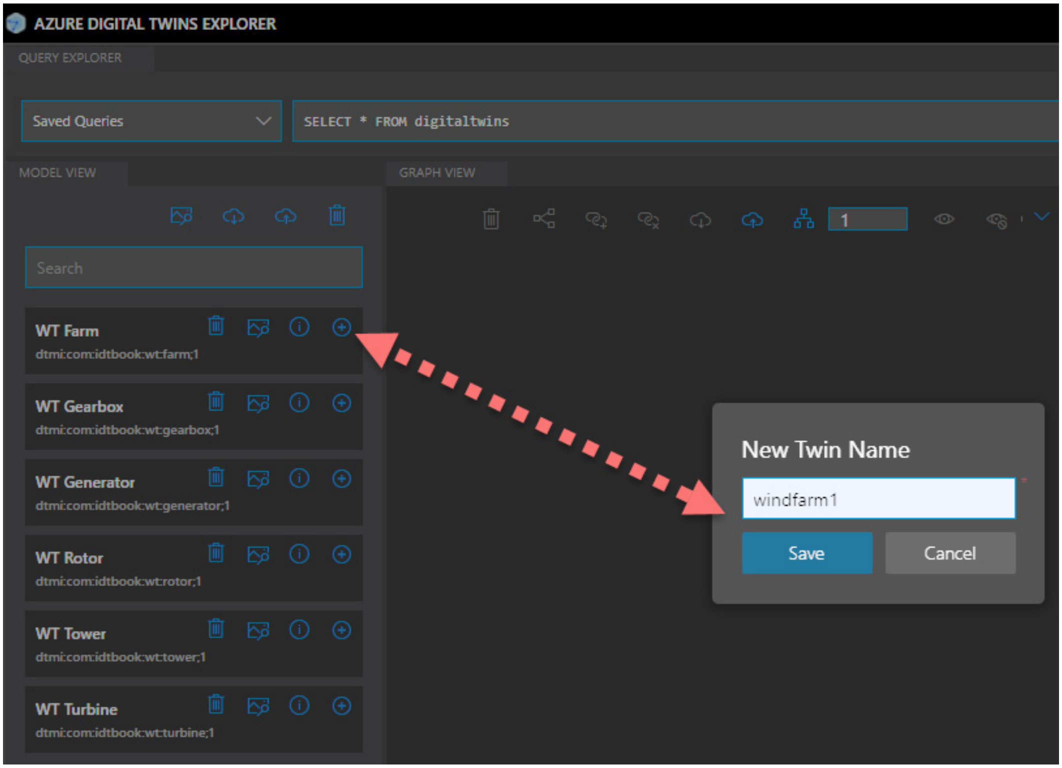

Figure 6.11 – Create a unique instance for a specific wind farm

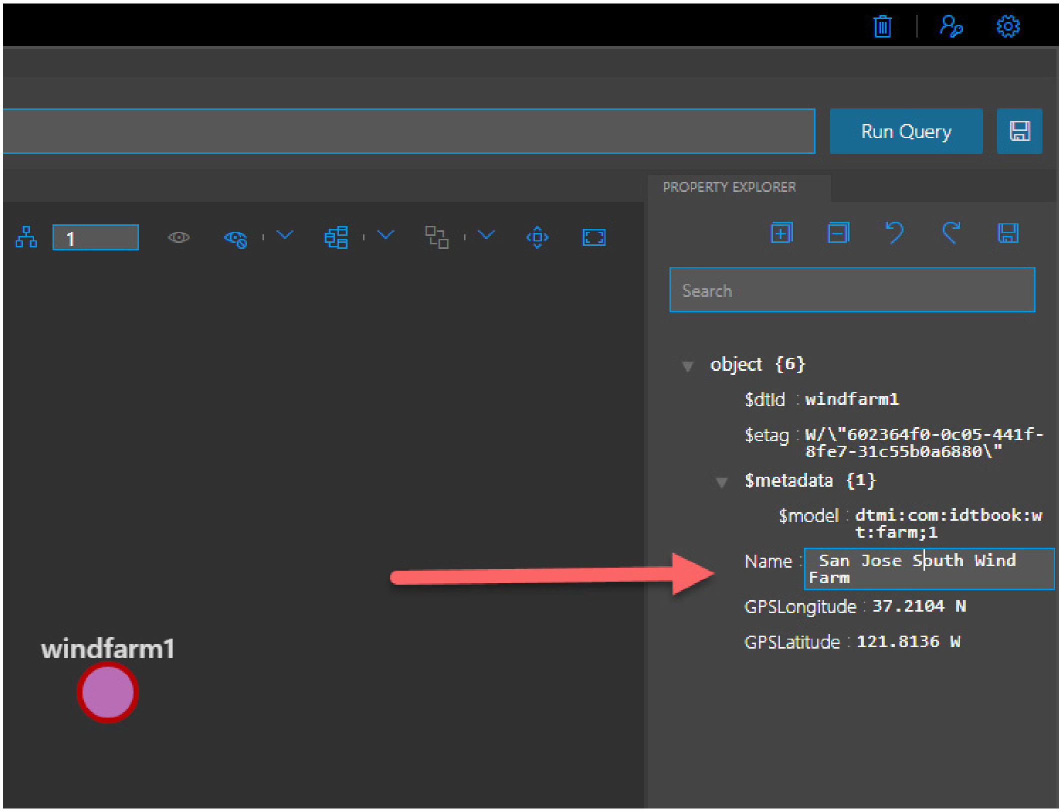

Figure 6.12 – Update instance-specific Digital Twin values

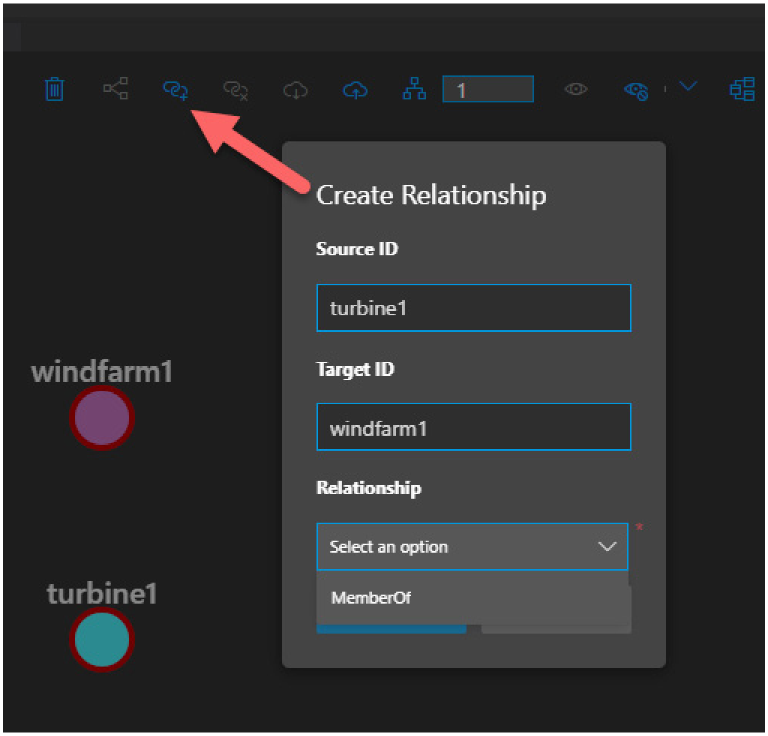

Figure 6.13 – Set the relationship between two instances

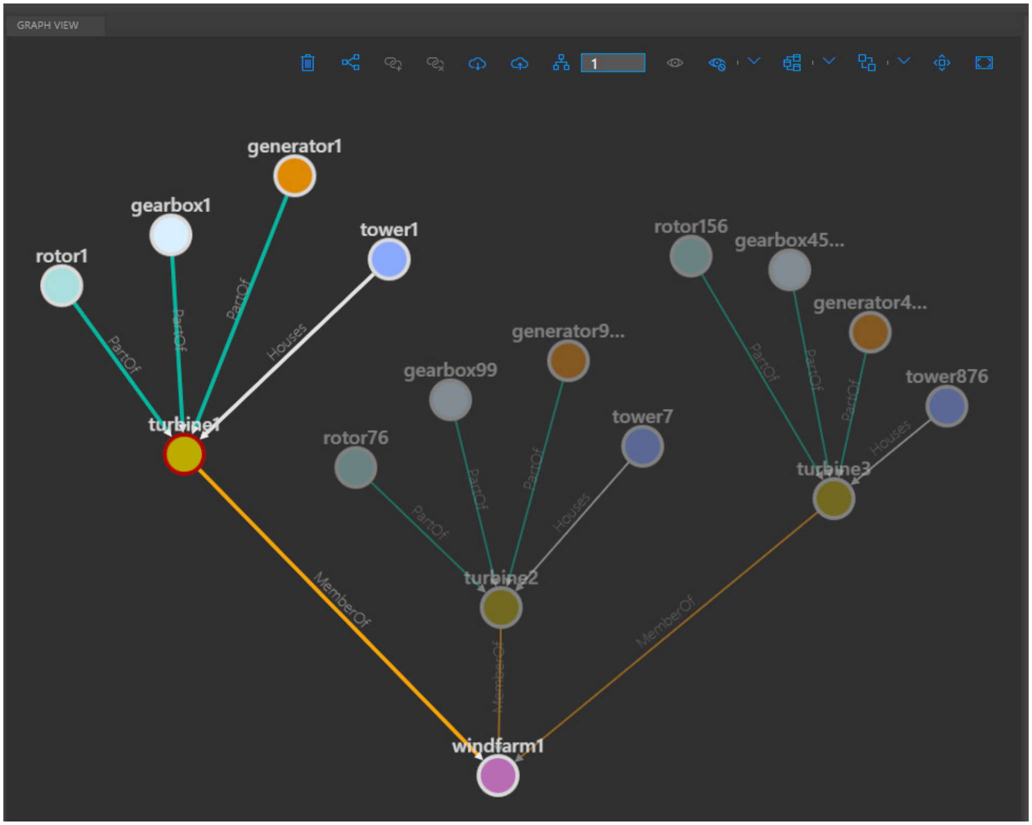

Figure 6.14 – Create a unique instance for a specific wind farm

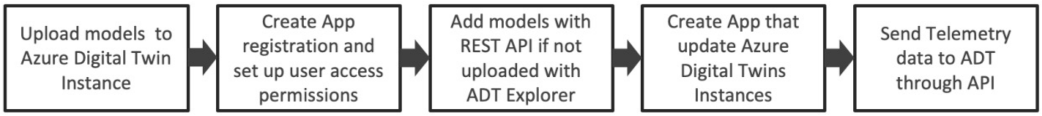

Figure 6.15 – Process for creating a custom-coded solution to update Azure Digital Twins

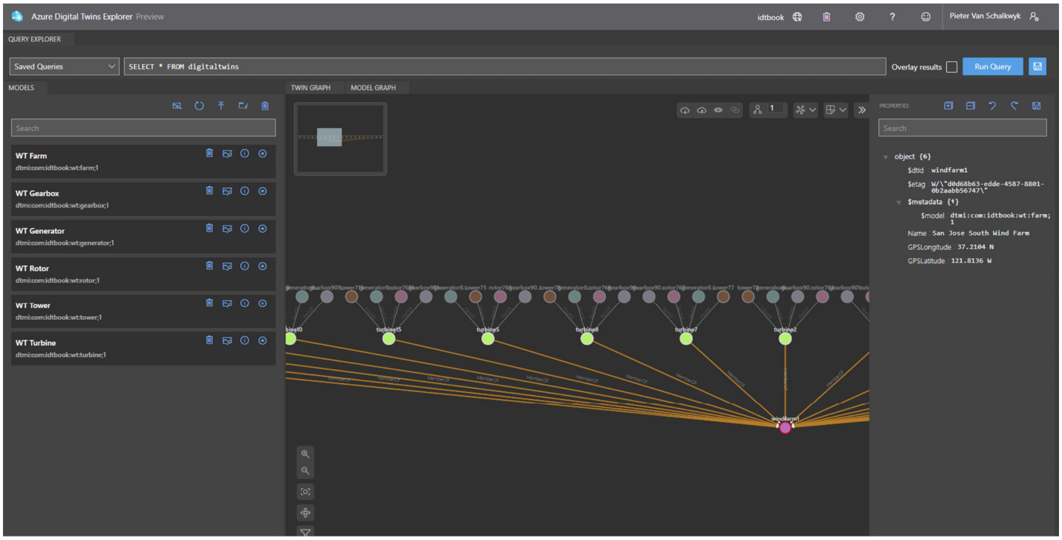

Figure 6.16 – Multi-turbine example

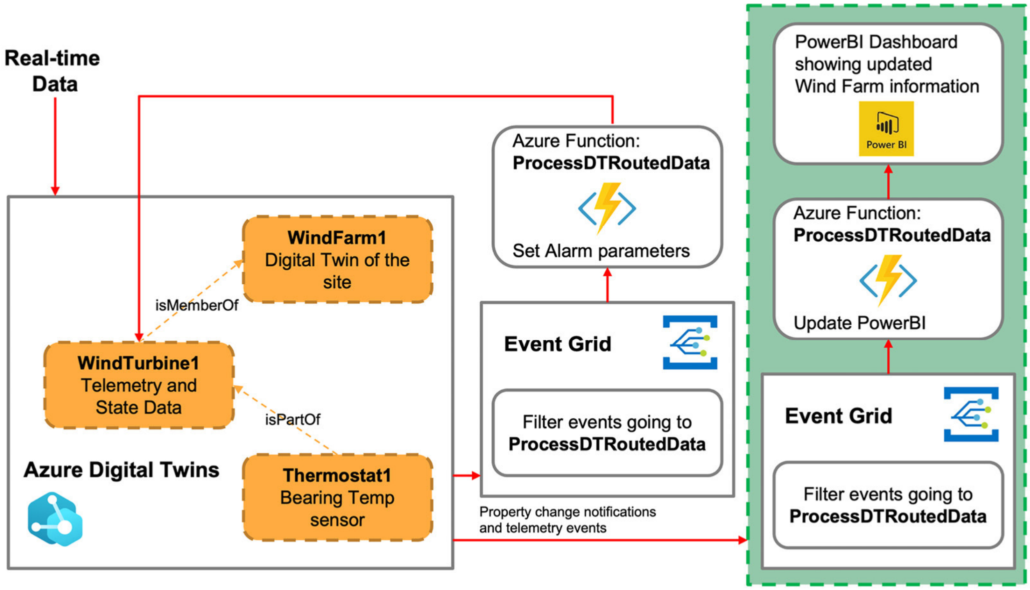

Figure 6.17 – Create a Power BI dashboard to view your Digital Twin

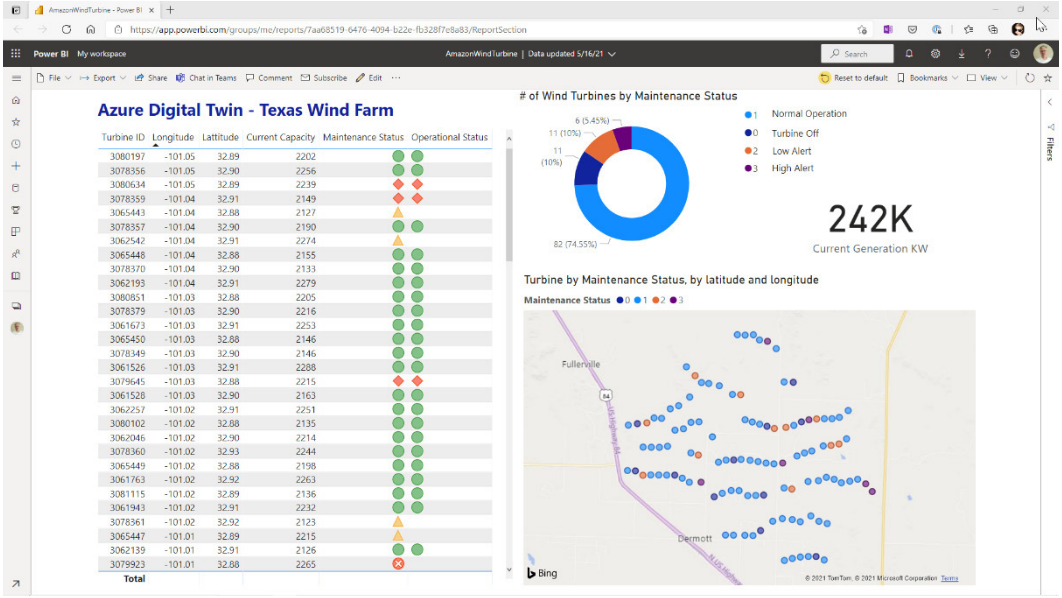

Figure 6.18 – Power BI dashboard example for our wind farm

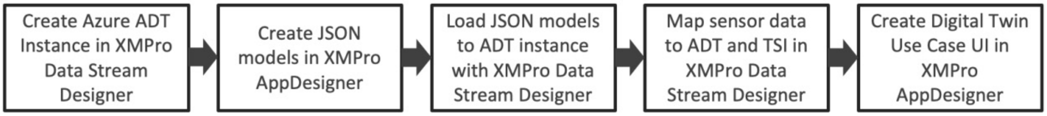

Figure 6.19 – Low-code approach to building our first Digital Twin on ADT

```
{
  "@type": "Property",
  "name": "Manufacturer",
  "schema": "string"
},
{
  "@type": "Telemetry",
  "name": "GearboxOilLevel",
  "schema": "double"
},
{
  "@type": "Telemetry",
  "name": "GearboxOilTemp",
  "schema": "double"
},
{
  "@type": "Telemetry",
  "name": "BearingTemp",
  "schema": "double"
},
```

Figure 6.25 – Example data elements of the wind turbine's gearbox

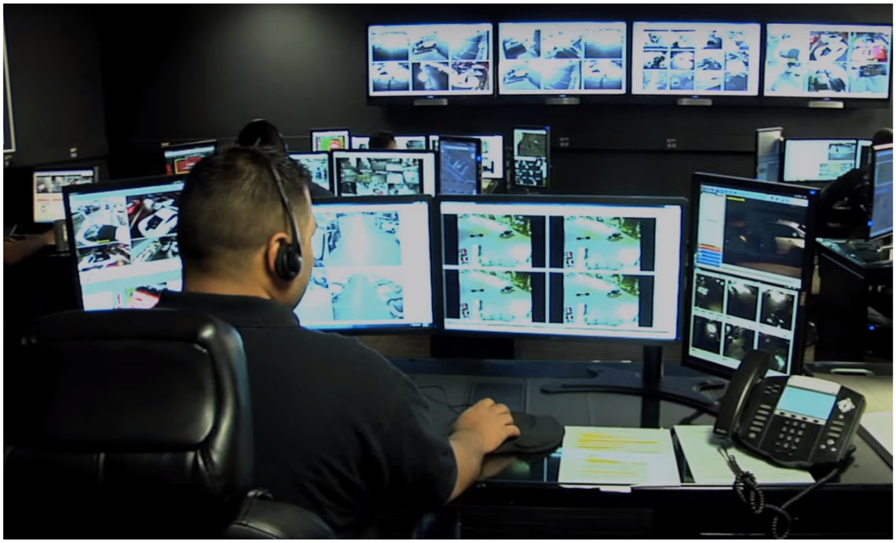

Figure 6.26 – Industrial M&D/command center

Note

Image source: https://commons.wikimedia.org/wiki/File:Elite_ISI_Command_Center.png

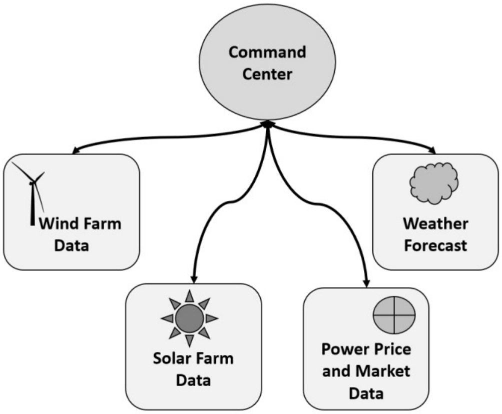

Figure 6.27 – Industrial M&D/command center

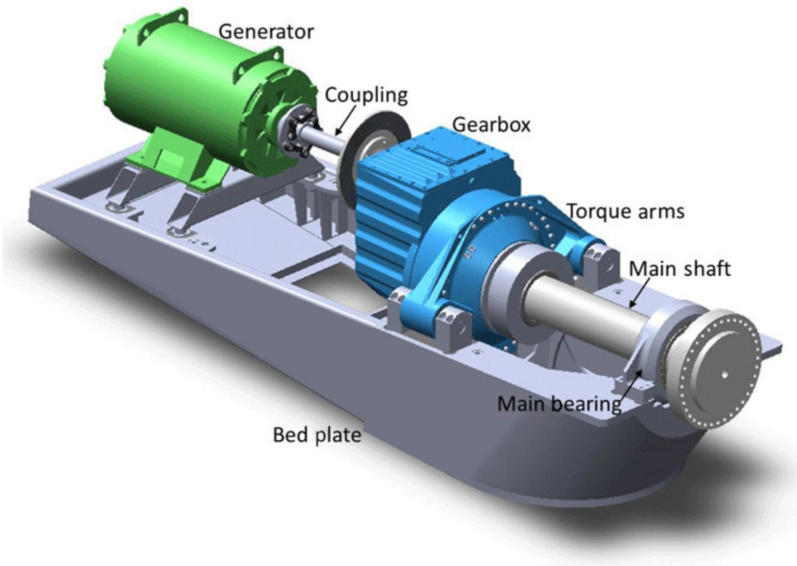

Figure 6.28 – Wind turbine sub-assemblies

Note

Image source: Keller, J., Guo, Y., Zhang, Z., and Lucas, D.: Comparison of planetary bearing load-sharing characteristics in wind turbine gearboxes, Wind Energ. Sci., 3, 947–960, https://doi.org/10.5194/wes-3-947-2018, 2018

Creating the Model files in the DTDL format

An example for DTDL for the wind farm is as follows:

```
{
    "@id":"dtmi:com:idtbook:wt:farm;1",
    "@type":"Interface",
    "@context":[
       "dtmi:dtdl:context;2"
    ],
    "displayName":"WT Farm",
    "description":"Wind farm with wind turbines",
    "contents":[
     {
       "@type": "Property",
       "name": "Name",
       "schema": "string"
     },
     {
       "@type": "Property",
       "name": "GPSLongitude",
       "schema": "double"
     },
     {
       "@type": "Property",
       "name": "GPSLatitude",
       "schema": "double"
     }
    ]
}
```

This is an example of an interface file that does not have any telemetry or relationship data. The typical structure of an interface file is described in *Figure 6.7* and is fully documented at `http://bit.ly/idt-dtdl2`.

Property	Required	Data type	Limits	Description
`@id`	required	DTMI	max 128 chars	A digital twin model identifier for the interface
`@type`	required	IRI		This must be "Interface"
`@context`	required (at least once in the doc)	IRI		The context to use when processing this interface. For this version, it must be set to "dtmi:dtdl:context;2"
`comment`	optional	*string*	1-512 chars	A comment for model authors
`contents`	optional	set of Telemetry, Properties, Commands, Relationships, Components	max 300 contents	A set of objects that define the contents (Telemetry, Properties, Commands, Relationships, and/or Components) of this interface
`description`	optional	*string*	1-512 chars	A localizable description for display
`displayName`	optional	*string*	1-64 chars	A localizable name for display
`extends`	optional	set of Interfaces	up to 2 interfaces per extends; max depth of 10 levels	A set of DTMIs that refer to interfaces this interface inherits from. Interfaces can inherit from multiple interfaces.
`schemas`	optional	set of interface schemas		A set of IRIs or objects that refer to the reusable schemas within this interface.

Figure 6.7 – Structure of an interface file

Microsoft provides a DTDL extension for Visual Studio and the free version of Visual Studio Code (`http://bit.ly/idt-vscodedtdl`).

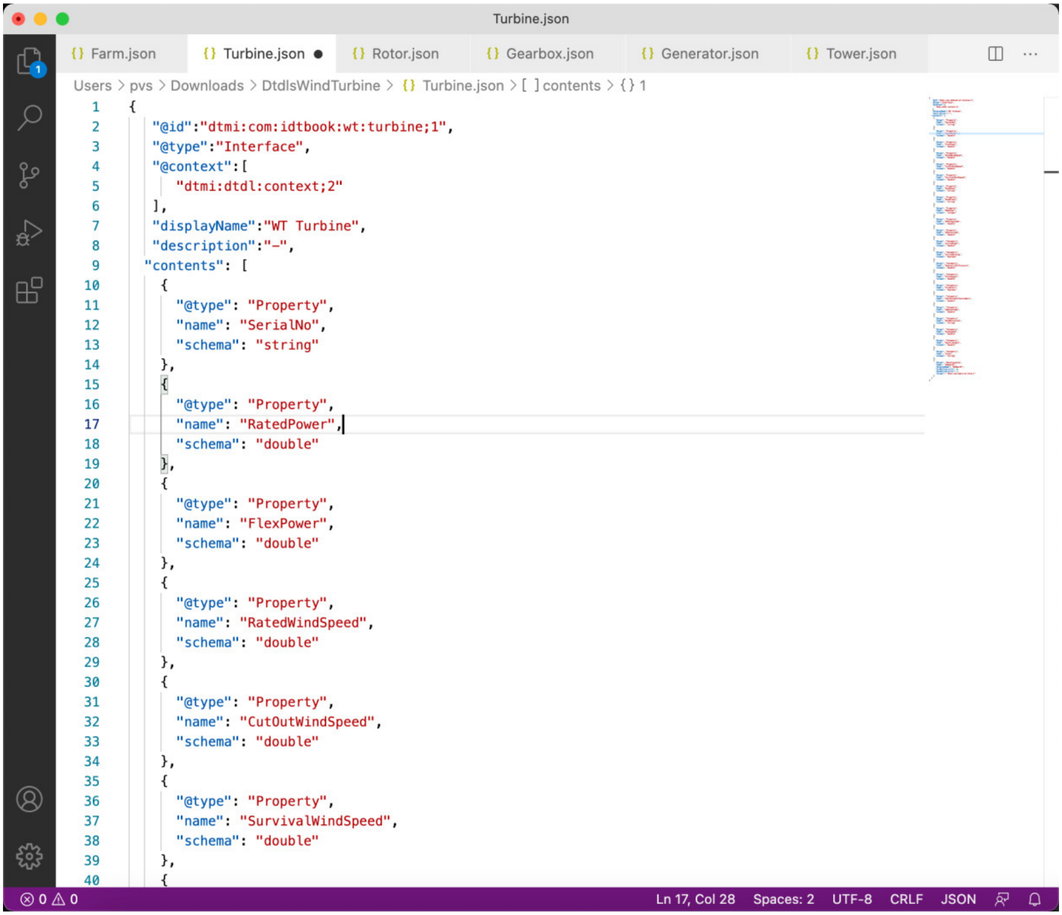

Figure 6.8 – DTDL extension for Visual Studio Code with IntelliSense

The extension provides the ability to create DTDL interfaces from templates. It supports IntelliSense and auto-completion and will validate the syntax of your DTDL file. *Figure 6.8* shows the wind turbine DDL file with IntelliSense and syntax checking.

The DTDL model, in JSON format, for the wind turbine includes additional metamodel classes for telemetry and relationships. It also describes all the data model elements for the turbine that we defined in the *Basics of a wind turbine and a high-level data model* section:

```
{
    "@id":"dtmi:com:idtbook:wt:turbine;1",
    "@type":"Interface",
    "@context":[
       "dtmi:dtdl:context;2"
```

```
    ],
    “displayName”:”WT Turbine”,
    “description”:”-”,
    “contents”: [
     {
       “@type”: “Property”,
       “name”: “SerialNo”,
       “schema”: “string”
     },
     {
       “@type”: “Property”,
       “name”: “RatedPower”,
       “schema”: “double”
     },
     . . . (See Github for full json files)
     {
       “@type”: “Telemetry”,
       “name”: “Windspeed”,
       “schema”: “double”
     },
     {
       “@type”: “Telemetry”,
       “name”: “NacelleAngle”,
       “schema”: “double”
     },
     {
       “@type”: “Telemetry”,
       “name”: “State”,
       “schema”: “string”
     },
     {
       “@type”: “Relationship”,
       “name”: “isMemberOf”,
       “displayName”: “MemberOf”,
       “minMultiplicity”: 0,
       “maxMultiplicity”: 1,
```

```
        "target": "dtmi:com:idtbook:wt:farm;1"
      }
    ]
  }
```

The sub-model for the generator, in turn, contains the relationship with the turbine model, as shown in *Figure 6.4*:

```
  {
     "@id":"dtmi:com:idtbook:wt:gearbox;1",
     "@type":"Interface",
     "@context":[
        "dtmi:dtdl:context;2"
     ],
     "displayName":"WT Gearbox",
     "description":"-",
     "contents": [
      {
        "@type": "Property",
        "name": "GearboxSerial",
        "schema": "string"
      },
      . . . (See Github for full json files)
      {
        "@type": "Relationship",
        "name": "isPartOf",
        "displayName": "PartOf",
        "minMultiplicity": 0,
        "maxMultiplicity": 1,
        "target": "dtmi:com:idtbook:wt:turbine;1"
      }
    ]
  }
```

The DTDL JSON files for the wind farm, turbine, and its components are available to download in the GitHub repository for the book at `https://github.com/PacktPublishing/Building-Industrial-Digital-Twin`.

It includes the following files:

- `Farm.json`
- `Turbine.json`
- `Rotor.json`
- `Gearbox.json`
- `Generator.json`
- `Tower.json`

Creating an application to update the Digital Twin prototype in no/low code

The first step is to create the Digital Twin resource in the free Azure subscription, as shown in *Figure 6.20*. This is similar to the process described in *Figure 5.9* of *Chapter 5, Setting Up a Digital Twin Prototype*. It still requires Azure portal access to configure user access rights, as described in *Figure 5.9*.

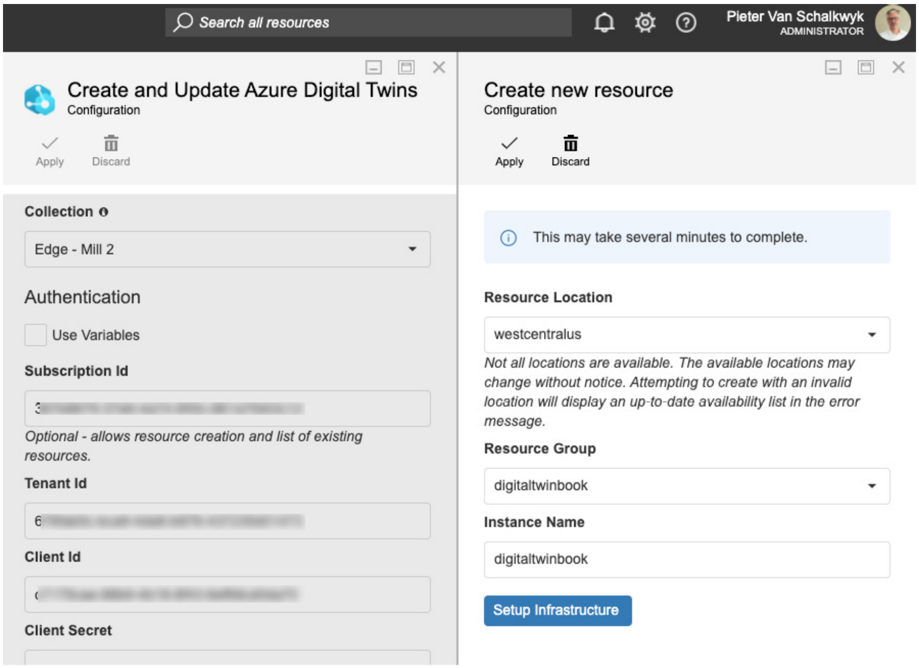

Figure 6.20 – Create an ADT instance from within the no-/low-code platform

The next step in the process in *Figure 6.19* is to create JSON models for each of the components of the wind turbine, including the rotor, gearbox, and generator. *Figure 6.21* shows an application for creating a DTDL JSON file in a no-/low-code page that is more aimed at an end user to define the properties of, for example, the wind turbine in this instance.

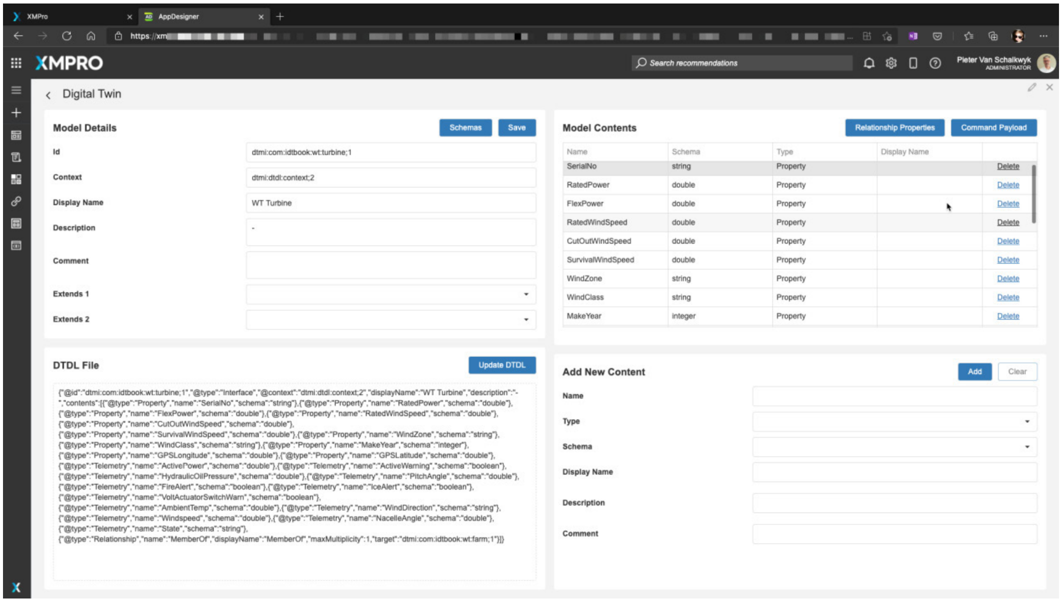

Figure 6.21 – Create JSON models in XMPro App Designer

The form creates the JSON file that we can then upload in the next step of the process in *Figure 6.19*. The XMPRO Azure Digital Twins connectors shown in *Figure 6.22* provide an upload function that automatically loads the Digital Twins models in ADT.

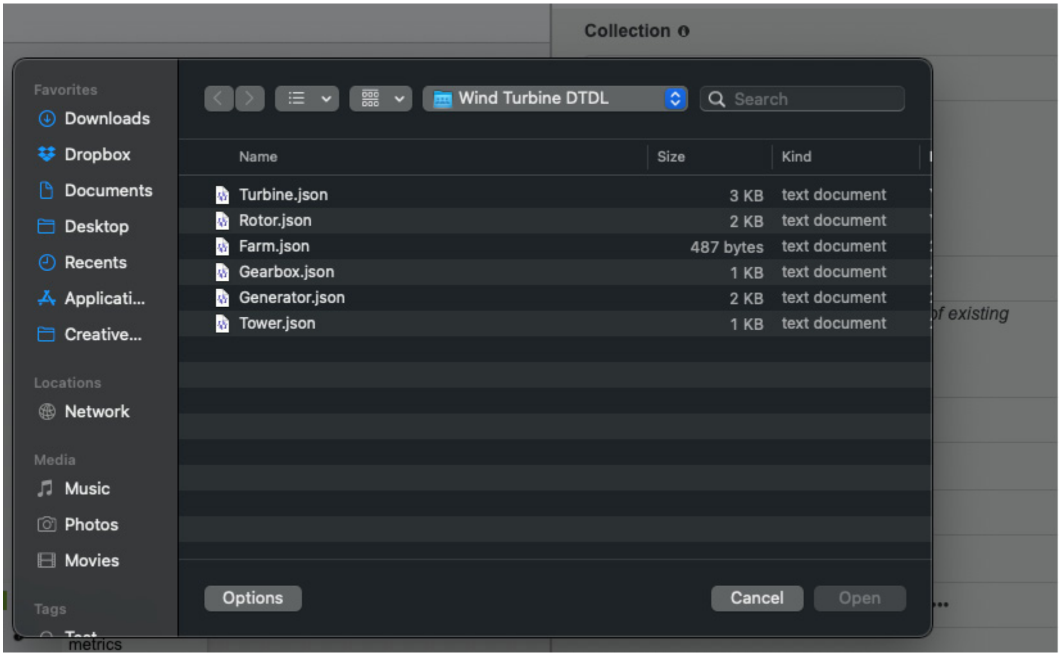

Figure 6.22 – Load JSON models to our ADT instance with XMPRO Data Stream Designer

The fourth step in *Figure 6.19* is to map the sensor data from either real-time telemetry or simulated values, as shown in *Figure 6.23*, to the property and telemetry fields in ADT.

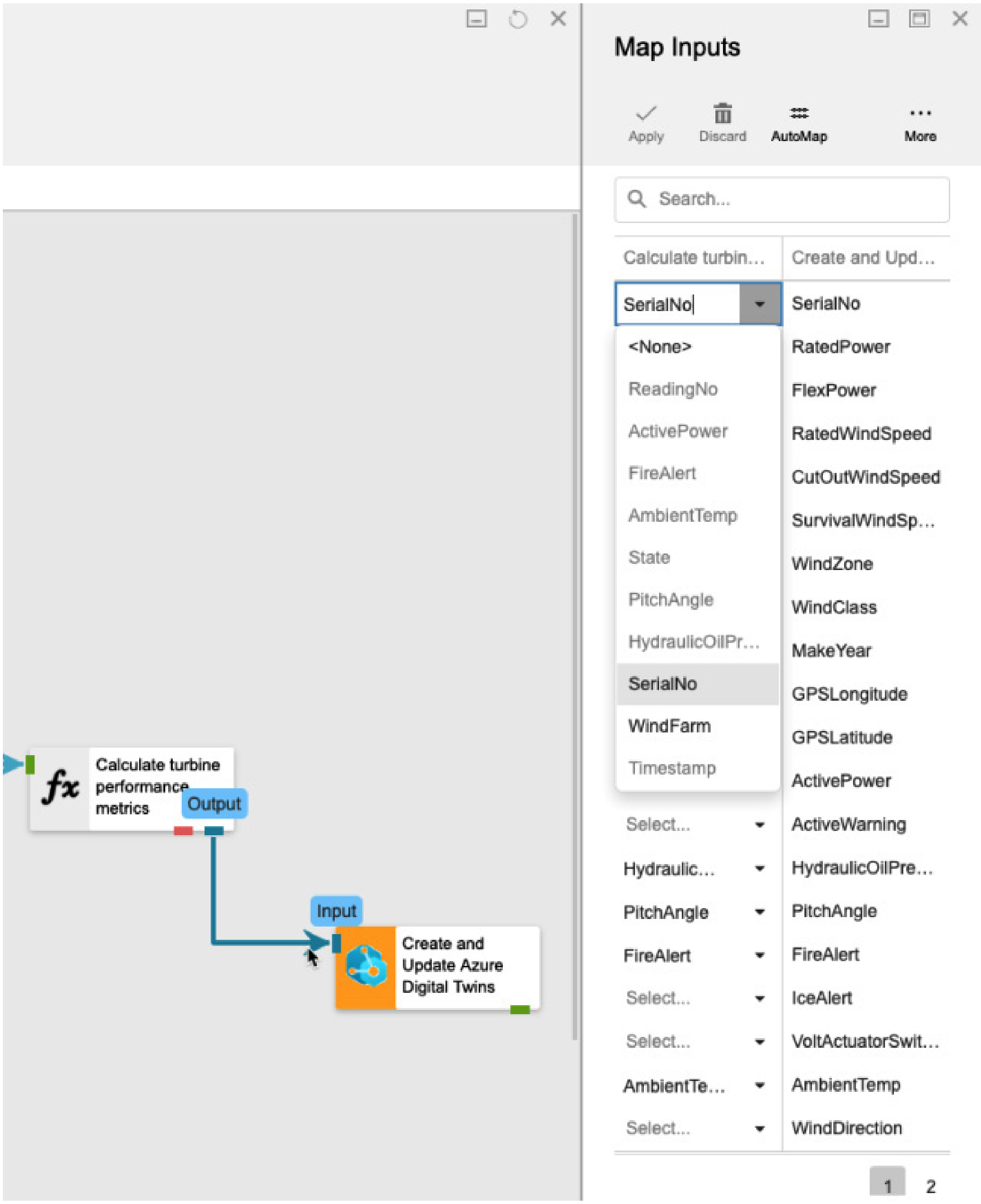

Figure 6.23 – Map sensor data to ADT and TSI in XMPro Data Stream Designer

The final step is to create a visualization for the maintenance and field service application in the drag-and-drop visual design in the no-/low-code platform.

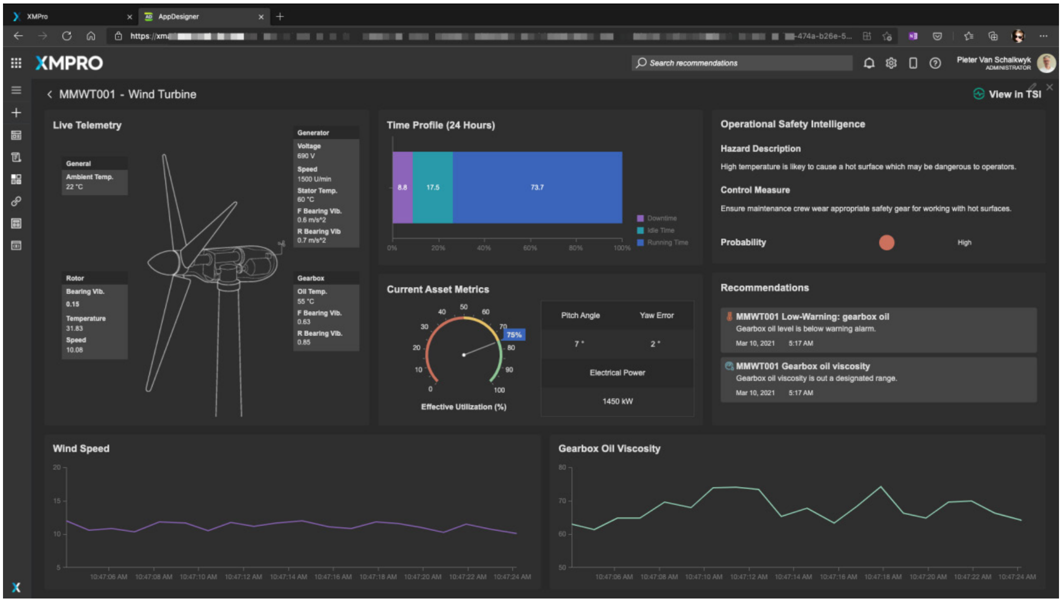

Figure 6.24 – Create Digital Twin Use Case UI in XMPro AppDesigner

Figure 6.24 shows an example of a wind turbine Digital Twin with real-time telemetry for condition monitoring. The platform also allows for the creation of analytics-based recommendations based on real-time telemetry data. The analytics for the recommendation can be based on engineering calculations from condition monitoring telemetry, machine learning models that receive real-time telemetry input, or business rules that are configured for the specific application.

This example shows a recommendation rule based on the observed gearbox oil level from a decision tree. This can be used to plan maintenance and provide feedback to the wind turbine manufacturer on gearbox oil consumption.

Code

Code 6.1:

Application examples are available at http://bit.ly/idt-adtapisdk and a basic Create Twin Instance example in C# is as follows:

```
string twinId = "turbine2";
var initData = new BasicDigitalTwin
{
    Id = twinId,
    Metadata = { ModelId = "dtmi:com:idtbook:wt:turbine;1" },
```

```
    // Initialize properties
    Contents =
    {
        { "SerialNo", "YF568" },
        { "RatedPower", 1500 },
    },
};
await client.
CreateOrReplaceDigitalTwinAsync<BasicDigitalTwin>(twinId,
initData);
```

Chapter 7

Links

Cisco Survey Reveals Close to Three-Fourths of IoT Projects Are Failing: http://bit.ly/idt-IoTWF.

DTDL ontology for Energy Grid: https://github.com/Azure/opendigitaltwins-energygrid/

About CIM Users Group: http://bit.ly/idt-cim

Wind turbines – Part 25-2: Communications for monitoring and control of wind power plants – http://bit.ly/idt-iec61400

Information models:http://bit.ly/idt-iec61400

Figure

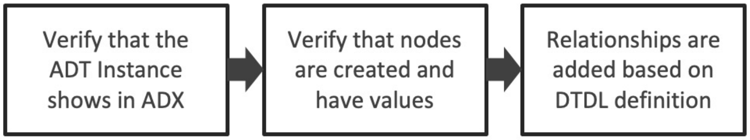

Figure 7.1 – Functional testing Digital Twin infrastructure

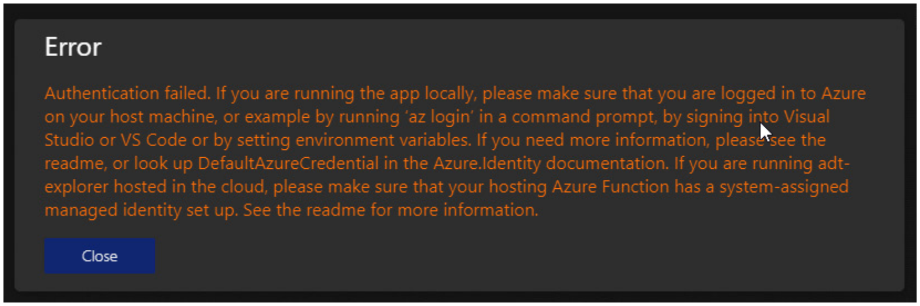

Figure 7.2 – Access rights error message in ADX

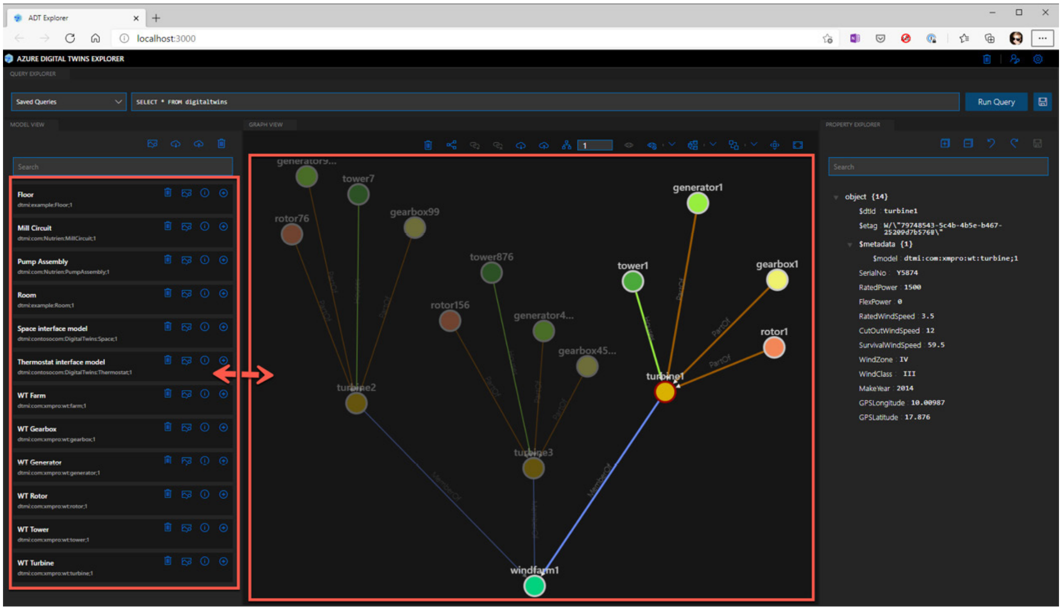

Figure 7.3 – Functional testing of Digital Twin infrastructure

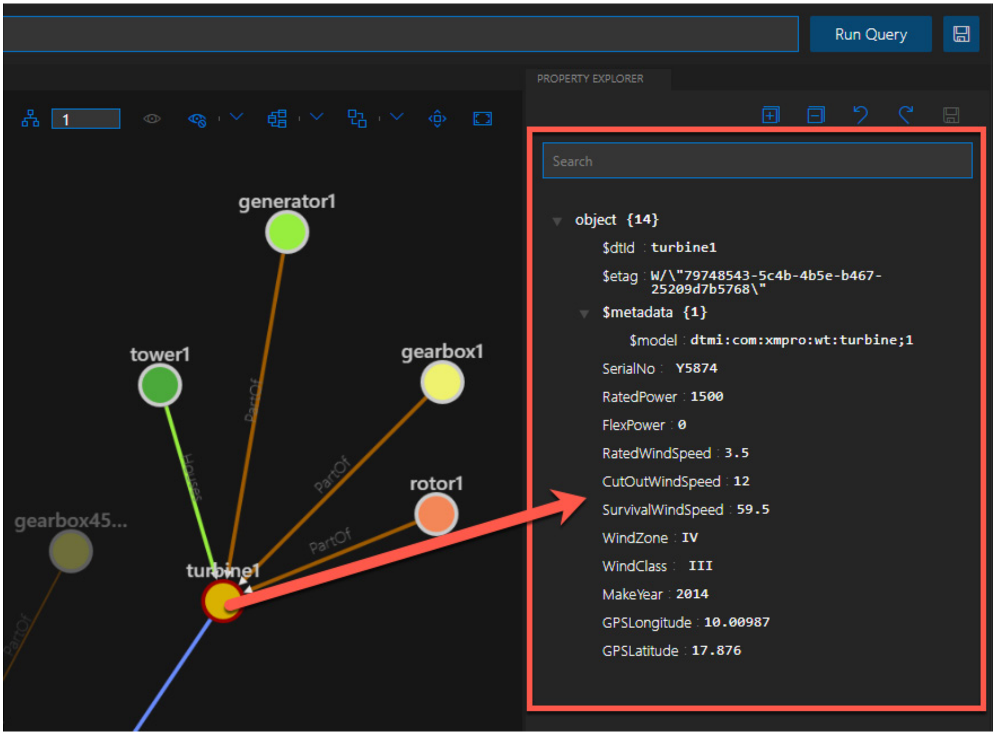

Figure 7.4 – Functional test for nodes and values

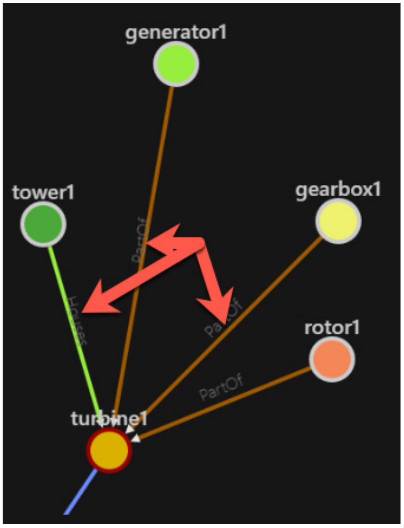

Figure 7.5 – Functional test for relationships

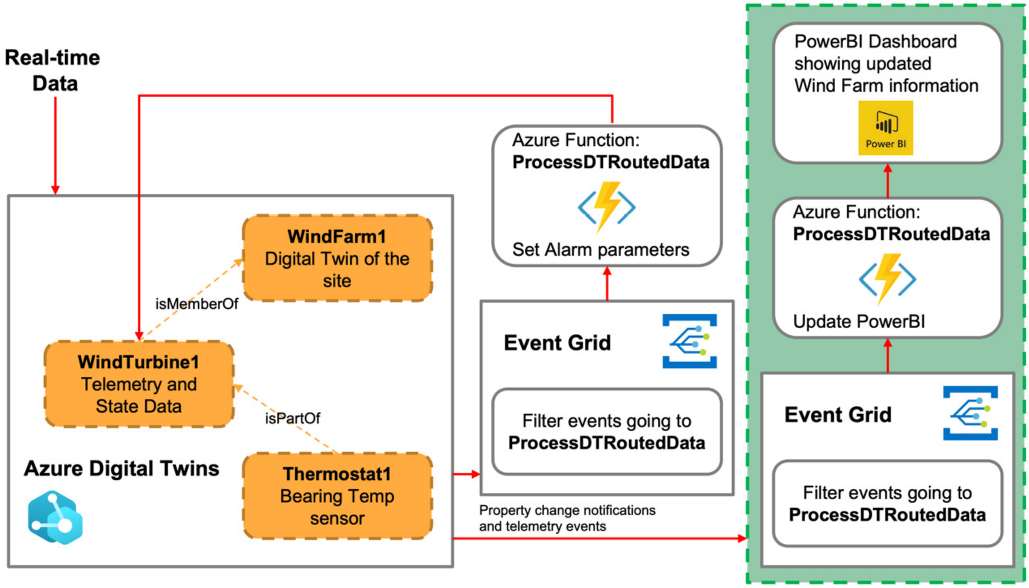

Figure 7.6 – Unit testing a coded Digital Twin

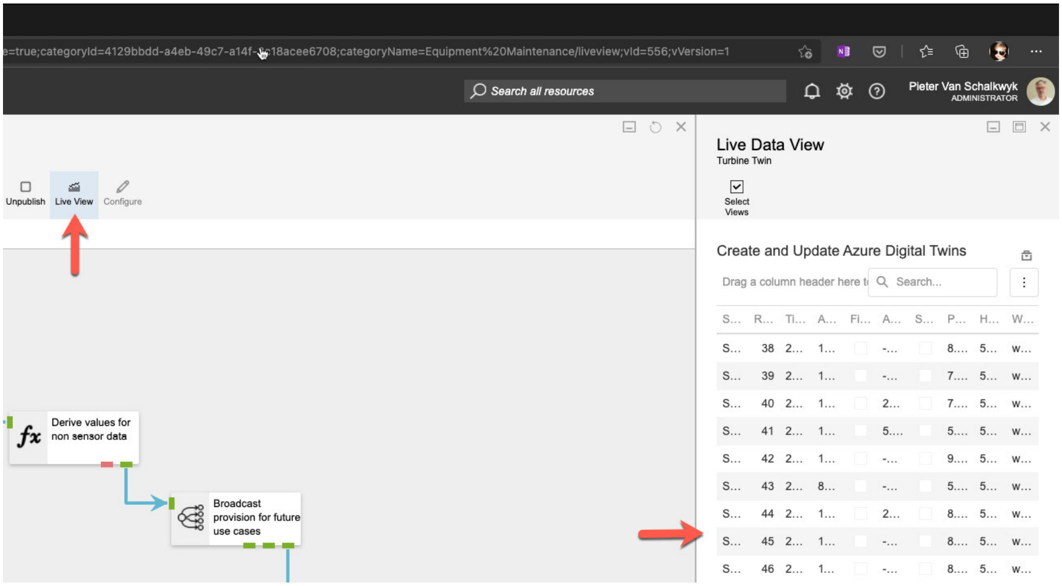

Figure 7.7 – Integration and black-box functional testing in no-code application development

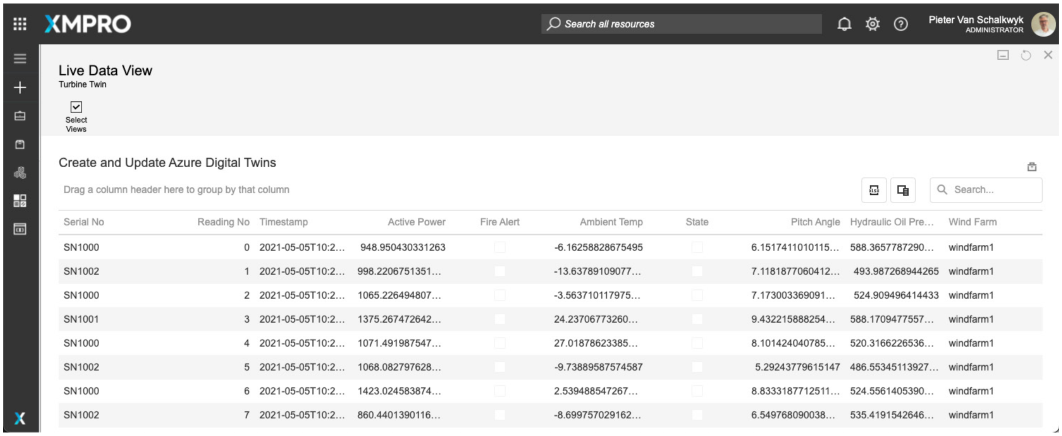

Figure 7.8 – Expanded Live View data

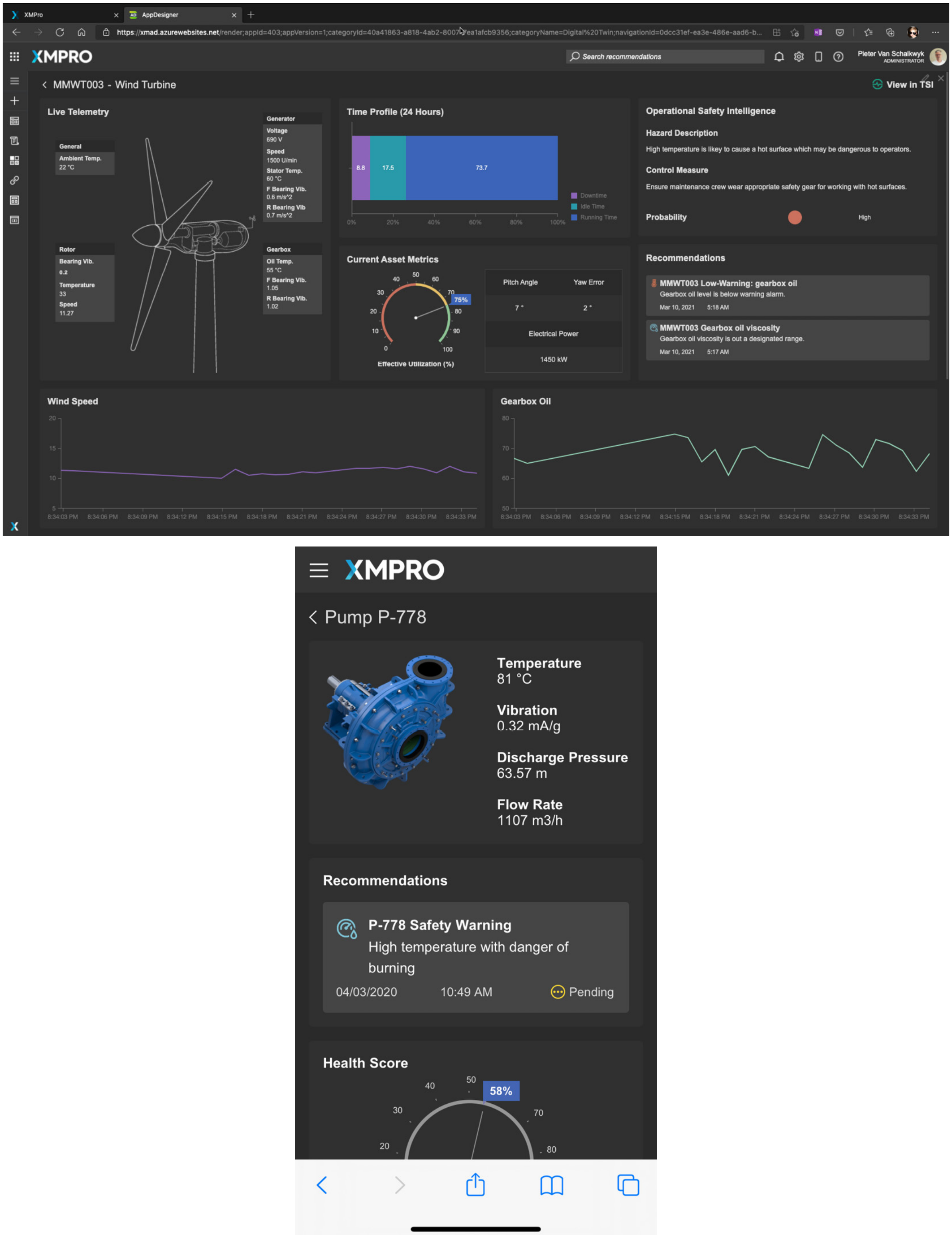

Figure 7.9 – UAT on desktop and mobile browsers

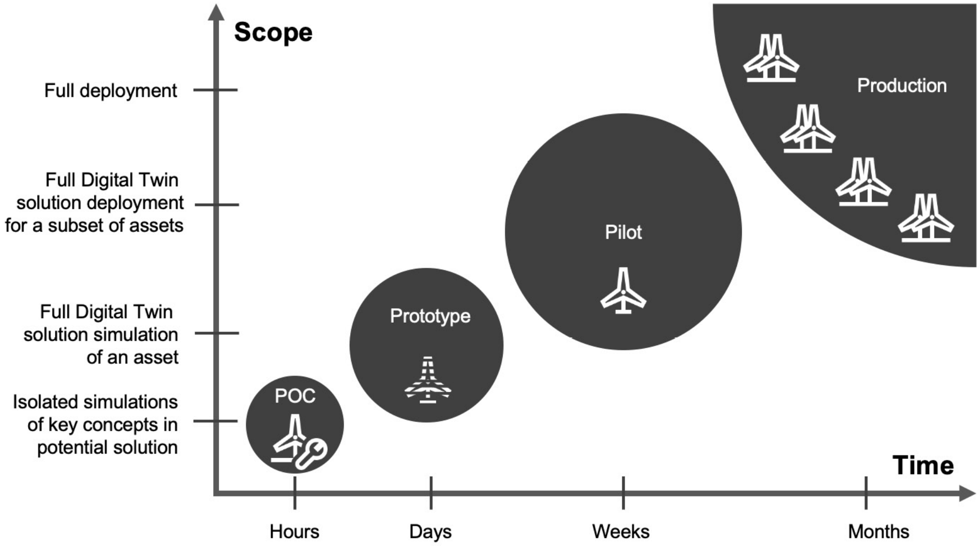

Figure 7.10 – Evolution from concept to full deployment

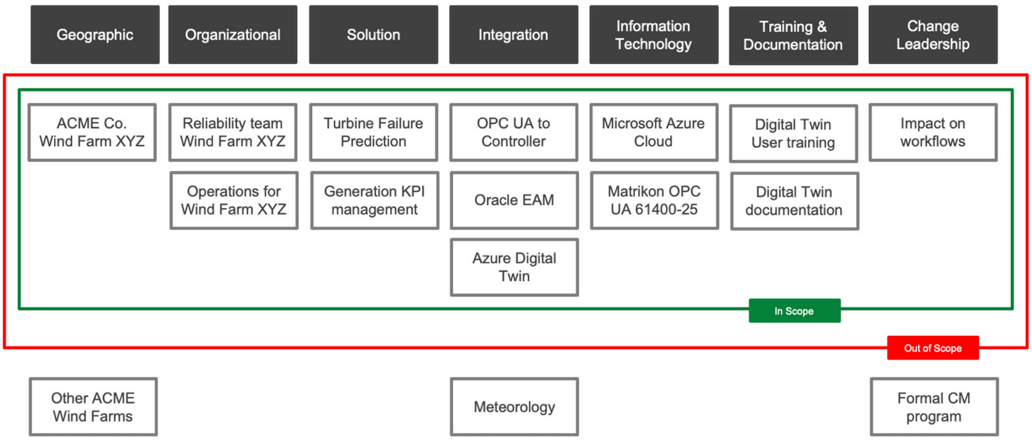

Figure 7.11 – Example pilot rollout scope diagram for wind-farm solution

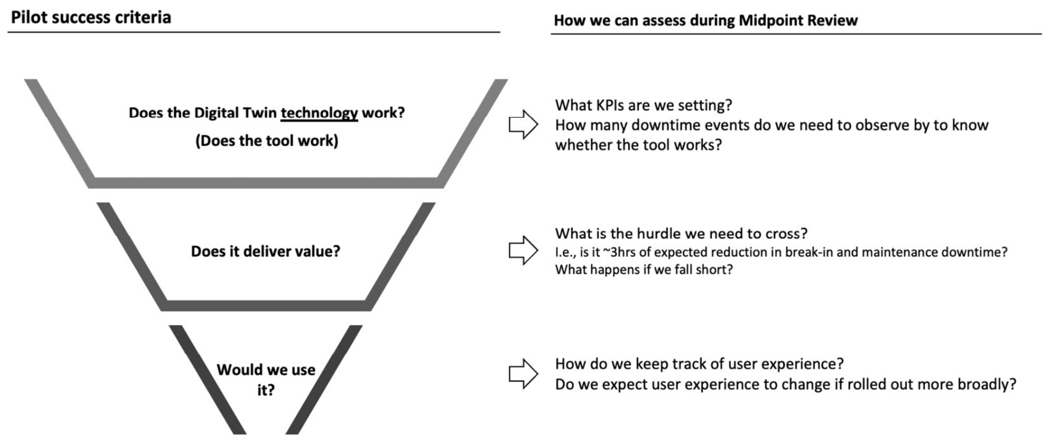

Figure 7.12 – Creating pilot success criteria

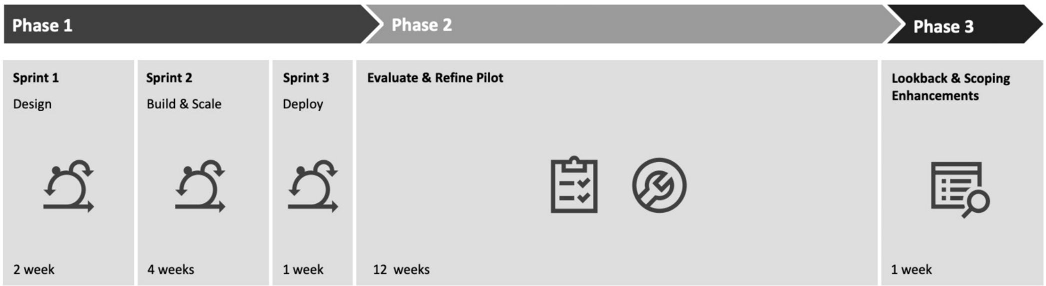

Figure 7.13 – Pilot rollout phases

Phase 1 Design, Build and Scale				
	Project Management	**IT, Integration and Data**	**Training and CM**	**Operational Capability**
Sprint 1: **Design**	**Description**			

	• Design the logic for one unit/asset
	  ○ Digital Twin Visualization at asset level (discrete twin)
	  ○ Data streams logic
	• Design how to scale the logic for multiple units/assets
	  ○ Digital Twin Visualization at portfolio level (composite twin)
	  ○ Data streams logic
	• Establish a baseline
	• Deploy software			

	Deliverables			
	• Test plan • Design specification • Sign off	• Integration plan • Data mapping • Target architecture		• UI prototype/s • Data Stream/s • Baseline established
Sprint 2: **Build and Scale**	**Description**			

	• Build the discrete twin
	  ○ Configure the data streams
	  ○ Configure the Digital Twin Visualization
	  ○ Test to the test plan
	• Build the composite twin
	  ○ Configure the data streams
	  ○ Configure the Digital Twin Visualization
	  ○ Test to the test plan			

	Deliverables			
	• Sign off	• Test results	• Material outline	• Data Stream/s • App page/s
Sprint 3: **Deploy**	**Description**			

	• Deploy
	  ○ IT governance
	  ○ User training
	  ○ Post go-live support
	  ○ Start evaluation			

	Deliverables			
	• Sign off • Start evaluation feedback	• IT governance signoff	• User material	• Live running production system

Figure 7.14 – Sprints in Phase 1: Designing, building, and scaling

Phase 2 Evaluate Pilot 90-day period			
Project Management	**IT, Integration & Data**	**Training & CM**	**Operational Capability**
Description			

• Monitor to the success KPI's
• Monitor to the baseline defined
• Evaluate and refine the:
    o data streams;
    o integration; and
    o monitor the data quality
• Evaluate and refine user experience on the Digital Twin Visualization
• Recommendations for optimization's (fine-tuning set points)
• Formal knowledge/skills Transfer			

Deliverables			
• KPI's Signed/Acknowledged by Project Owner and Project Coordinator • Quantify the improvements against the baseline		• User Material	• Recommendations for operations optimization

Figure 7.15 – Phase 2: Evaluating pilot

Phase 3 Optimize & Realize

Description

- Project lookback
- Scoping the extending of the functionality of this solution for additional capabilities
- Scoping the deployment of this solution to other sites

Figure 7.16 – Phase 3: Optimization and realization

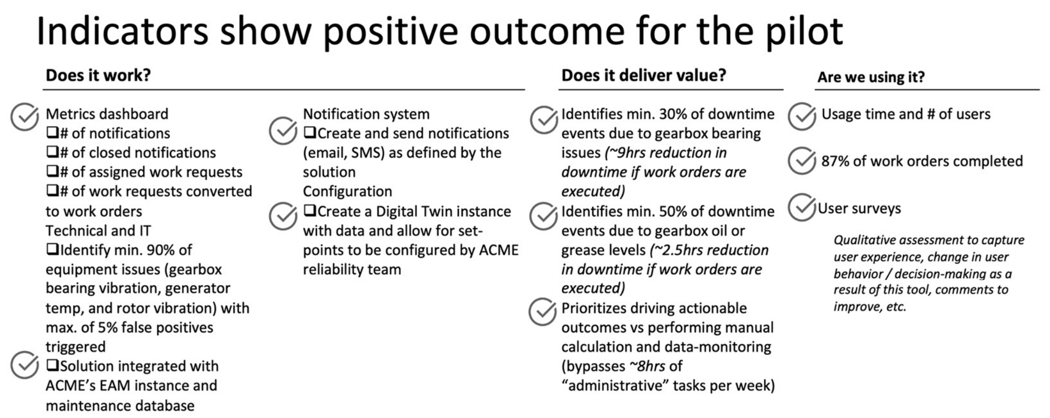

Figure 7.17 – Presenting pilot results

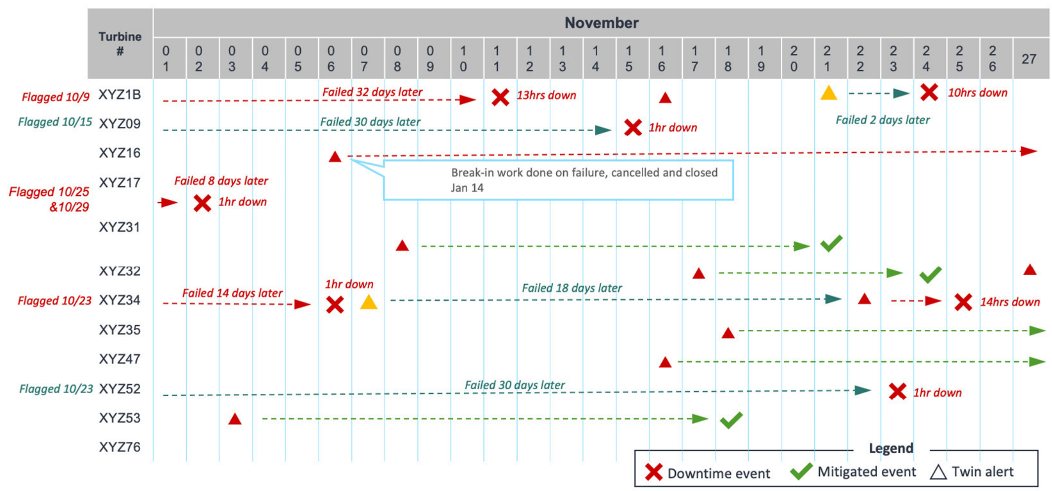

Figure 7.18 – KPI performance at the start of the pilot

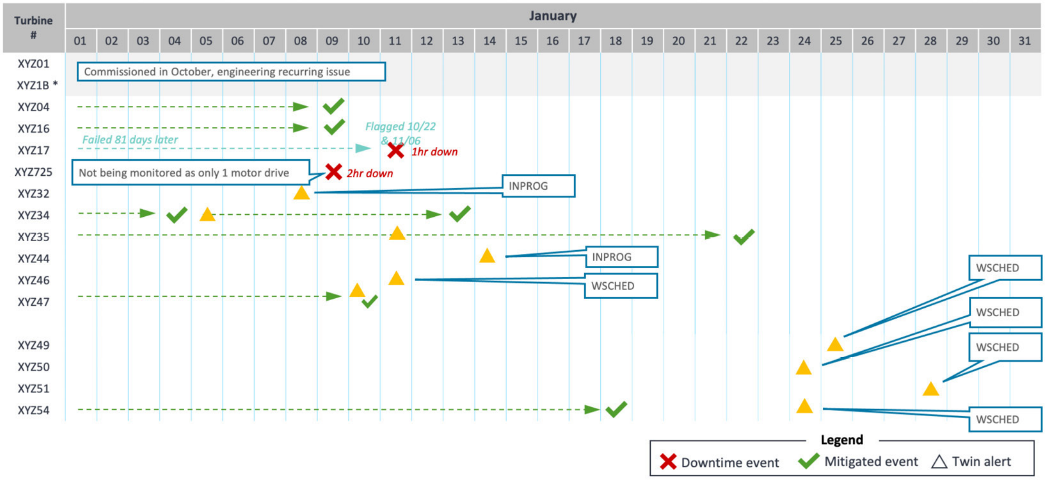

Figure 7.19 – KPI performance at the end of the pilot

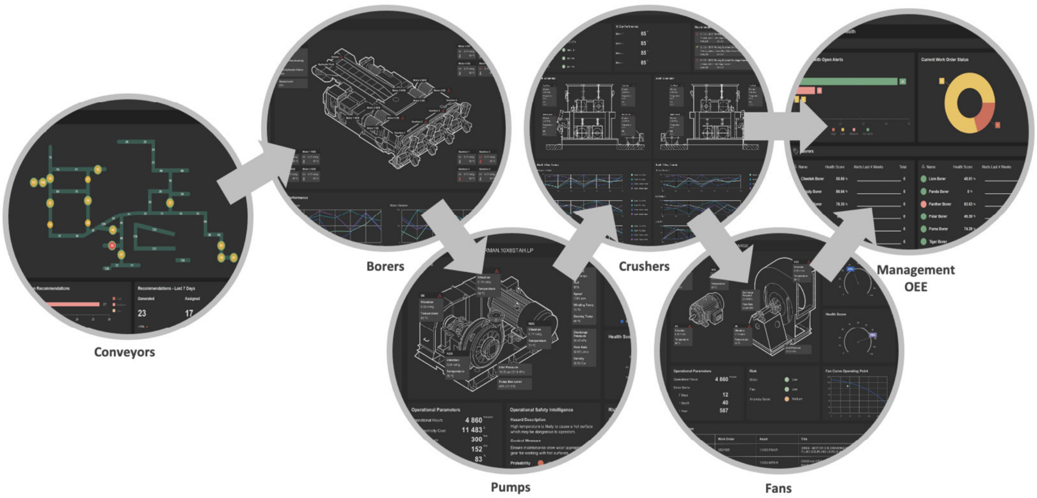

Figure 7.20 – Phased by geography and Digital Twin use case (image courtesy of XMPro Inc)

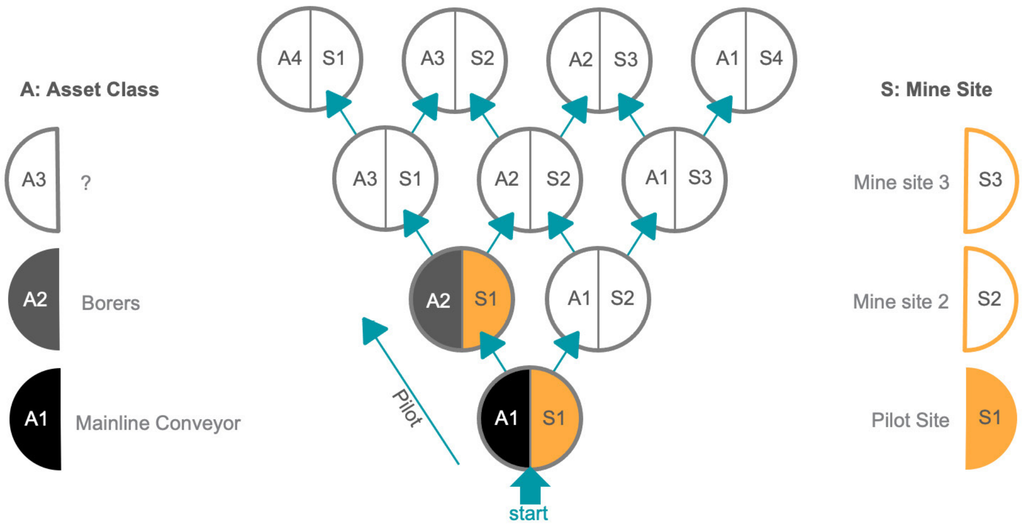

Figure 7.21 – Bowling-alley plan for a phased rollout

Digital Twin Use Case	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Conveyors	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6
Borers		Mine 1	Mine 2	Mine 3	Mine 4	Mine 5
Pumps			Mine 1	Mine 2	Mine 3	Mine 4
Crushers				Mine 1	Mine 2	Mine 3
Fans					Mine 1	Mine 2
OEE						Mine 1

Figure 7.22 – Phased rollout timeline by mine site

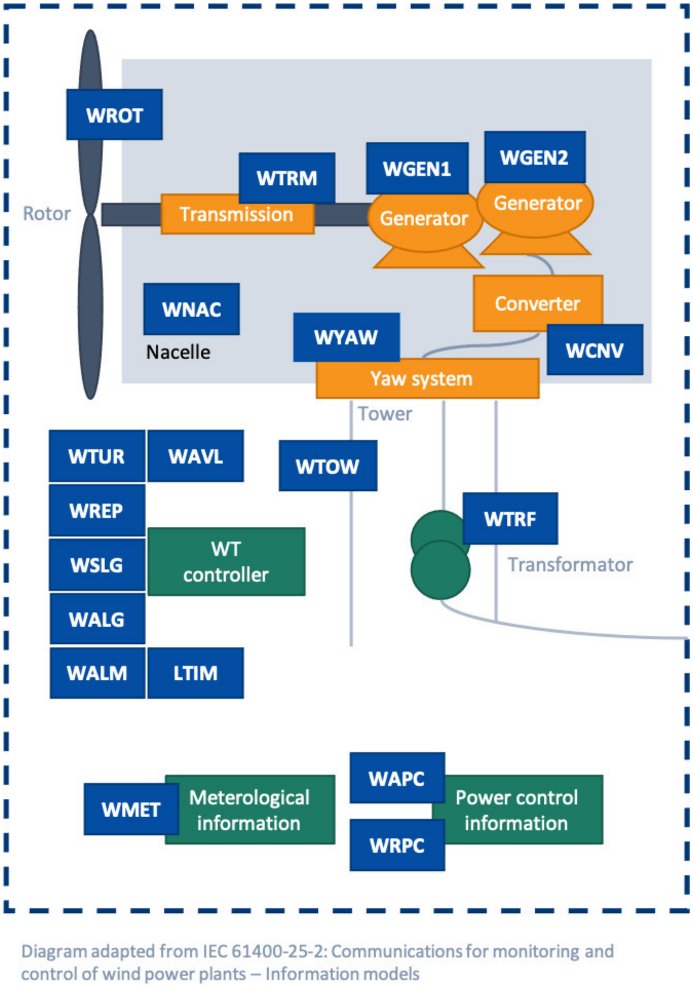

Figure 7.23 – IEC 614100-25 information model logic nodes (Image credit: https://bit.ly/idt-iec61400model)

Chapter 8

Links

Reliability Analysis of Sub Assemblies for Wind Turbine at High Uncertain Wind:

https://www.researchgate.net/publication/271973476_Reliability_Analysis_of_Sub_Assemblies_for_Wind_Turbine_at_High_Uncertain_Wind

International Organization for Standardization (ISO) https://www.iso.org/committee/6483279.html and

International Electrotechnical Commission (IEC) https://www.iec.ch/blog/moving-ahead-standardization-digital-twin

Standards hat trick for the Internet of Things: https://www.iso.org/news/ref2529.html

ISO/IEC JTC 1/SC 41-Internet of Things and Digital Twin: https://www.iec.ch/dyn/www/f?p=103:23:0::::FSP_ORG_ID:20486.

Considerations for Digital Twin Technology and Emerging Standards: Draft NISTIR 8356 Available for Comment: https://csrc.nist.gov/News/2021/draft-nistir-8356-digital-twin-technology.

Gartner Launches Emerging Technologies Radar 2021: https://blogs.gartner.com/tuong-nguyen/2020/12/07/gartner-launches-emerging-technologies-radar-2021/

HOW MUCH MONEY DOES A WIND TURBINE PRODUCE FROM ELECTRICITY IT GENERATES?: http://anemoiservices.com/industry-news/how-much-money-does-a-wind-turbine-produce-from-electricity-it-generates/.

Detailed view of the cross-section of a wind turbine, including the yaw system: https://www.windpowerengineering.com/wp-content/uploads/2016/04/Haliade_cutaway.png

The French Connection: Digital Twins From Paris Will Protect Wind Turbines Against Battering North Atlantic Gales: https://www.ge.com/news/reports/french-connection-digital-twins-paris-will-protect-wind-turbines-battering-north-atlantic-gales

A Diverse Clean Energy Portfolio: https://www.exeloncorp.com/companies/exelon-generation

Poor Planning Left California Short of Electricity in a Heat Wave: https://www.nytimes.com/2020/08/20/business/energy-environment/california-blackout-electric-grid.html

Boeing 747-8: https://www.boeing.com/commercial/747/

Boeing Celebrates Delivery of 50th 747-8: https://boeing.mediaroom.com/2013-05-29-Boeing-Celebrates-Delivery-of-50th-747-8

Digital Twins for Hydropower: https://www.pnnl.gov/projects/digital-twins-hydropower.

US recovers millions in cryptocurrency paid to Colonial Pipeline ransomware hackers: https://www.cnn.com/2021/06/07/politics/colonial-pipeline-ransomware-recovered/index.html

Dam Powerful: These Engineers Are Connecting Hydropower To The Internet: https://www.ge.com/news/reports/dam-powerful-ge-connected-hydropower-internet

Provincial and Territorial Energy Profiles – Quebec https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-quebec.html

Efficient hydroenergy conversion technologies, challenges, and policy implication: Francis turbine https://www.sciencedirect.com/topics/engineering/francis-turbines

To learn more about such physics-based computations, see the research paper here: https://www.researchgate.net/publication/226204151_Torque_model_of_hydro_turbine_with_inner_energy_loss_characteristics

Gemini Solar Project: https://www.nsenergybusiness.com/projects/gemini-solar-project/.

Engineering students simulate plan for solar energy: https://www.unb.ca/alumni/magazine/2021-spring-summer/solar-energy.html

Research paper titled *Performance evaluation of 10 MW grid connected solar photovoltaic*: https://www.sciencedirect.com/science/article/pii/S2352484715000311

PV System Predictive Maintenance: Challenges, Current Approaches, and Opportunities: https://www.mdpi.com/1996-1073/13/6/1398/htm

Hybrid Wind and Solar Electric Systems: https://www.energy.gov/energysaver/hybrid-wind-and-solar-electric-systems

Unleashing the power of offshore wind using wind catching: https://windcatching.com/

Massive floating solar farm: https://www.scmp.com/video/asia/3141298/singapore-unveils-one-worlds-biggest-floating-solar-panel-farms

IoT Intelligent Applications from Oracle (https://www.oracle.com/internet-of-things/

Building a Software Start-Up Inside GE: https://hbr.org/2015/01/building-a-software-start-up-inside-ge

Minnesota State Energy CoE: https://www.energycareersminnesota.org/.

Why you need a digital transformation center of excellence: https://techbeacon.com/enterprise-it/why-you-need-digital-transformation-center-excellence

Recommended reading

How to drive digital transformation via technology COEs: https://enterprisersproject.com/article/2021/2/digital-transformation-via-technology-centers-excellence-COE

https://reveconsulting.com/pages/creating-digital-center-excellence-global-giant/

https://www.coe-iot.com/

https://www.robolab.in/center-of-excellence-in-internet-of-things/

Figure

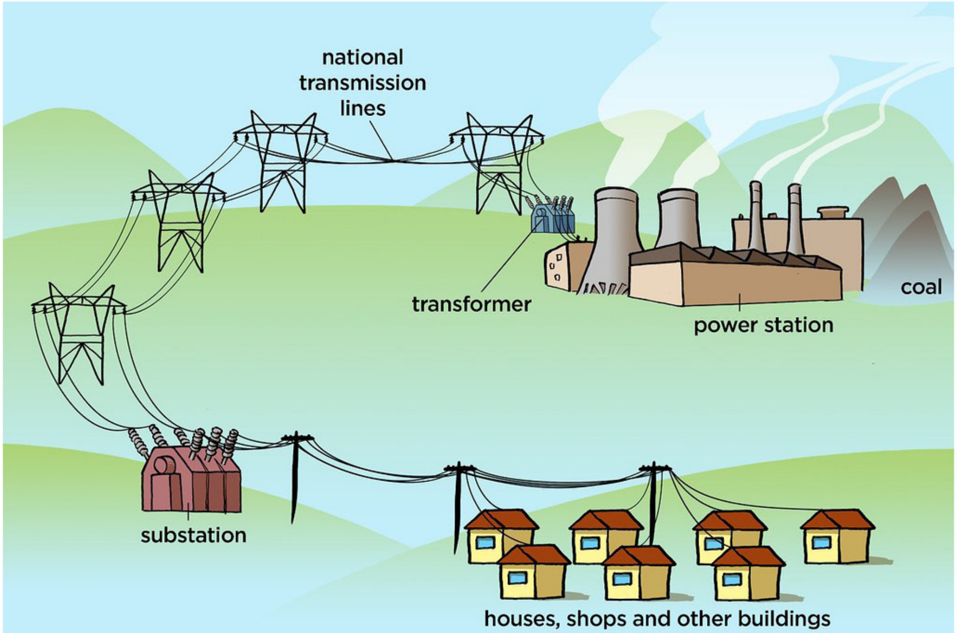

Figure 8.1 – The energy value chain, including generation, transmission, and distribution

> **Note**
>
> Image source: `https://www.flickr.com/photos/121935927@N06/13580677703`

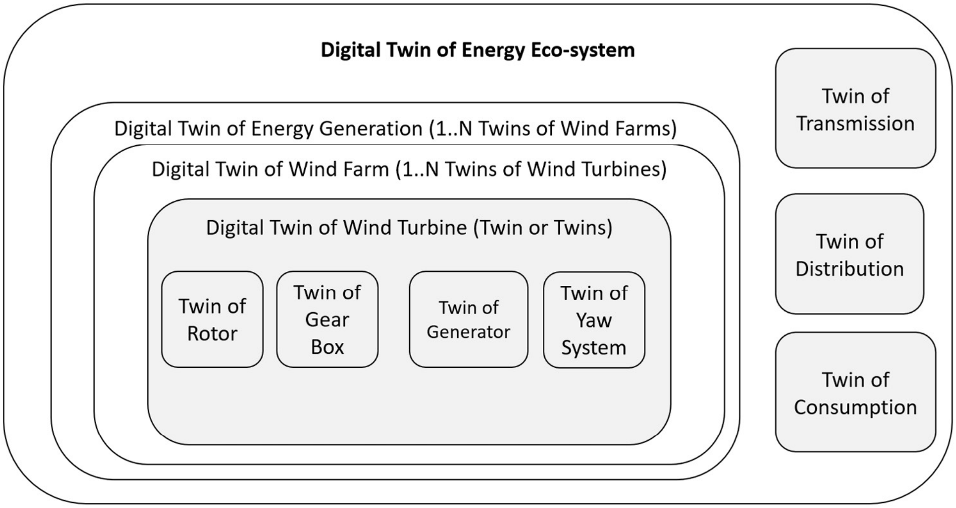

Figure 8.2 – The concept of the Digital Twin of twins for the energy ecosystem

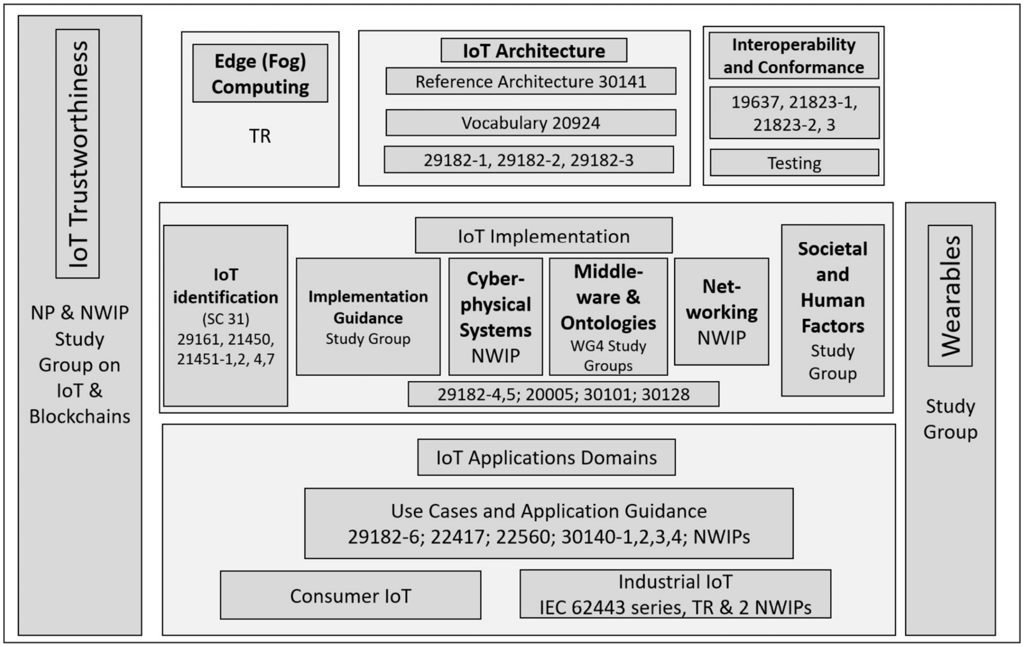

Figure 8.3 – Scope of SC 41 and its activities

Note

Image recreated from source: https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20180604/Documents/Francois_Coallier_P_V2.pdf]

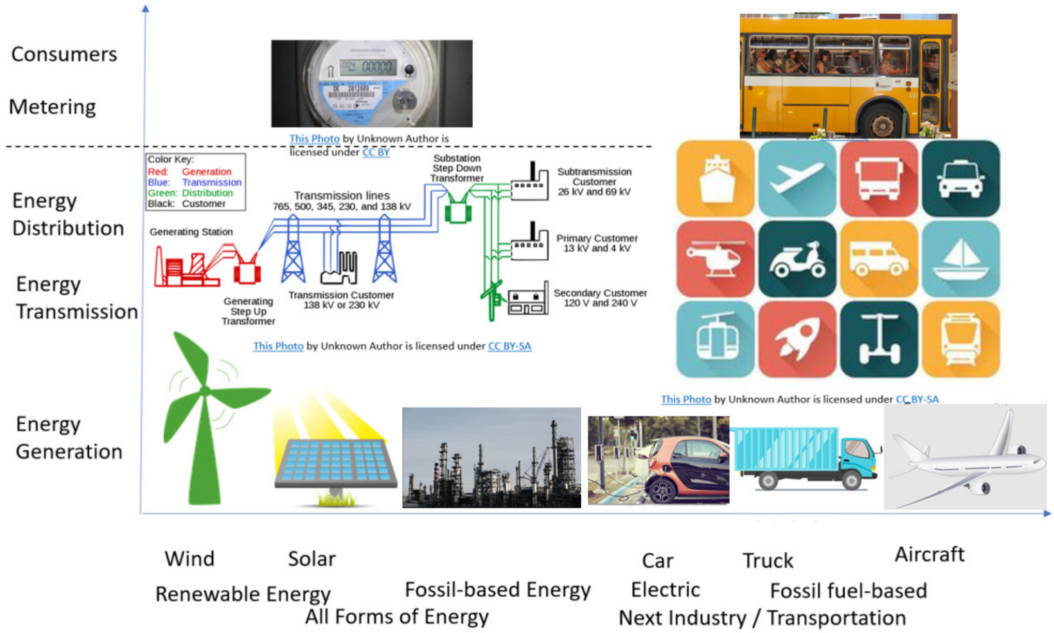

Figure 8.4 – Setting the Digital Twins vision across the industry segments

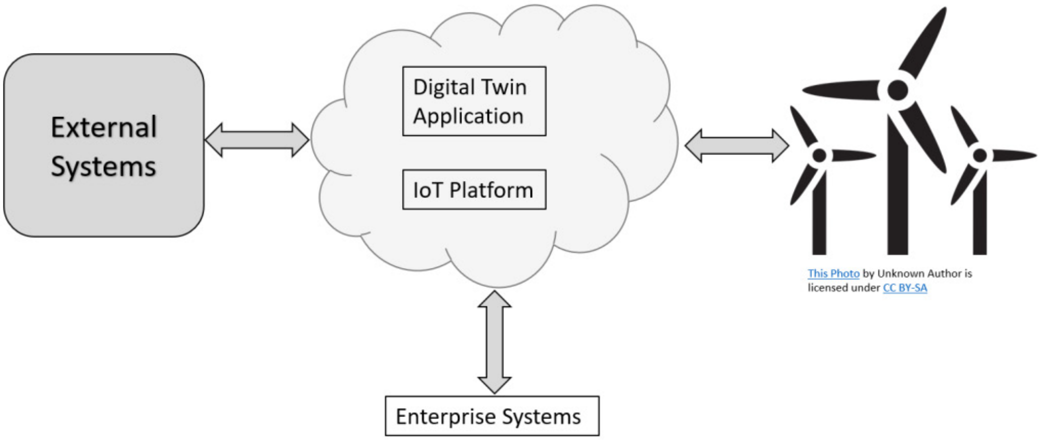

Figure 8.5 – Digital Twin rollout view at a high level

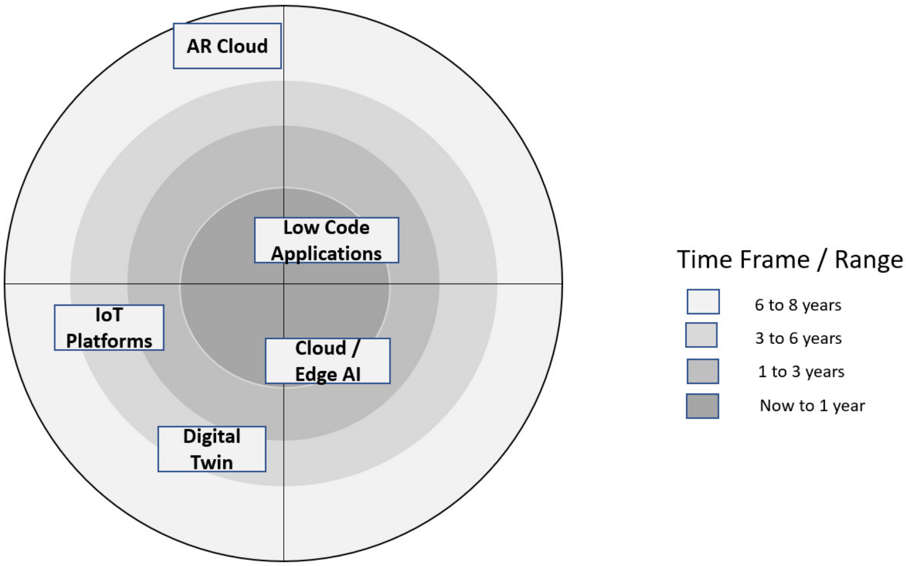

Figure 8.6 – Impact radar for emerging technologies and trends

> **Note**
>
> For more information, refer to the following:
>
> https://blogs.gartner.com/tuong-nguyen/2020/12/07/gartner-launches-emerging-technologies-radar-2021/

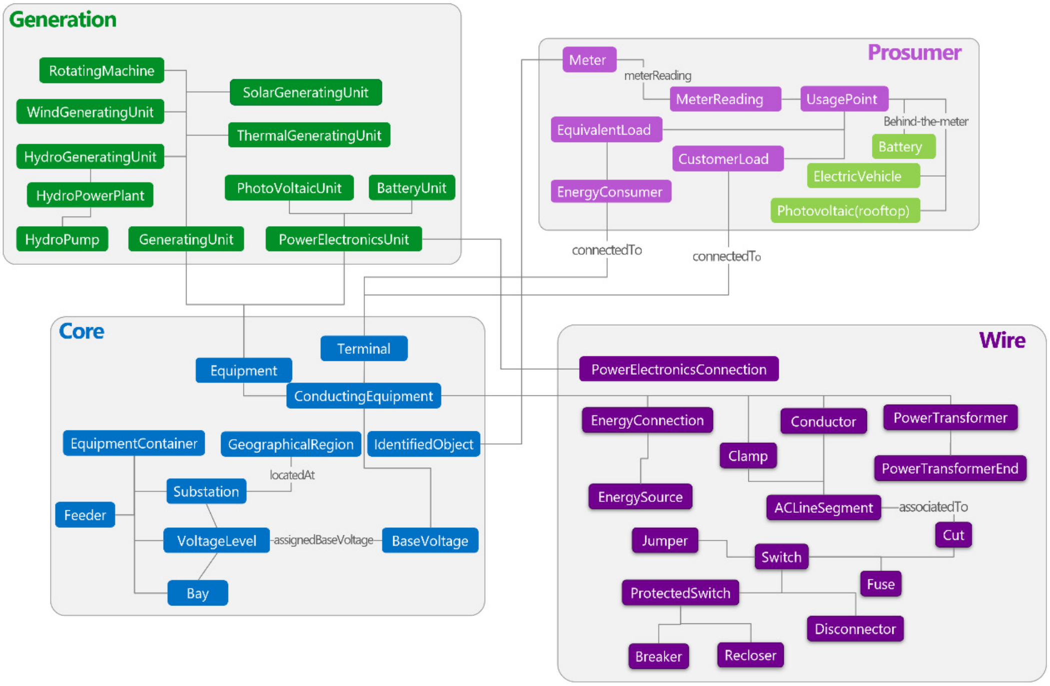

Figure 8.7 – Digital Twin ontology for the energy grid

> **Note**
>
> Image source: https://github.com/Azure/opendigitaltwins-energygrid

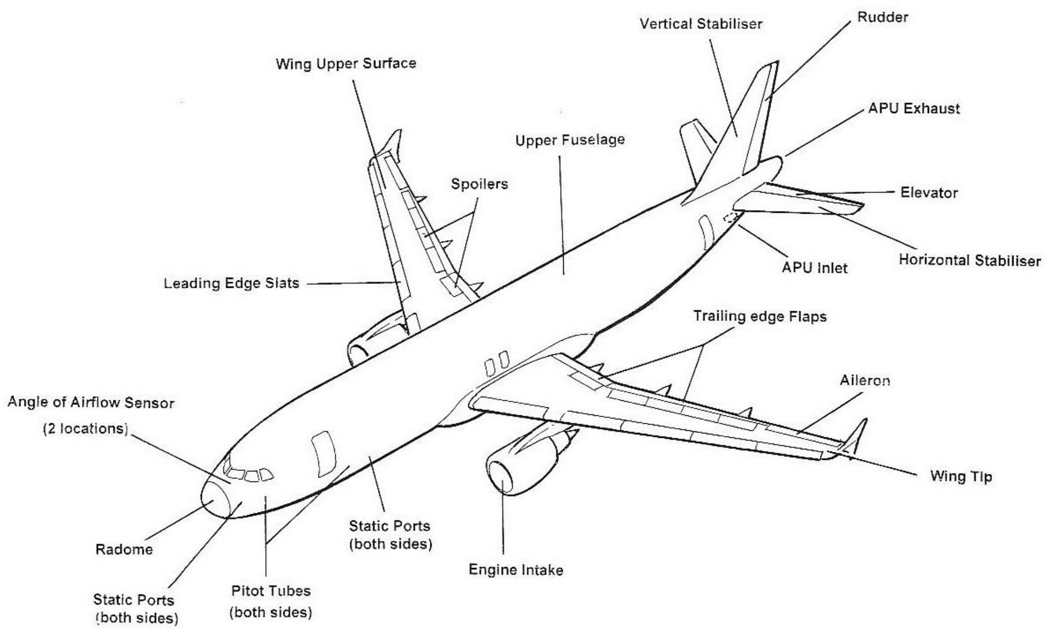

Figure 8.8 – A simplified view of the major components of a commercial aircraft

Note

Image source: https://it.wikipedia.org/wiki/File:Aircraft_Parts_eng.jpg

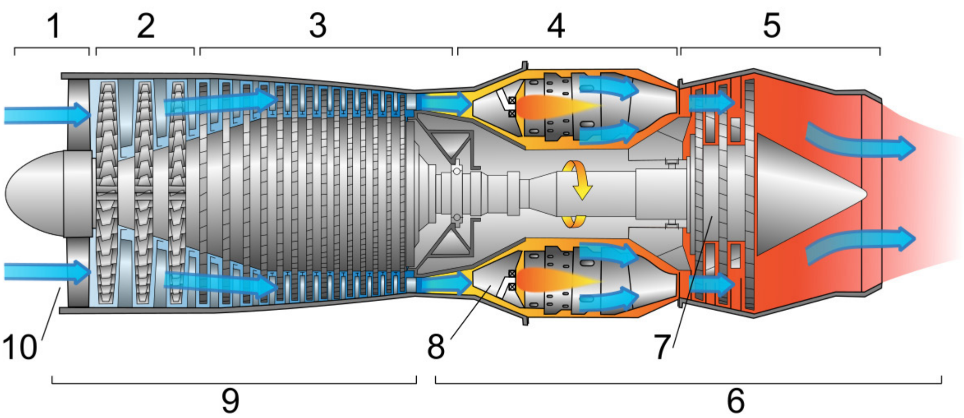

Figure 8.9 – Cross-section view of the engine of a commercial aircraft

Note

Image source: `https://en.wikipedia.org/wiki/Components_of_jet_engines`

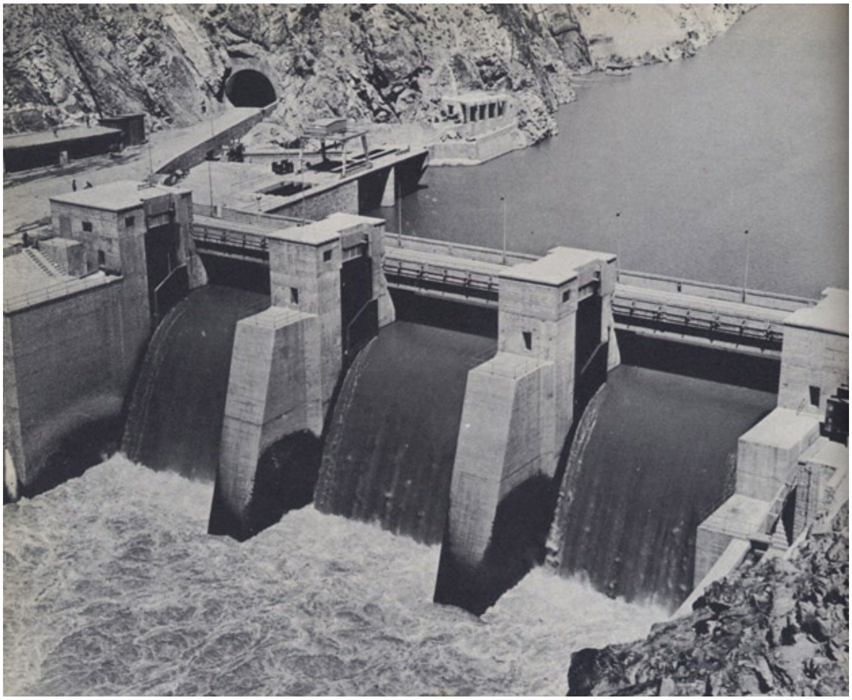

Figure 8.10 – Renewable energy from hydropower

Note

Image source: `https://no.wikipedia.org/wiki/Energi_i_Afghanistan`

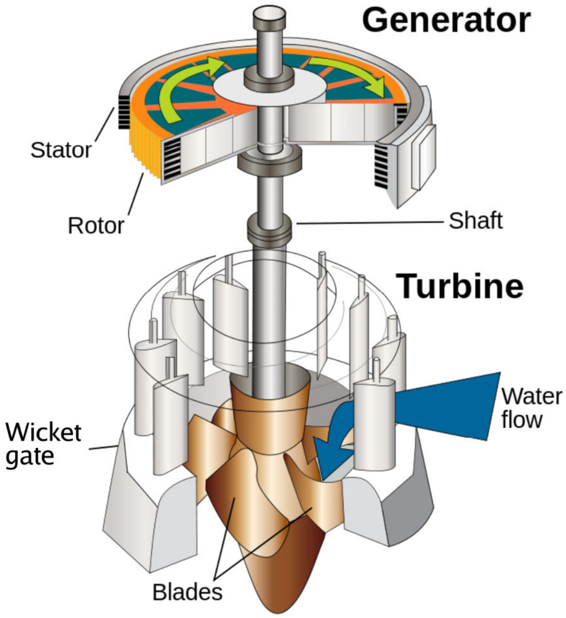

Figure 8.11 – A simplified view of a hydropower turbine

Note

Image source: https://en.wikipedia.org/wiki/Water_turbine

Figure 8.12 – A residential solar system

Figure 8.13 – A solar photovoltaic plant

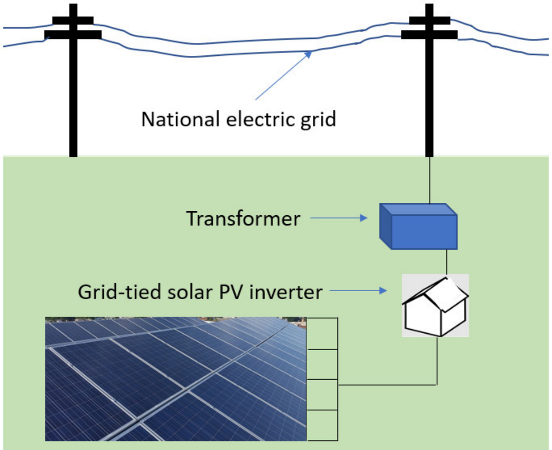

Figure 8.14 – A solar plant connection to the power grid

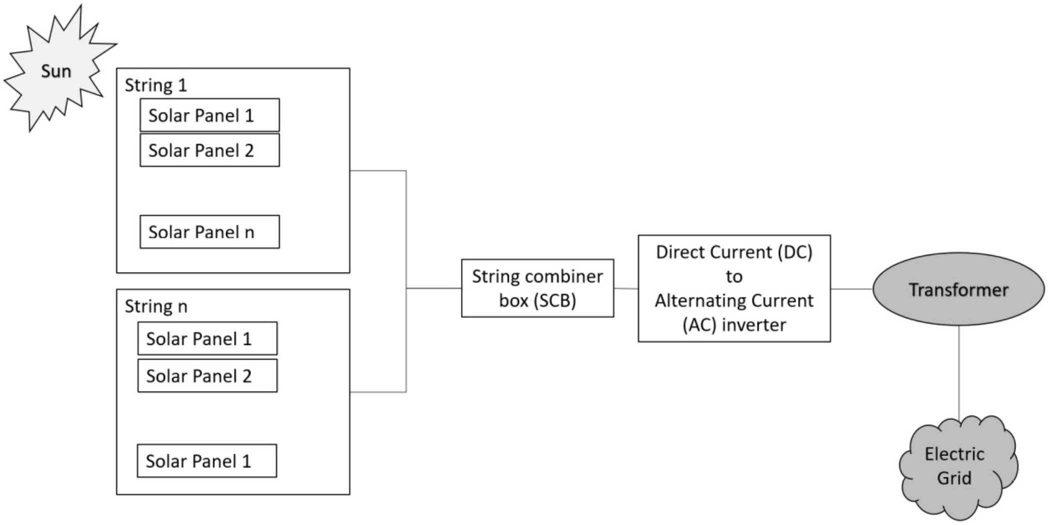

Figure 8.15 – The solar plant block diagram

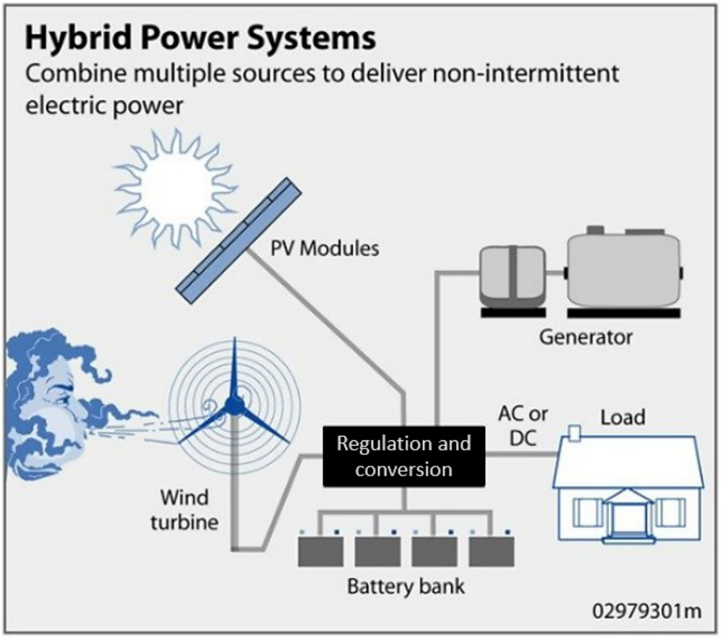

Figure 8.16 – Hybrid power plant

Note

Image source: `https://www.energy.gov/energysaver/hybrid-wind-and-solar-electric-systems`

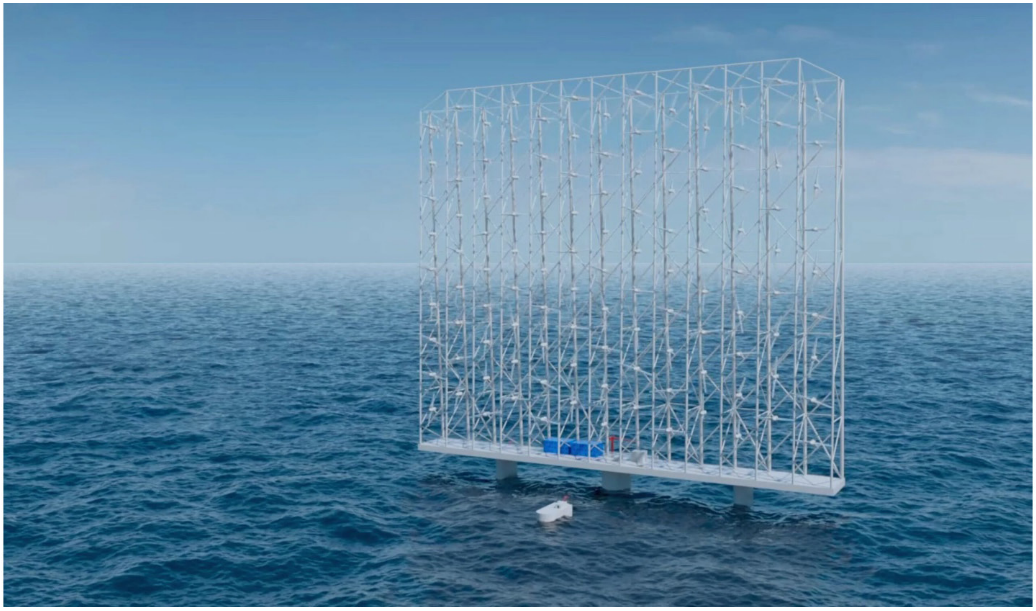

Figure 8.17 – Wind-catching design for offshore installation

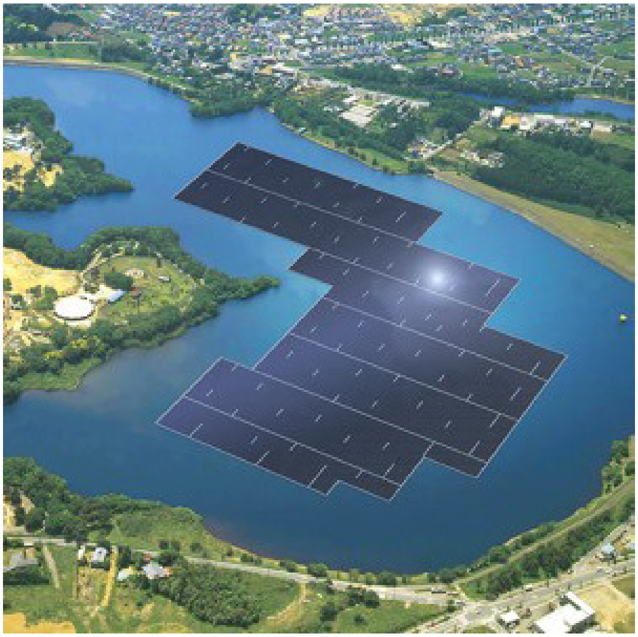

Figure 8.18 – A floating solar plant
(This photo by KYOCERA CORP is licensed under CC BY.
)

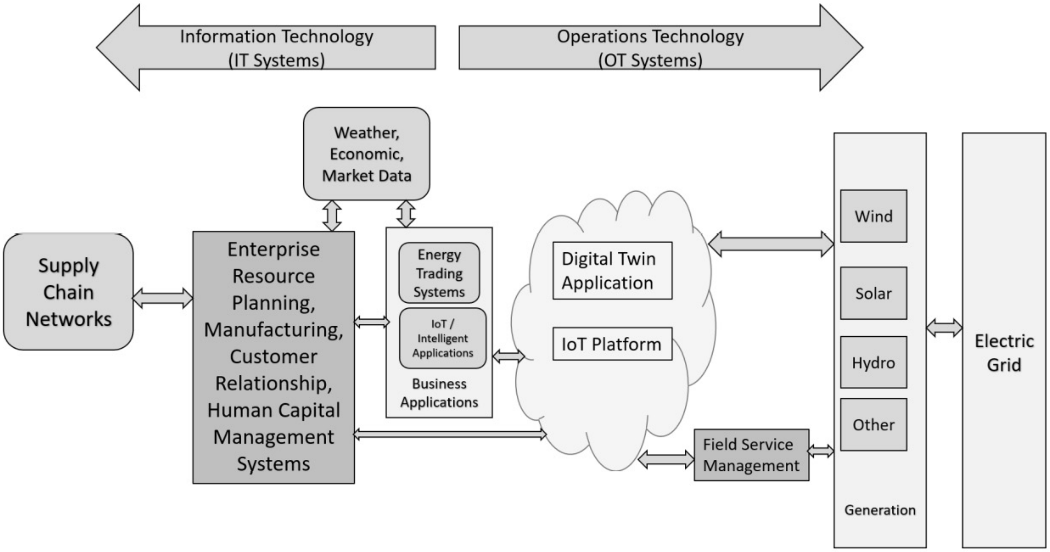

Figure 8.19 – The enterprise landscape for the Digital Twin solution deployment

Table

	Item	Baseline Cost	Twin Cost	Benefit	RoI
1	Current O&M system cost	50 x $45,000 a year	50 x $5,000 a year	$15,000	50 x $10,000 a year
2	Overhead costs due to Digital Twin / cloud computing	0	$50,000 a year		-$50,000
3	Human costs	0	$50K/year		-$50K
				Net >	$400K/year

Table 8.1 – Quantifying the benefits of the Digital Twin phased rollout

Interview

Lendlease leadership: https://www.lendlease.com/us/company/leadership/william-ruh/

Further key links from Lendlease:

www.Lendleasepodium.com

https://www.prnewswire.com/news-releases/digital-and-sustainable-lendlease-and-google-cloud-partner-to-digitally-transform-the-built-world-301370423.html

Anwar Ahmed Patents:

- First. Digital twin interface for operating wind farms: https://patents.google.com/patent/US9995278B2/
- Second. Digital system and method for managing a wind farm having plurality of wind turbines coupled to power grid: https://patents.google.com/patent/US10132295B2/