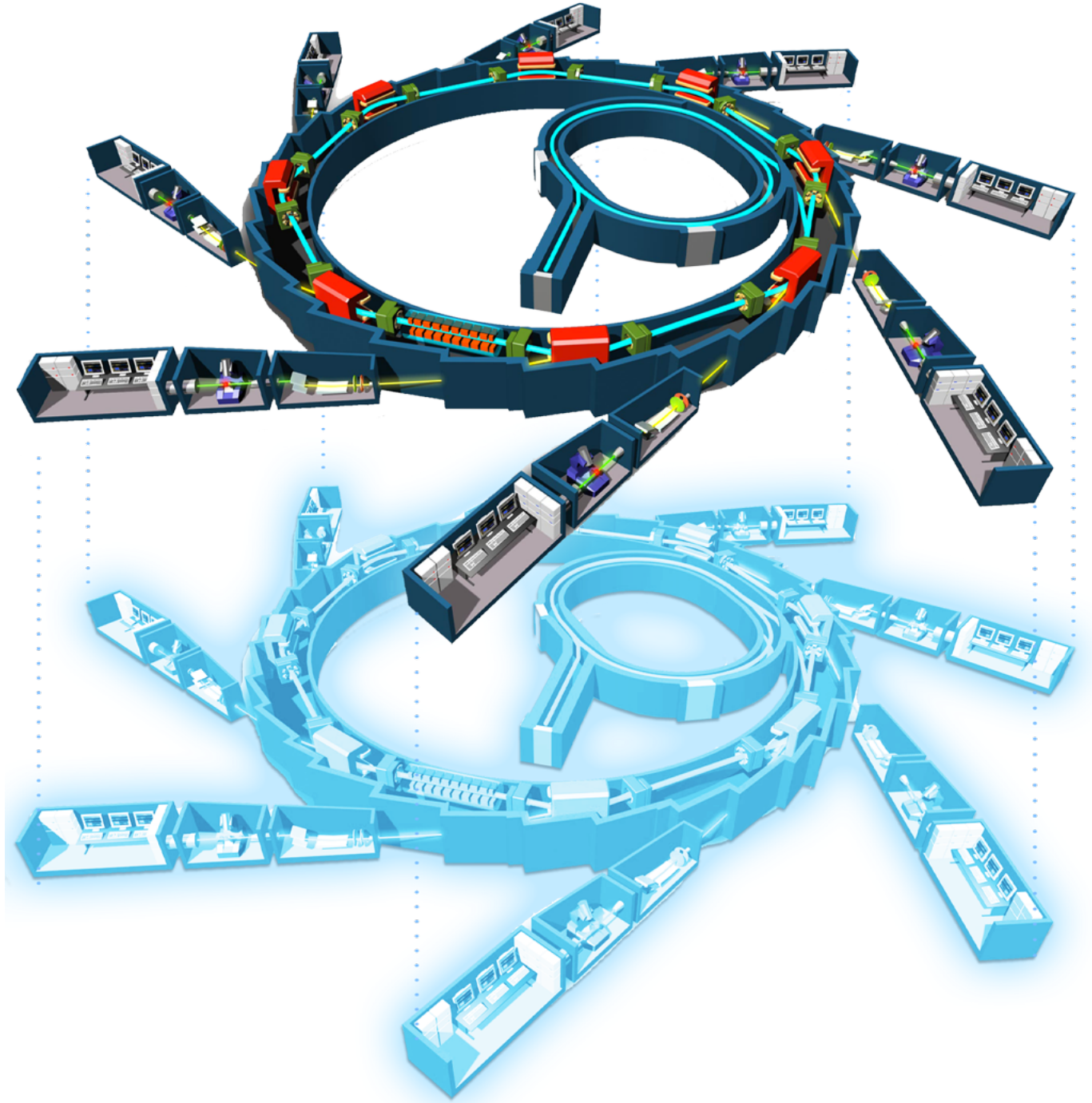
LEAPS

# Digital Twin(ning)

## Beyond the buzz word

A light sources perspective



*Nicolas Leclercq - ESRF*
*LEAPS Integrated Platform Workshop*
*May 11th 2021*

ESRF
The European Synchrotron

# About this presentation

- Introduction to Digital Twin(ning) from a light source perspective [⏱ = 23’]

- Will be followed by a presentation of the ESRF-EBS Simulator by Simone Liuzzo [⏱ = 7’]

# The promise of the Digital Twin

**Data-driven technologies**(1) to enhance asset lifecycle management

A **virtual twin** to deliver **smart** [

**design** → manufacturing → **service** → dismantling

]

*(1) data-centric technics: advanced analytics, knowledge extraction, machine learning*

# The promise of the Digital Twin

Use cases?

**Place of physics-based simulation?**

Role of control systems?

IT resources?

## Digital Twin(ning) for Accelerator-based Light Sources?

What's beyond AI?

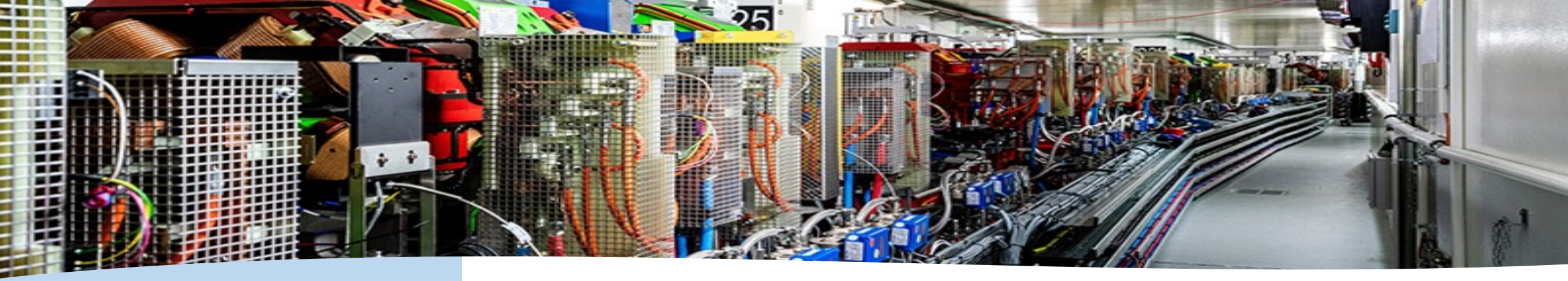
**Added value?**

Deployment scale?

End-to-End simulation?

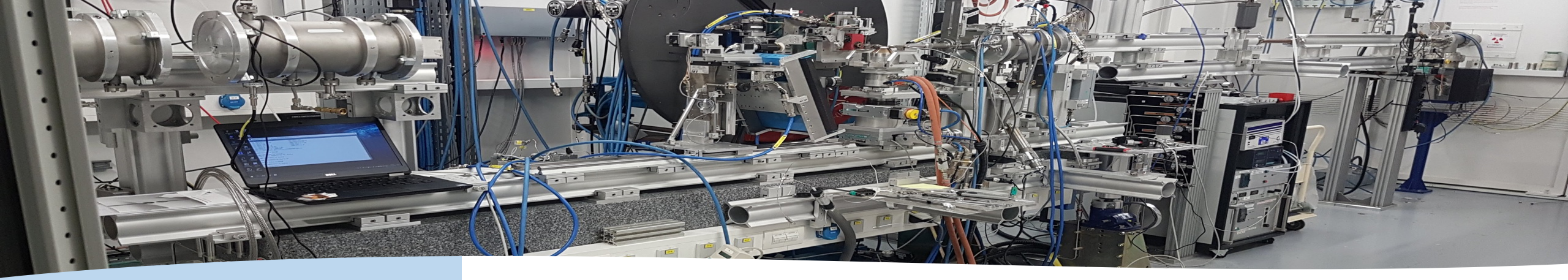
Cost?

Offline simulation capability?



# Daily challenges of a light source

1. **maintain ultimate performances on both machine & experiments**
   - monitoring, controls, (*hard and soft*) real-time optimization
2. **ensure high reliability & availability of the systems**
   - react to failures and maintain a proper maintenance plan
   - maximize *User-Beamtime* / *Total-Beamtime* ratio
3. **evolve while delivering beam to users**
   - design + R&D tools : simulation, testing, validation, training sandbox



# Daily challenges of a light source

How could DT enhance our ability to achieve these goals?

How to go one step further using DT?


# Daily challenges of a light source

1. **maintain ultimate performances on both machine & experiments**
   - → **smart operation, advanced controls & feedbacks, AI-assisted decision-making**
   - → AI (ML & DL) - e.g., reinforcement learning for feedbacks

2. **ensure reliability & availability of the systems**
   - → grail: **minimized & planned downtime, "infinite MTBF"**
   - → faults detection & diagnostics, predictive maintenance
   - → AI (ML & DL) - e.g., unsupervised learning for predictive maintenance

3. **evolve while delivering beam to users**
   - → **offline tools, virtual environments, high-fidelity simulations**
   - → physics-based models and/or data-driven models (1)
   - → AI (ML & DL) - e.g., AI-augmented physics-based simulation

*(1) ML models trained on real-world data*

# Daily challenges of a light source

**Digital Twinning** (DT)
and the underlying data-driven technologies could indeed help...

# About DT

## Definition

*Globally accepted definition:*

A virtual representation that serves as the **real-time**(1) **digital counterpart** of a **physical object** (or a process)

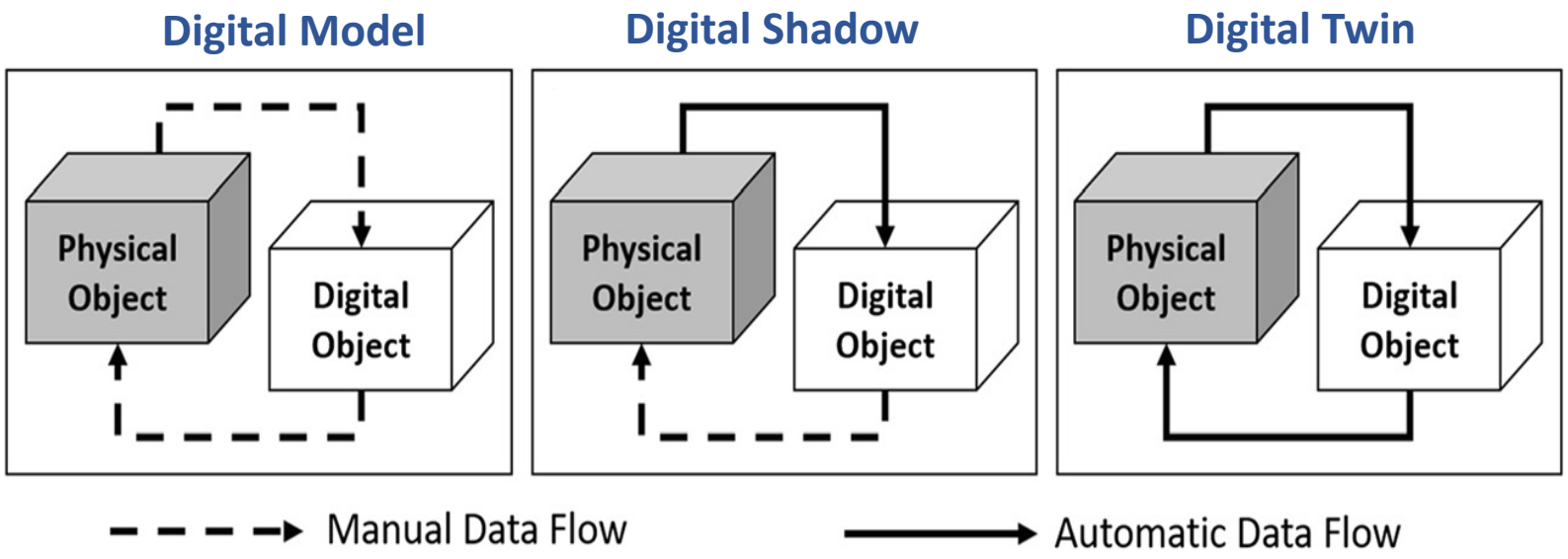
(from IEEE *Xplore*)

*(1) twins coexist and are synchronized (mutual update)*

# About DT

## Definition

The definition of DT mainly relies on the ***automatic***, ***real-time*** and ***bidirectional*** nature of the connection between the physical object and its digital equivalent

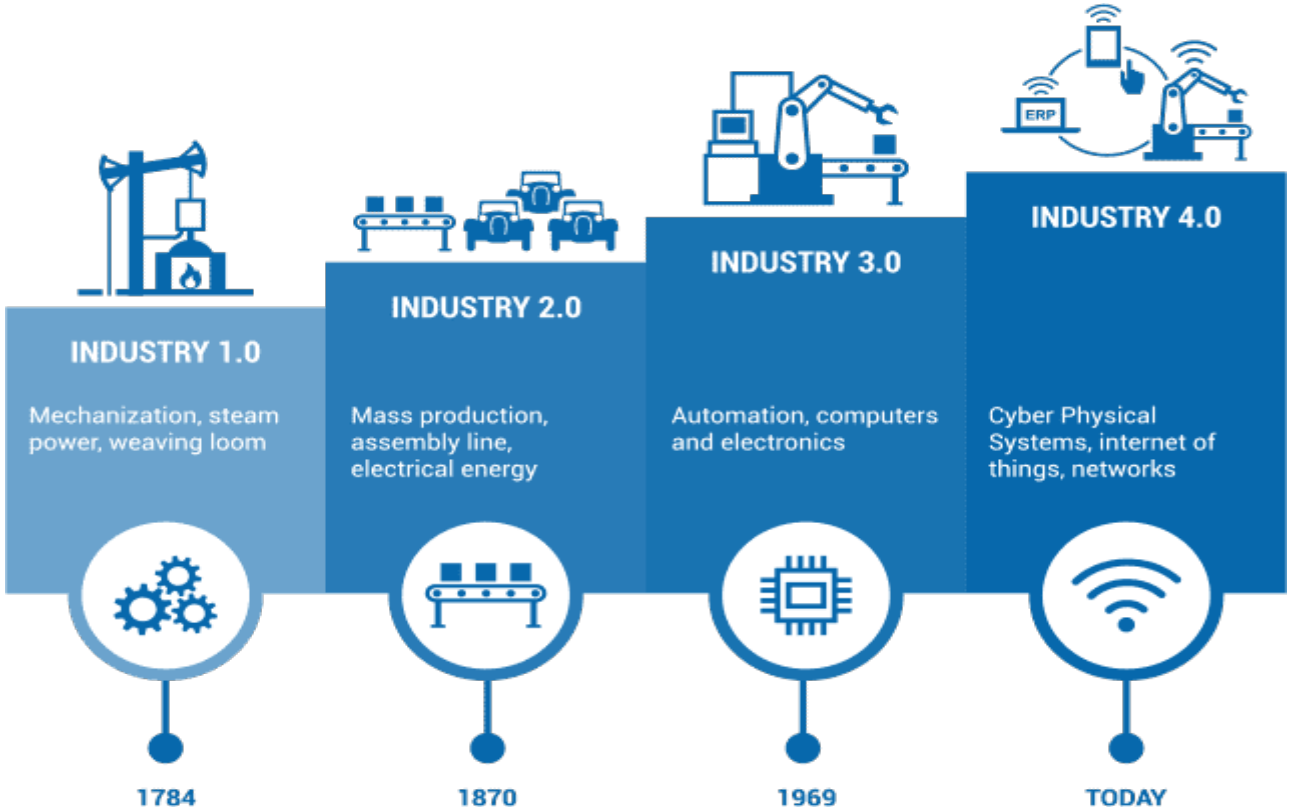


# About DT

## Origin

## Core component of the Industry 4.0

digital transformation applied to industrial processes



# About DT

## Purpose

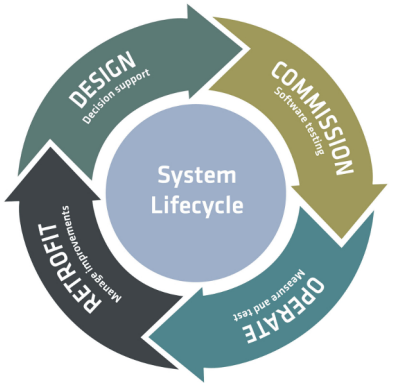
Optimize(1) each phase of the lifecycle of the physical twin: *Design→ Manufacturing → Operation (or Service) → Dismantling* using physics-based(2) simulation, data-driven(3) models and advanced analytics

*(1) in terms of performances & maintenance*

*(2) i.e., Physics-based simulation models*

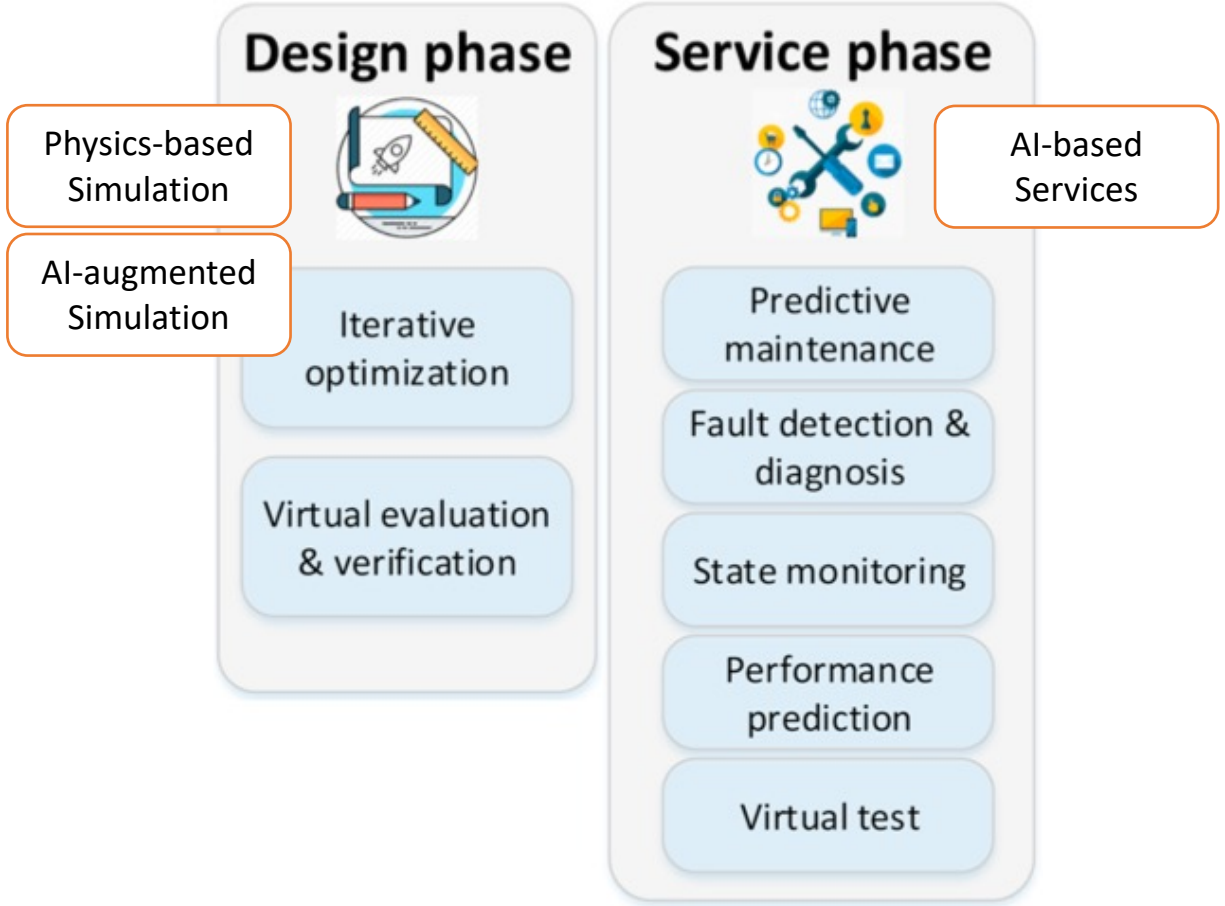
*(3) e.g., Machine Learning models trained on time-series coming from the physical twin*

Most DT related works focus on a *Design → Commissioning → Operation → Upgrade* cycle



# About DT

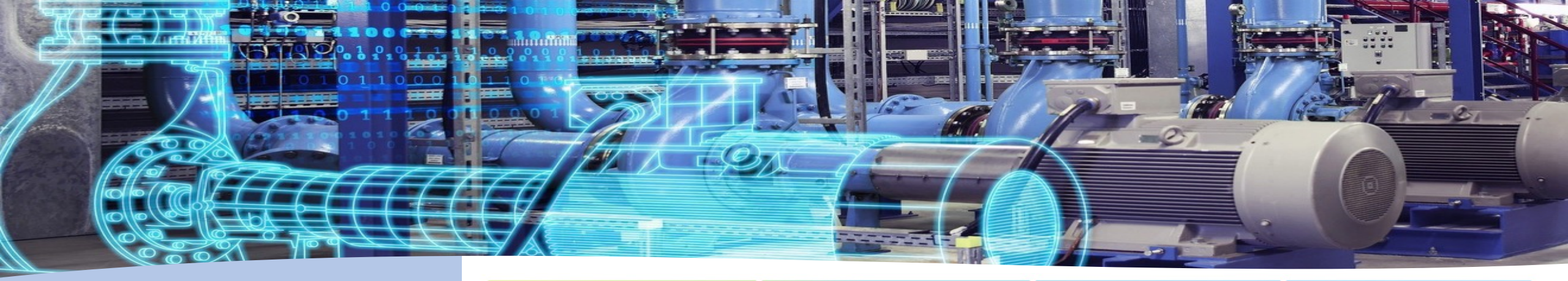
## Features & Services



# About DT

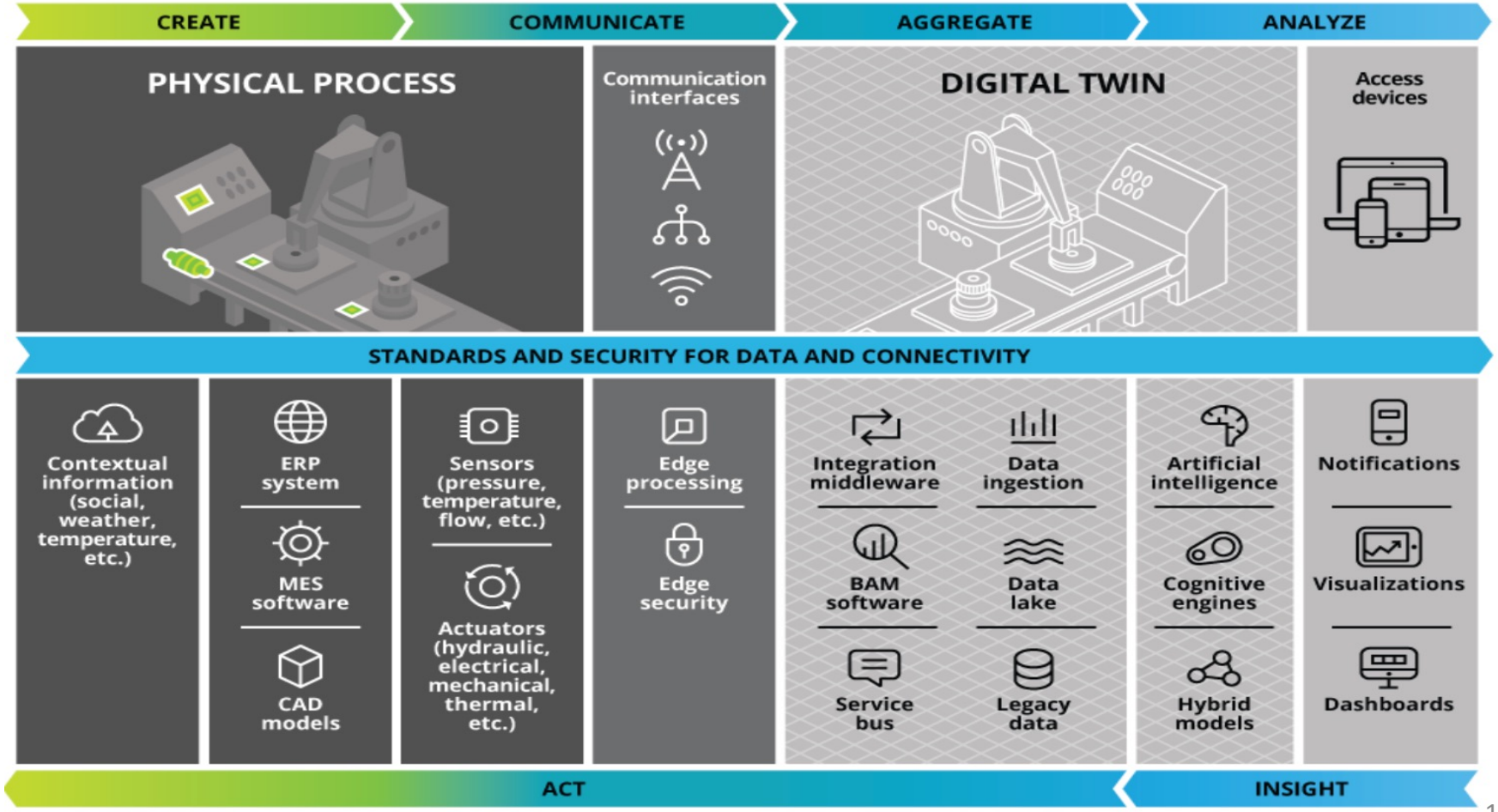
## Beyond the concept

- Logical Architecture
  - DT as a single entity or an ecosystems of interconnected DTs (compositional approach)
- IT Architecture
  - the Cloud is the standard for DT (i.e., the DT is supposed to run in the Cloud)
  - Sensors -> Edge Computing -> Cloud -> Big Data solutions -> AI-based services
  - DT as a Service (REST/GraphQL API)
- Solutions exist
  - proprietary: General Electric, Microsoft Azure, Siemens, PTC, …
  - open-source: Eclipse Foundation Hono (sensors connectivity) & Ditto (API, sponsor=Bosch)
  - ready to run your DT in the Cloud or deploy a private Cloud like infrastructure on premises?
- so, what's beyond the buzz word?
  - digital convergence platform, digital ecosystem
  - even more buzz words…



# About DT

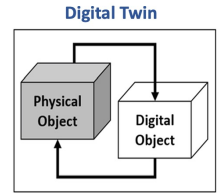
## The Industry 4.0 approach



# Mapping DT concepts to light sources

## The Control System (CS) as the foundations of a DT

- our control systems are already implementing part of the DT concepts
- sensors connectivity + edge computing → CS agent (e.g., a Device instance in Tango)
- DT as a service → yet another CS agent
- middleware for DTs interconnection → CS native protocols
  - bidirectional data flow is just a question of reads & writes on CS agents
  - e.g., slow feedbacks are soft real-time optimizations mapping the DT model
- storage for time-series
  - e.g., TimescaleDB at the ESRF
- infrastructures for advanced analytics and models training
  - HPC clusters with GPUs



# Mapping DT concepts to light sources

## So, what is missing to switch from CS to DT?

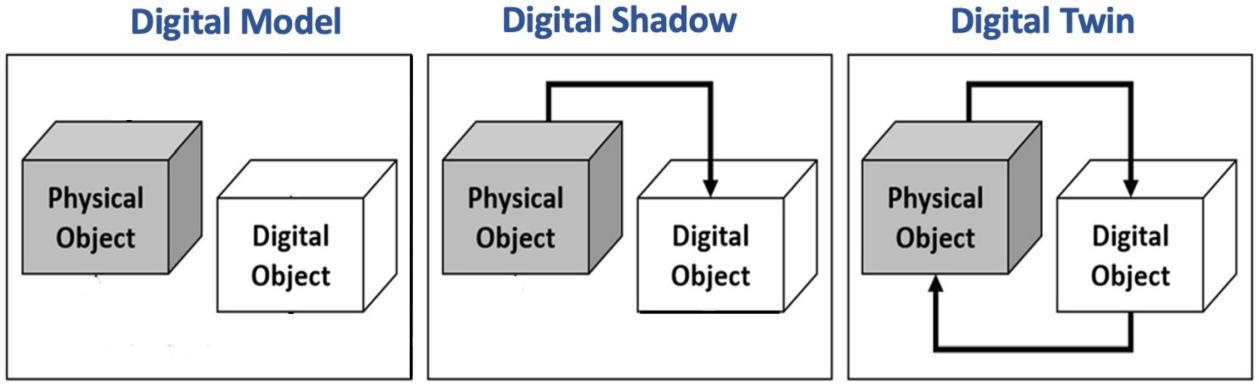
- isn’t it just a question of integrating AI-based smart services into the CS?
- predictive maintenance
  - easy, use supervised learning (ML and/or DL)
    - proper dataset? not so easy…
    - moreover, predicts the past, doesn’t generalize very well to unknown situations
  - consider unsupervised approaches
    - The grail, expertise required
- smart operation
  - AI-based feedbacks
    - just feedbacks making use of AI (nothing to do with DT, so what?)
    - many potential uses cases for reinforcement learning
    - see recent “READS” paper from Fermilab (embedded AI platform for feedbacks)
  - Other use cases
    - smart monitoring, AI-assisted decision-making, …

# Mapping DT concepts to light sources

## Beyond Extended Control System acting as a Digital Twin?

Other potential use-cases for light sources

- online and offline virtual environments
- contextualized simulation & testing: **online Digital Shadow**
- advanced simulation/replay/dev. env./training: **offline Digital Model**



# Mapping DT concepts to light sources

## One word about Physics-based Simulation vs Data-driven Models

- Physics-based model always more accurate than data-driven models…
  - based of laws of nature => no bias
- Data-driven model can capture uncertainty or unmodeled dynamics
  - AI-augmented simulation (improved overall model accuracy)
  - limit: as accurate as the dataset it learned from (doesn't generalize)
- Deep learning excels at complex (highly nonlinear) and/or high dimensional problems
  - blackbox, adapted where no time/no need/no way to fully understand the physics
- Other AI added-value in simulation context
  - deep learning applied to Reduced-Order Models (ROMs): simplified models for faster computation
  - data augmentation: GAN model to generate synthetic data similar to physical data
  - fast simulation: inference time of a trained model << computation of its physics-based equivalent
- Physics-based simulation and Data-driven Models complement each other
- **AI can help to achieve Light Source End-to-End simulations**

# Conclusion

## Takeaways

- Digital Twin(ning) is mainly an inspiring concept
- Requires a pragmatic transposition to light sources
- The control system can act as the foundations of a DT
- AI ubiquity for smart operation and maintenance
- Online & offline simulation also required

# Conclusion

## DT for a Light Source

AI-augmented Operation & Simulation

This workshop is the beginning of a long journey

# Thanks!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# Enjoy this Workshop!