Digital Twins

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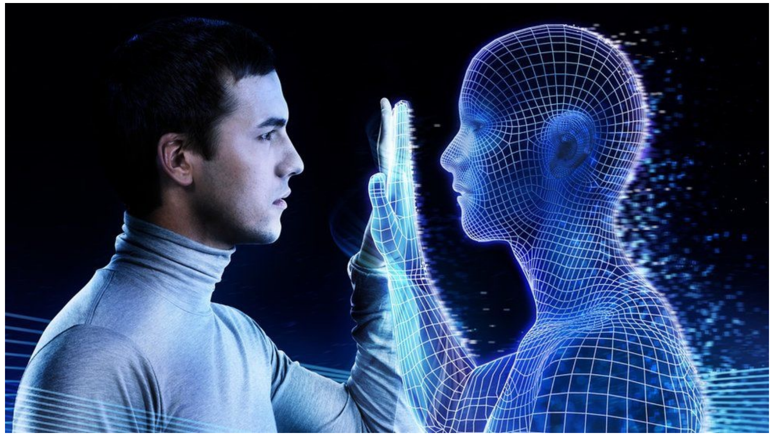
Outline of Discussion

1. What is a digital twin?
2. How do digital twins work and what are the technologies behind them?
3. Digital twins vs. simulations
4. Types of digital twins
5. The history
6. Challenges/Limitations
7. Advantages
8. Who needs digital twins?
9. Potential use cases
10. Current real-world applications
11. The future
12. Proof of concept

Introduction to Digital Twins

- What is a digital twin?
  - A virtual representation of an object or system designed to reflect a physical object accurately
  - It spans the object's lifecycle, is updated from real-time data and uses simulation, machine learning, and reasoning to make decisions



The Essence of Digital Twins

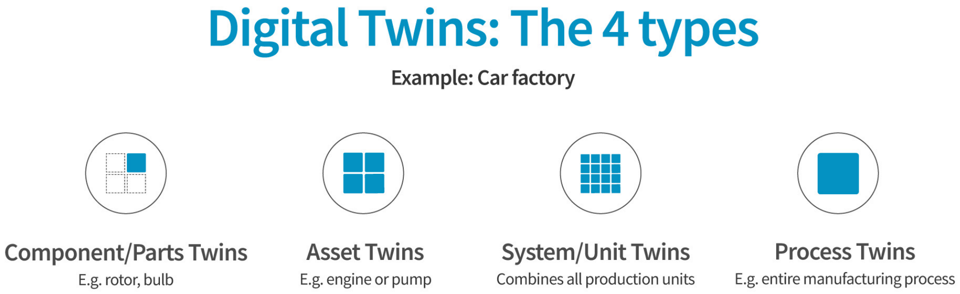
- A digital twin works by digitally replicating a physical asset in the virtual environment, including its functionality, features, and behavior
- A real-time digital representation of the asset is created using smart sensors that collect data from the product
- Core technologies behind digital twins
  - Internet of Things (IoT)
    - Digital twins rely on IoT sensor data to transmit information from the real-world object into the digital world object
    - The data inputs into a software platform or dashboard where you can see data updating in real time
  - Artificial Intelligence
    - Digital twin technology uses machine learning algorithms to process large quantities of sensor data and identify data patterns
    - AI and ML provide insights about performance optimization, maintenance, emissions outputs, and efficiencies
  - Cloud storage and retrieval solutions
  - Extended, Augmented, and Mixed Reality (XR)

Digital Twins vs. Simulations

Simulations	Digital Twins
Studies one process	Can run numerous simulations to study multiple processes
Typically, does not utilize real-time data	Designed around a two-way flow of real-time information
Used for prediction and analysis based on static models	Uses real-time data, simulation, machine learning, and reasoning for decision-making
Operates independently of the physical object or system	Continuously updated based on data from its physical counterpart
Focuses on theoretical outcomes	Focuses on both theoretical outcomes and real-time monitoring and optimization
Provides insights based on historical and hypothetical data	Provides actionable insights based on current, real-world data
Often used for initial testing and scenario exploration	Used for ongoing monitoring, optimization, and lifecycle management

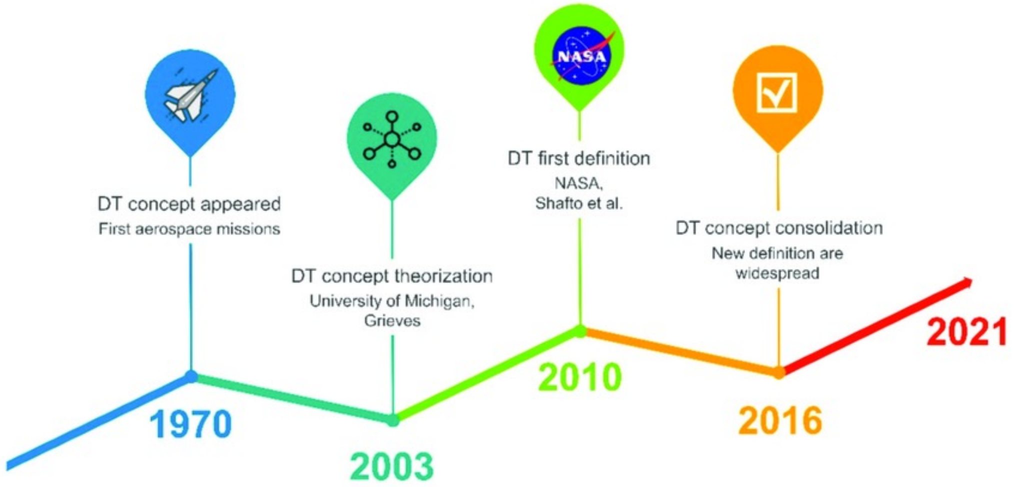
Types of Digital Twins

- Component twins or parts twins
    - These are the basic unit of a digital twin, the smallest example of a functioning component
    - Part twins are roughly the same idea, but pertain to components of slightly less importance
- Asset twins
    - When they two or more components work together, they form what is known as an asset
    - Asset twins let you study the interaction of those components, creating a wealth of performance data
- System or unit twins
    - Next level of magnification
    - Enable you to see how different assets come together to form an entire functioning system
- Process twins
    - The macro level of magnification
    - Reveal how systems work together to create an entire production facility
    - Can help determine the precise timing schemes that influence overall effectiveness



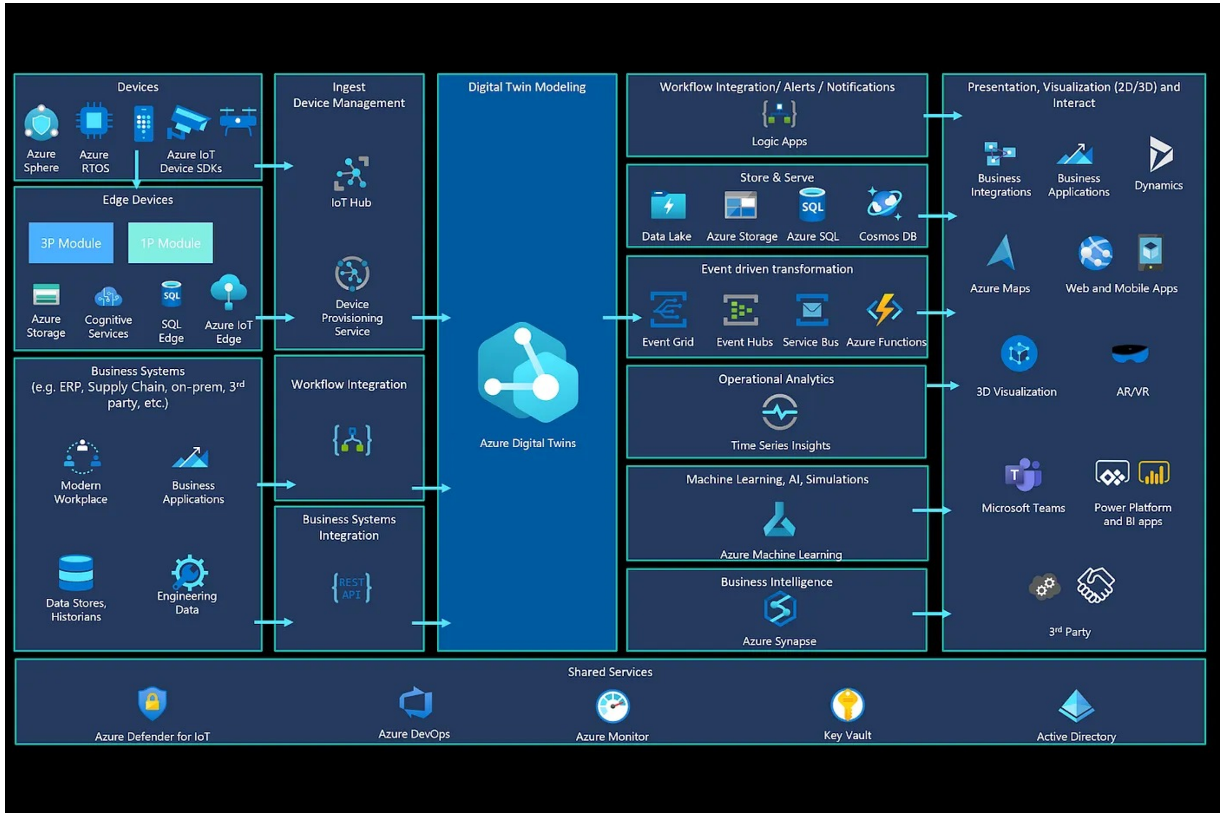
Historical Background

- The idea of digital twin technology was first voiced in 1991, with the publication of Mirror Worlds, by David Gelernter
- However, Dr. Michael Grieves is credited with first applying the concept of digital twins to manufacturing in 2002 and formally announcing the digital twin software concept
- Eventually, NASA's John Vickers introduced a new term - "digital twin"- in 2010
- However, the core idea of using a digital twin as a means of studying a physical object can be witnessed much earlier
    - NASA pioneered the use of digital twin technology during its space exploration missions of the 1960s, when each voyaging spacecraft was exactly replicated in an earthbound version that was used for study and simulation purposes by NASA personnel serving on flight crews



Challenges and Limitations

- Cost
- Amount of real-world data
- Lack of common data standards and tools
- Diversity in source systems



Advantages of Digital Twins

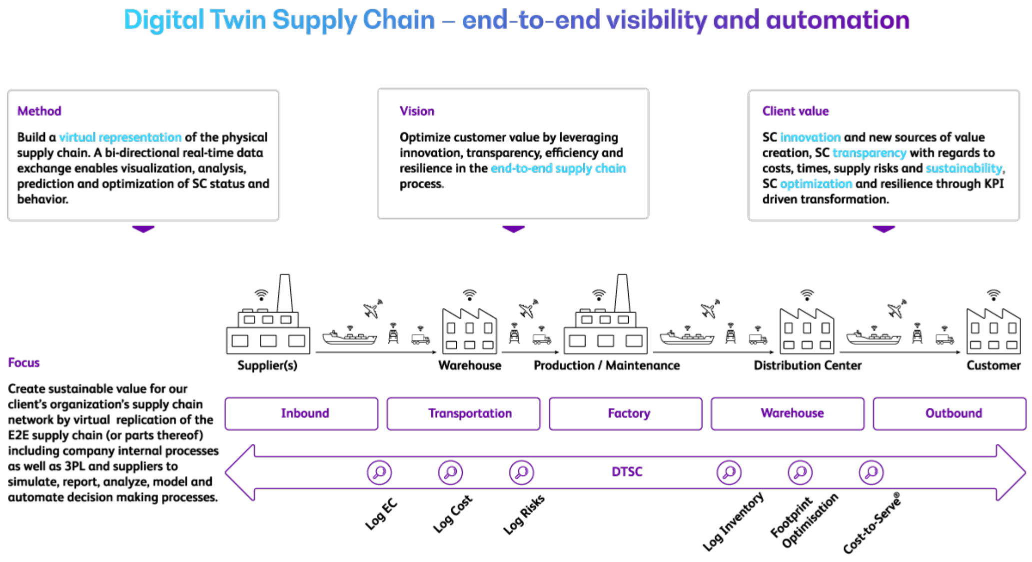
- Better R&D
  - Digital twins enable more effective research and design of products, with an abundance of data created about likely performance outcomes
  - This information can lead to insights that help companies make needed product refinements before starting production
- Greater Efficiency
  - Digital twins can help mirror and monitor production systems, with an eye to achieving and maintaining peak efficiency throughout the entire manufacturing process
- Product end-of-life
  - Digital twins can help manufacturers decide what to do with products that reach end of their product lifecycle

Who Needs Digital Twins?

- While digital twins are invaluable for what they offer, their use isn't warranted for every manufacturer, or every product created
  - Not every object is complex enough to warrant a digital twin
  - Nor is it worth it from a financial standpoint to invest in a digital twin
- There are numerous types of projects that do benefit from the use of digital models:
  - Physically large buildings
  - Mechanically complex projects
  - Power equipment
  - Manufacturing projects
- Some industries that achieve great success with digital twins:
  - Engineering
  - Automobile manufacturing
  - Aircraft production (Boeing take notes)
  - Railcar design
  - Building construction
  - Manufacturing
  - Power utilities

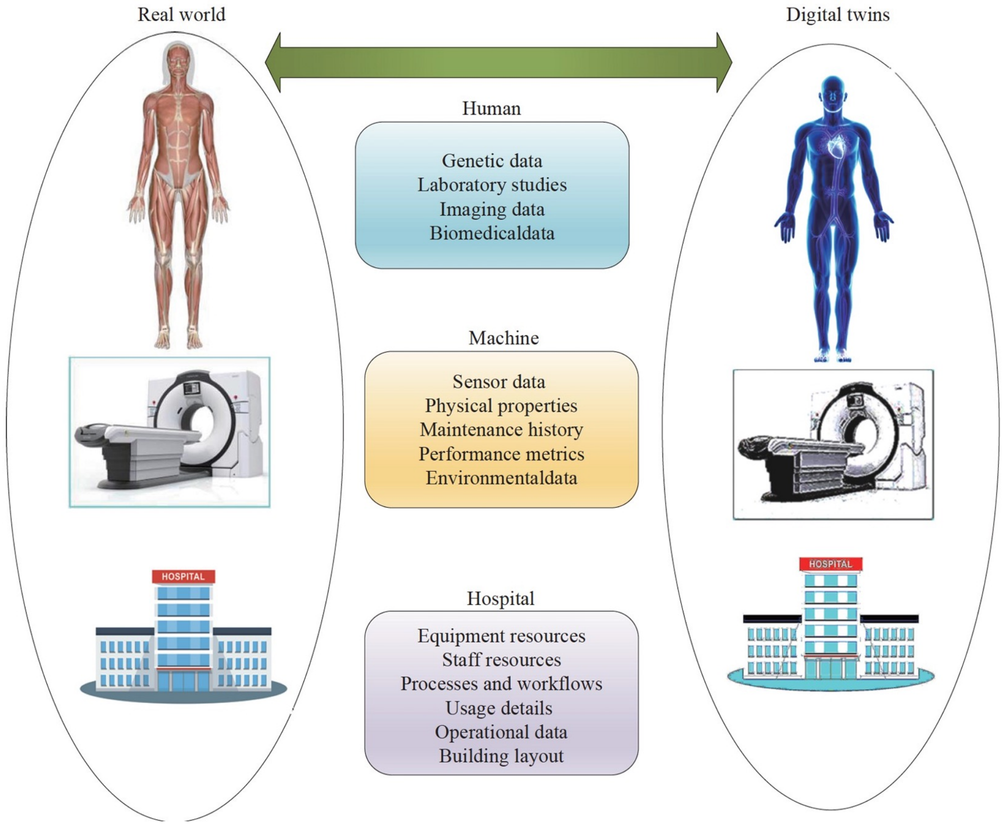
Use Cases for Digital Twins

- Healthcare services
- Urban planning
- Design
- Logistics and Supply Chain



Current Real-World Applications

- Application 1: Utilities: Energy Output Optimization
- Application 2: Medicine: Deep Learning Image Analysis
- Application 3: Civil Engineering: Italy's Smart Trains



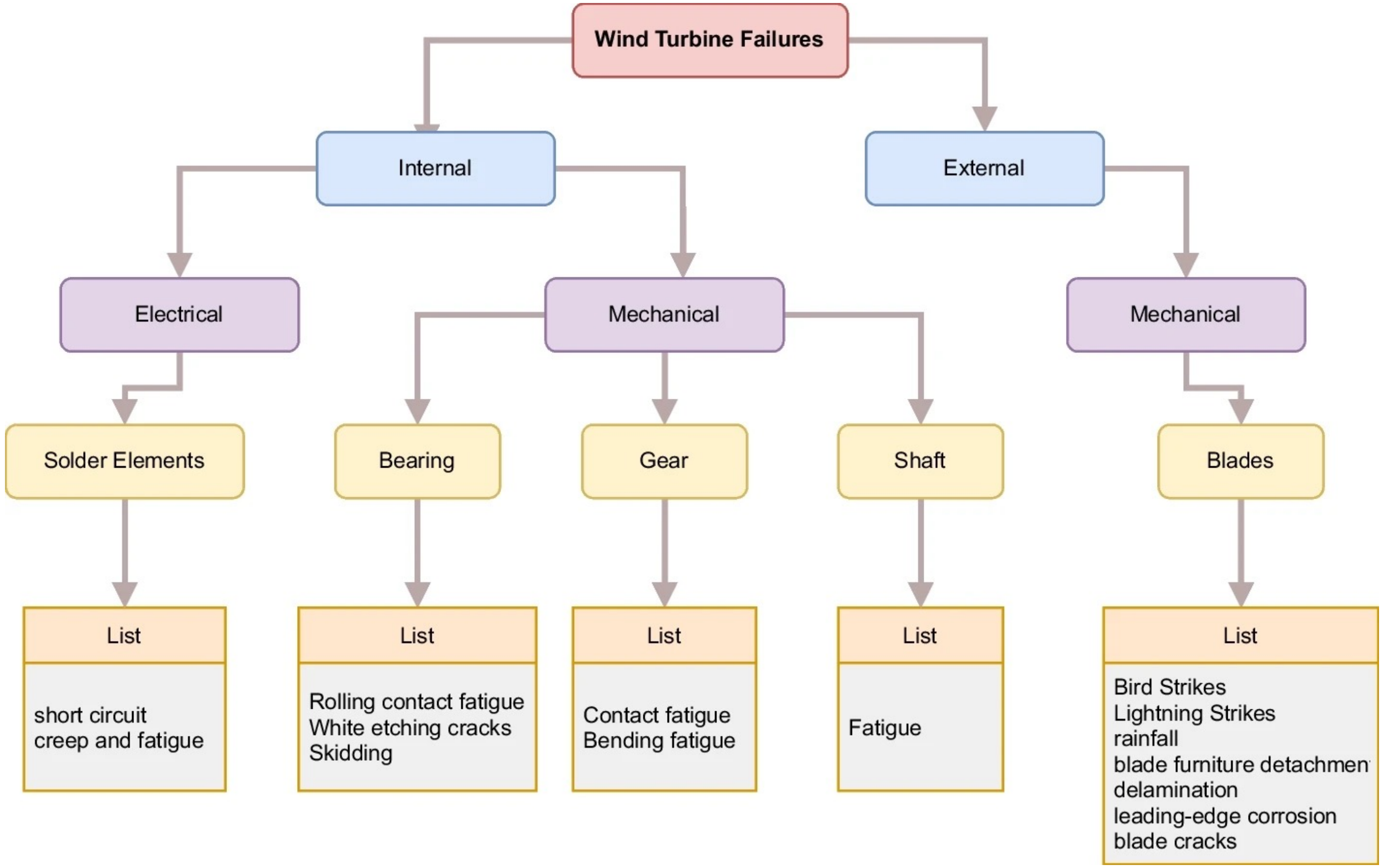
The Future of Digital Twins

- The digital twin market indicates that while digital twins are already in use in many industries, the demand for digital twins will continue to escalate for some time
- In 2022, the global digital twins' market was projected to reach USD 73.5 billion by 2027

Proof of Concept – Digital Twin for Offshore Wind Farms

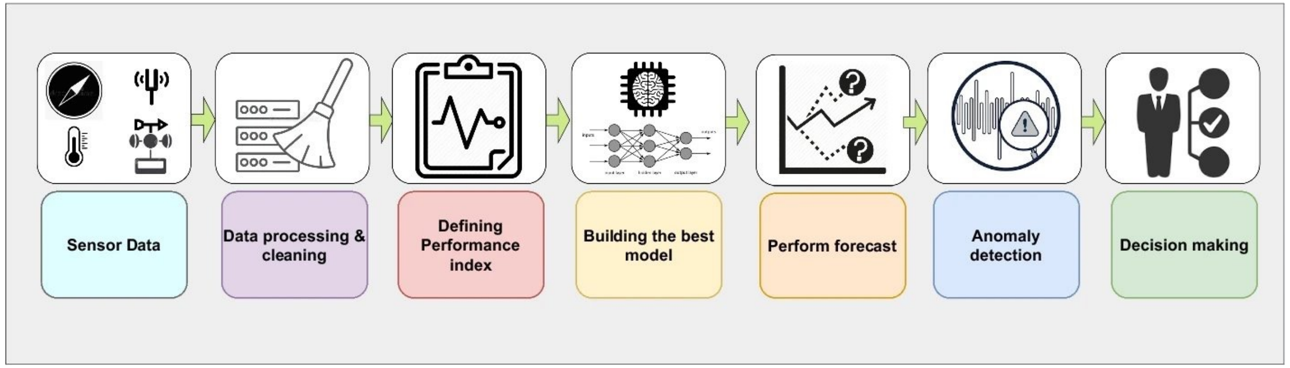
- Introduction and Motivation
  - Wind turbines, especially offshore ones, are deployed in environments that are operationally demanding and hostile
  - Operation and maintenance of wind turbines in such environments are both challenging and expensive
  - Need for enhanced safety and cost reduction
  - Predictive maintenance and failure prevention

Proof of Concept – Digital Twin for Offshore Wind Farms



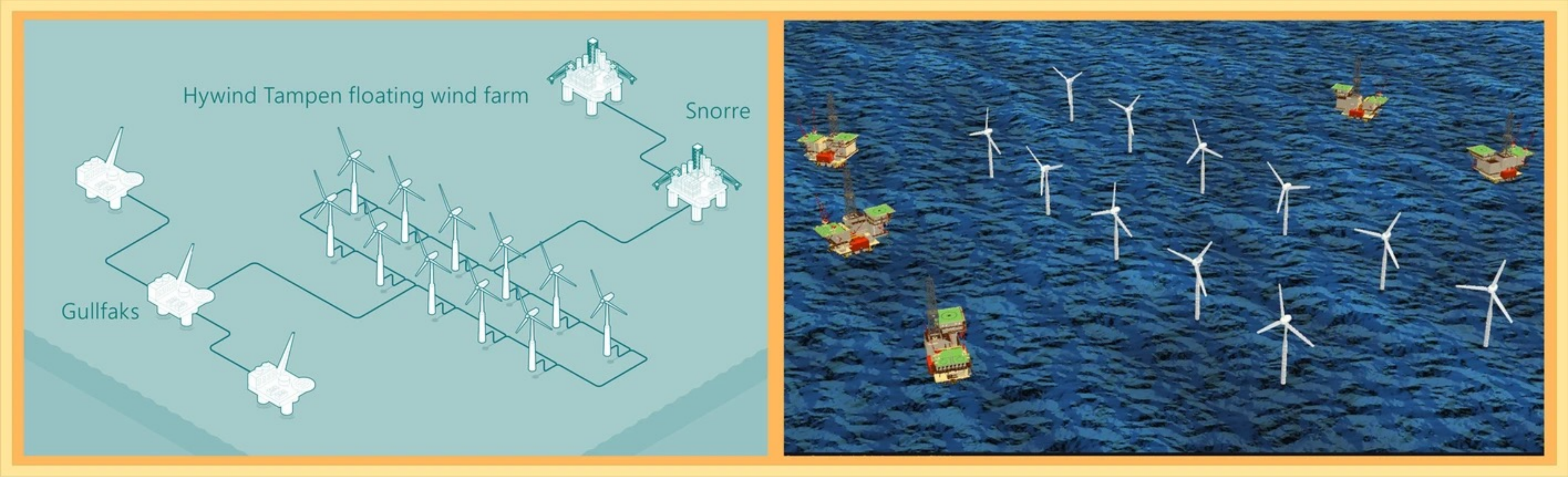
Different types of wind turbine failures

Proof of Concept – Digital Twin for Offshore Wind Farms



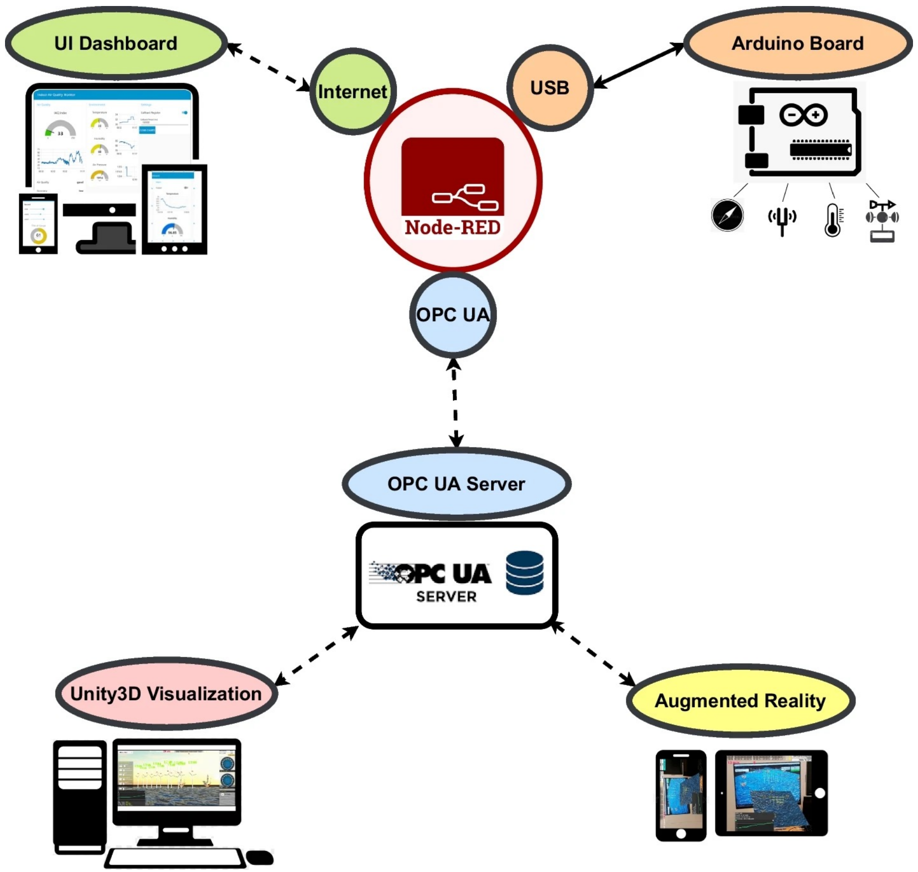
A typical failure prediction procedure

Proof of Concept – Digital Twin for Offshore Wind Farms



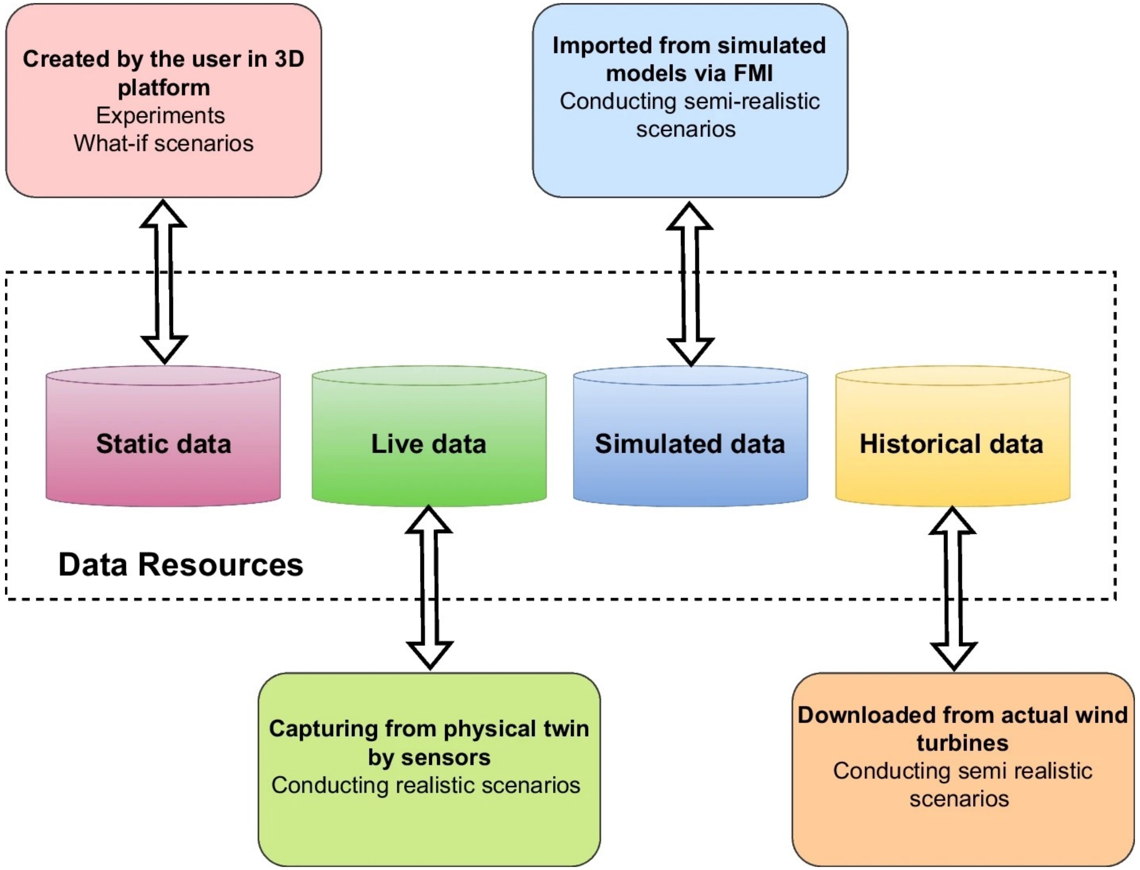
Left: Hywind Tampen project developed by Equinor ASA. Right: Digital twin representation in Unity3D

Proof of Concept – Digital Twin for Offshore Wind Farms



Communication architecture based on the OPC-UA for connecting digital twin components

Proof of Concept – Digital Twin for Offshore Wind Farms

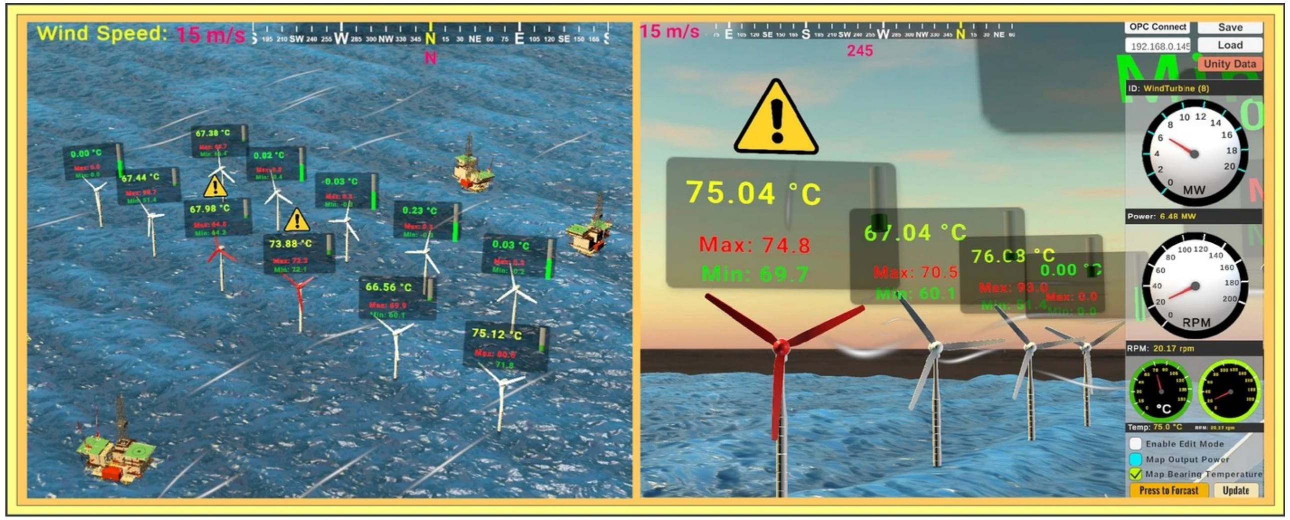


Different data resources and their use for conducting diverse scenarios

Proof of Concept – Digital Twin for Offshore Wind Farms

Visualization of desired scenario in Unity3D platform including asset inventory and UI indicators

Proof of Concept – Digital Twin for Offshore Wind Farms



Condition monitoring of the turbine

Proof of Concept – Digital Twin for Offshore Wind Farms

AR-based visualization of a digital twin of a wind farm

Conclusion

- Digital twins are advanced digital replicas of physical entities
- Integration of IoT, AI, and ML technologies
- Enhance predictive maintenance, operational efficiency, and innovation
- The future of digital twins lies in greater integration, enhanced interoperability standards, and broader adoption

Sources Used

- https://www.ibm.com/topics/what-is-a-digital-twin
- https://aws.amazon.com/what-is/digital-twin
- https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-digital-twin-technology
- https://www.computer.org/publications/tech-news/trends/digital-twin-use-cases
- https://energyinformatics.springeropen.com/articles/10.1186/s42162-023-00257-4
- https://www.mdpi.com/2075-5309/12/2/120
- https://ntrs.nasa.gov/citations/20210023699

Q&A

- Any Questions?