Use of Artificial Intelligence and Digital Twins in Building Energy Modeling

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Agenda

- Building and Energy Industry Trends
- Use of Simulation in Buildings and Energy Industry
- Use of AI/ML and Simulation in Buildings and Energy Industry
- Use of Digital Twins in Buildings and Energy Industry

Energy Transition Requires Demand Side and Supply Side Action

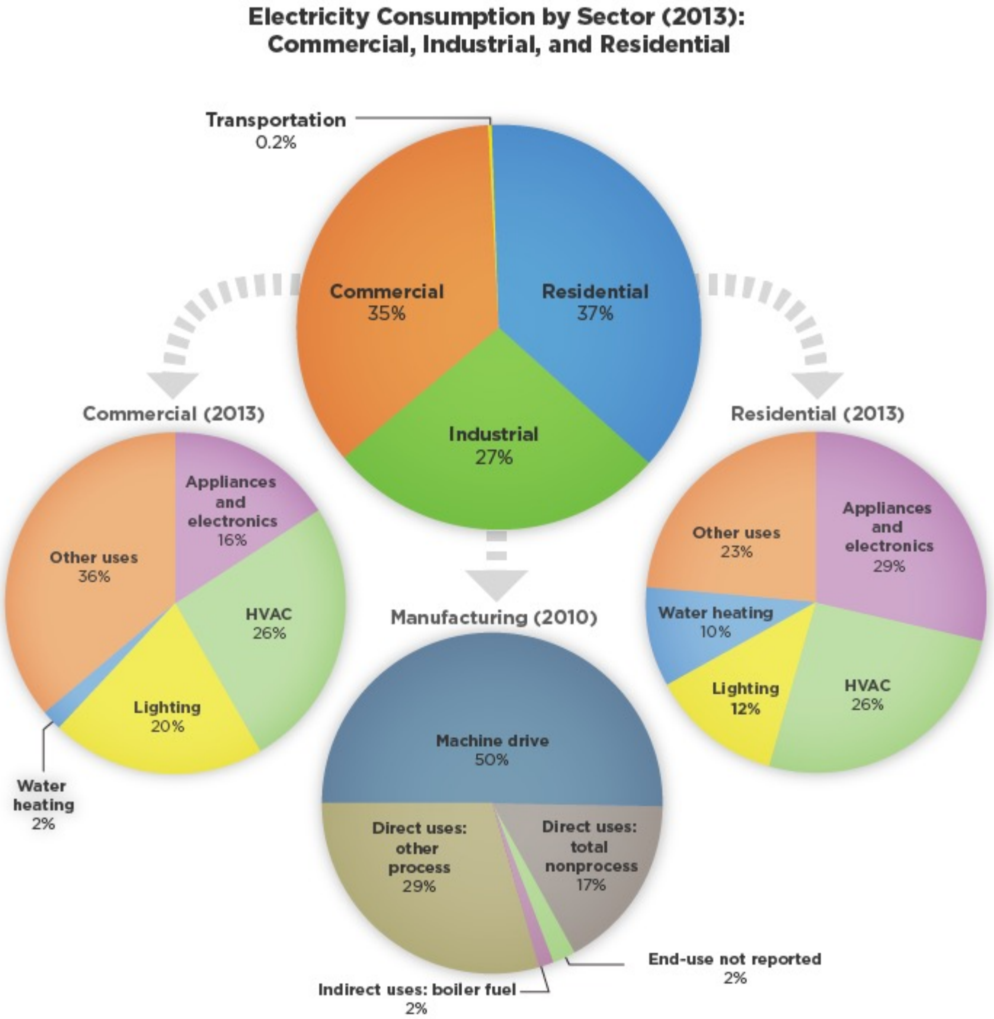
SUPPLY SIDE

- Move away from fossil fuels to renewables
- Wind, solar, hydrogen, fuel cells, microgrids
- Carbon capture

DEMAND SIDE

- More efficient usage; US has energy efficiency of 42%; 58% of energy is wasted

- More efficient energy consumption in HVAC, lighting, appliances



Future of Energy and Buildings

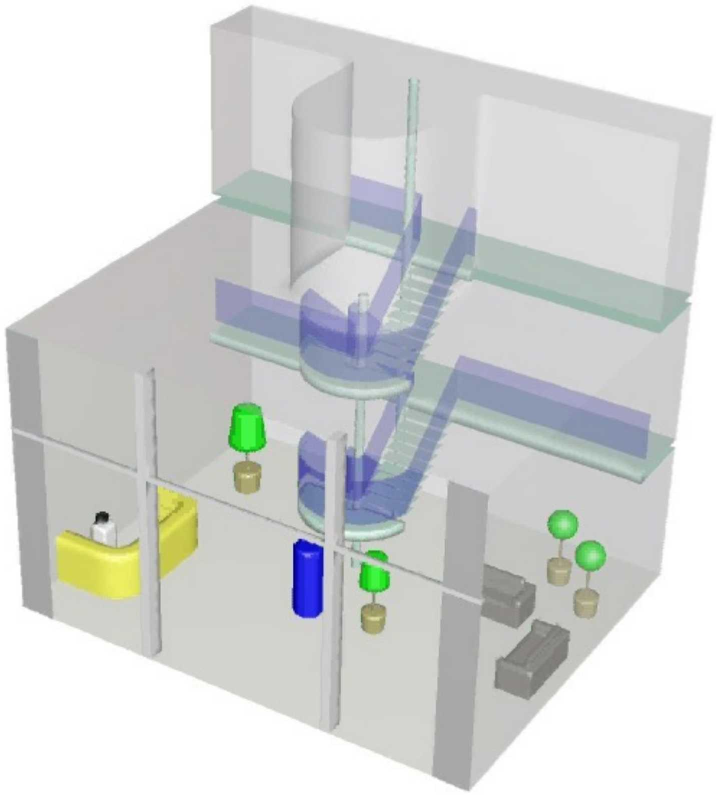
Virtual Building

If

- A building could be modeled with a great accuracy
- Origin of the event reproduced
- Transient fire and smoke behavior described in a reliable way
- Structural behavior of the building predicted with accuracy

Then

- Different scenarios could be studied
- Best solutions identified
- Buildings designed to resist extreme situations better



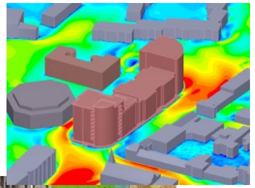
Fire at the front desk of ANSYS UK in Sheffield. Smoke dispersion

➔ Engineering Simulations

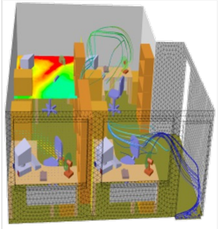
Simulation Driven Building Design

- Designing new, innovative buildings raises numerous challenges

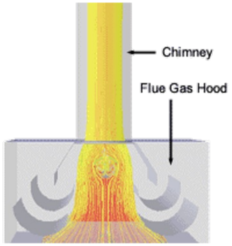
  - Selection and location of safety equipment
  - Behavior under extreme conditions
  - Stress and fatigue of parts
  - Environmental impact
  - Material selection
  - Sustainability
  - Stability



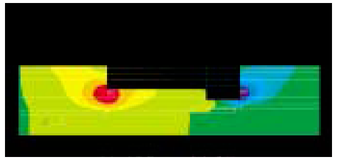
External aerodynamics



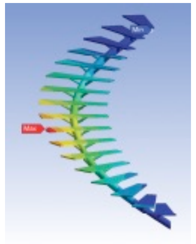
Ventilation



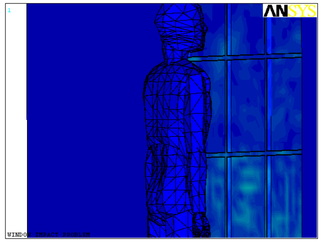
Domestic burner design



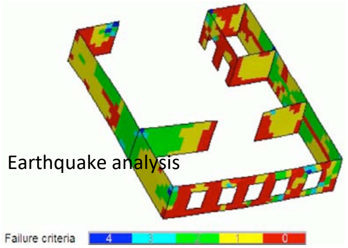
Soil mechanism modeling



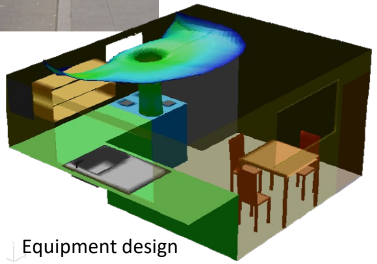
Modeling of structure



Impact of objects on window



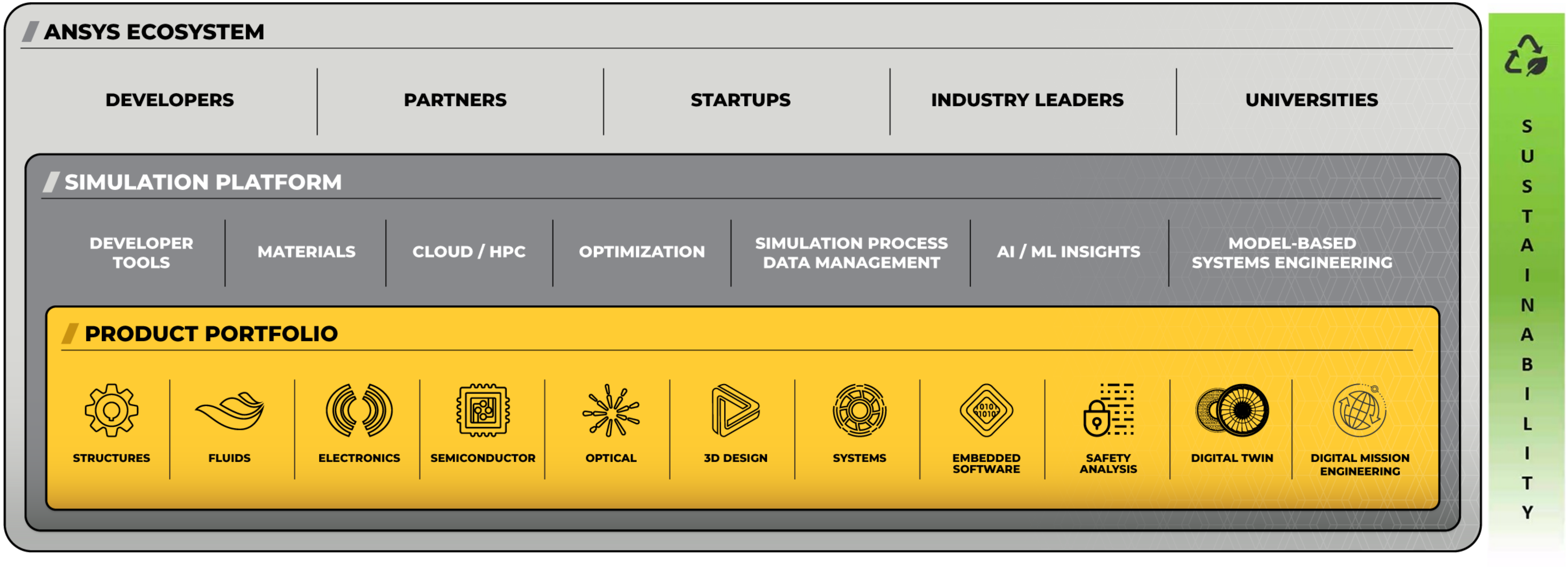
Earthquake analysis



Equipment design

Depth and Breadth of Ansys Simulation Portfolio

Unique design of the Ansys product portfolio, platform, and ecosystem fits our customer's development processes



Ansys Simulation Solutions Across Industry Verticals

High-tech & Semiconductor

Bespoke silicon, semiconductor & manufacturing, intelligent connectivity

Automotive & Transportation

Electro-mobility, software defined vehicles, ADAS/autonomy, Vehicle development

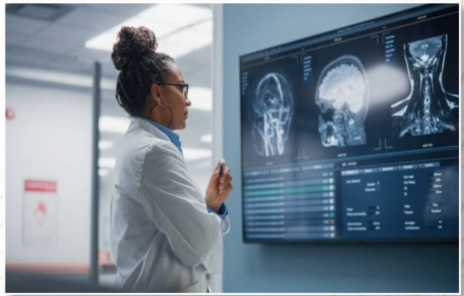
Aerospace & Defense

Digital engineering, autonomous systems, safety reliability & cybersecurity, spectrum operations, propulsion systems

Energy & Industrials & Buildings

Efficiency improvements, improving reliability & affordability, scaling & maturing low carbon solutions, accelerate all w/digital transformation

Healthcare



Digitization of healthcare, democratization of simulation, digital evidence for regulatory

SUSTAINABILITY: Clean Environment, Materials and Circularity, Energy Systems, Operational Efficiency

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Ansys Energy Focused Pillars - Delivering Industry Solutions

1

Efficiency Improvements

- Fuel production
  - Upstream
  - Midstream
  - Downstream
- Energy conversion
  - Electricity
  - Heat
  - Motion
- Operational efficiencies, assets & processes health

2

Improving Reliability & Affordability

- Safe energy production/transmission
- Energy storage solutions
- Integrated energy systems
- Life & performance prediction
- Grid resilience security, stability
- GHG leak mitigation
- Electrification
- New Energy Infrastructure

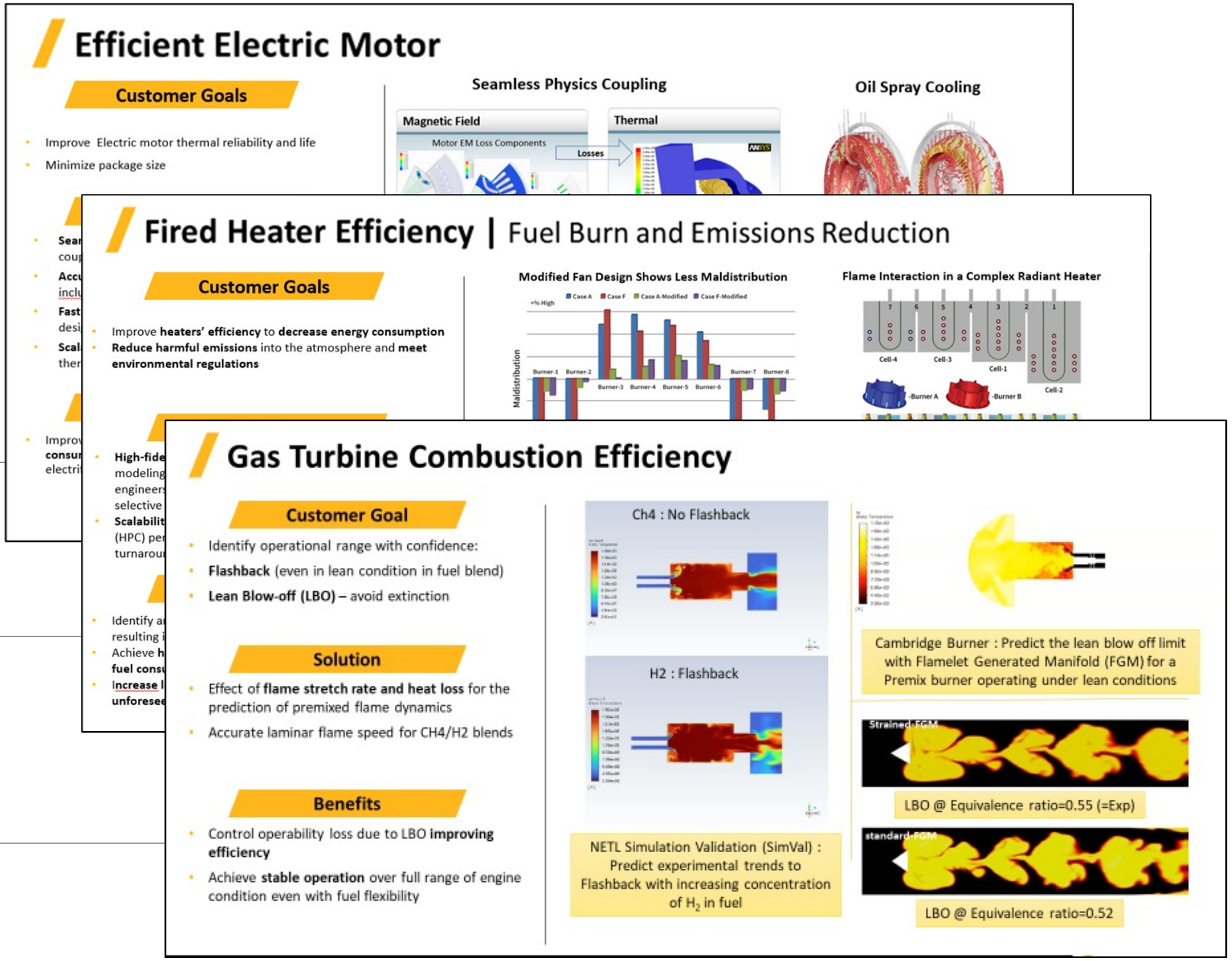
3

Scaling & Maturing Low Carbon Solutions

- Renewable energy
- Nuclear energy
  - Fusion
  - Fission
- Hydrogen value chain
- Offshore wind
- Carbon capture/storage
- Material circularity

Digital engineering will accelerate all three pillars and drive maturity scaling for new low-carbon tech.

1 Efficiency Improvements



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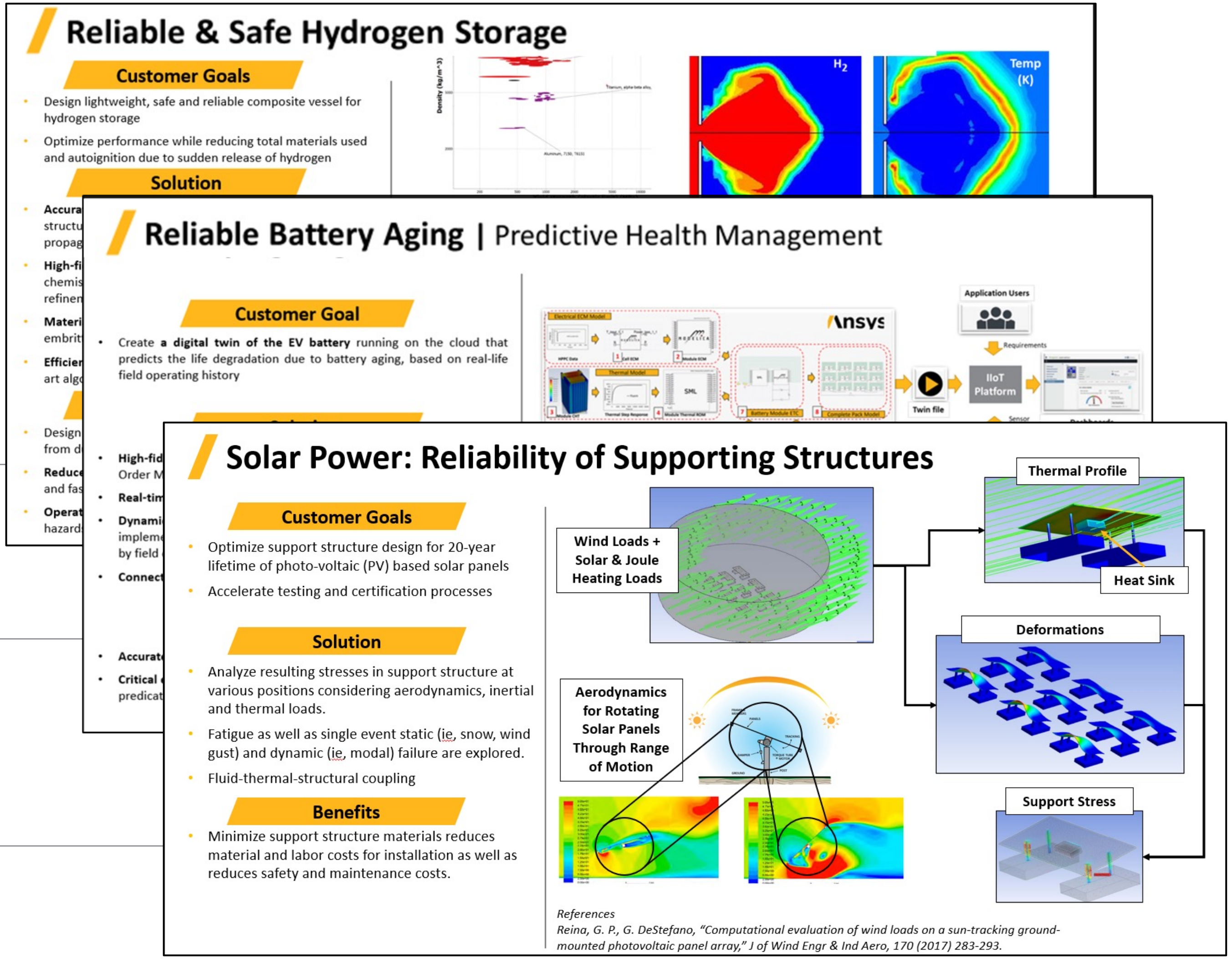
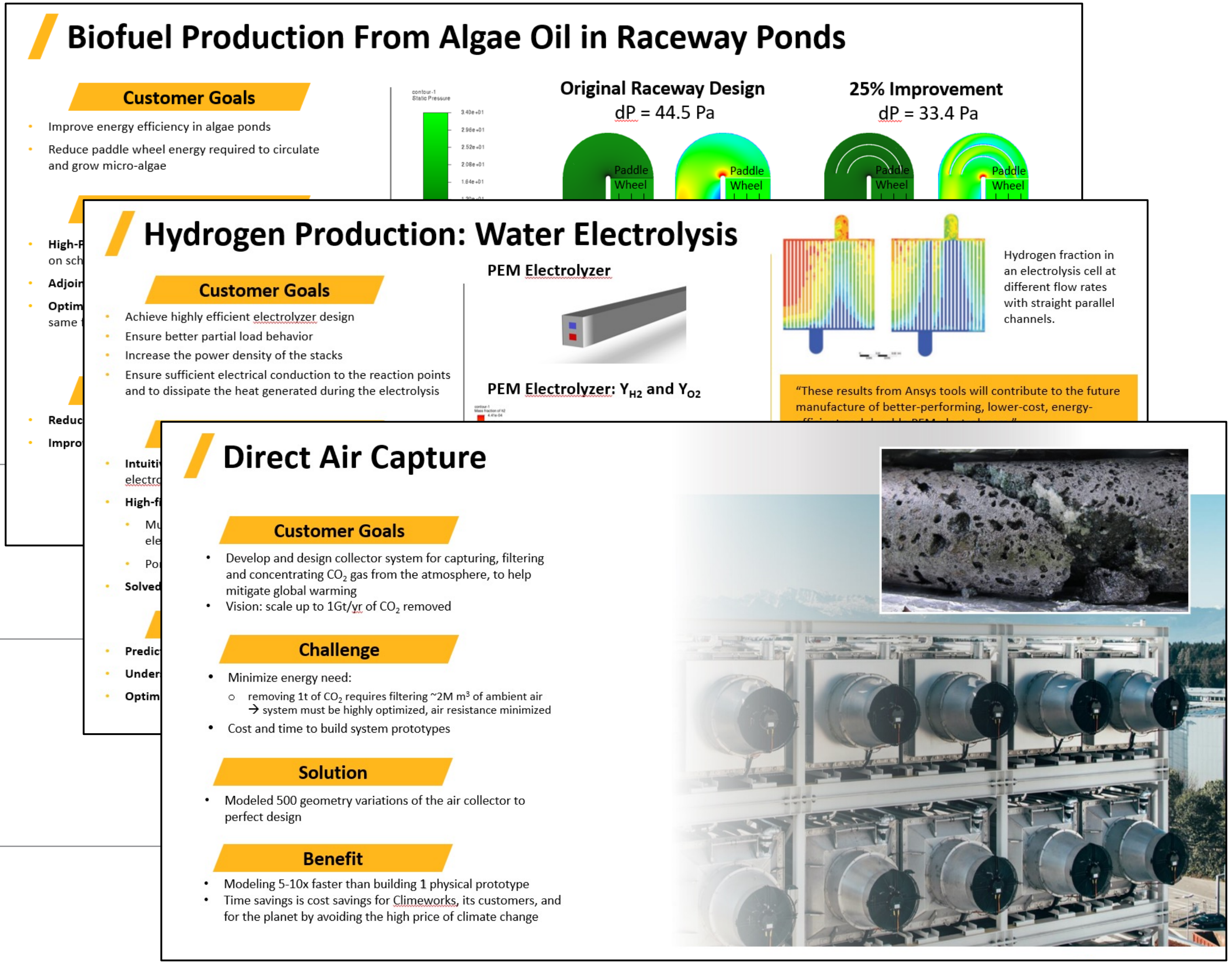
2 Improving Reliability & Affordability



3 Scaling & Maturing Low Carbon Solutions



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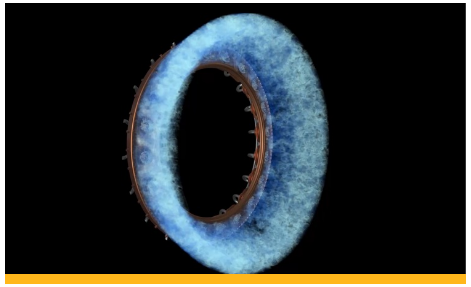
Simulation Technology Strategy Pillars

Core Physics Numerical Methods and Models



- Solver methods
- Geometry and meshing
- Shape and topology optimization
- Advanced analysis
- Multi-physics
- Multi-scale

High-Performance Computing

- Shared-memory
- Message-passing
- Fine-grained GPUs
- New architectures: FPGAs & AI hardware
- Quantum computing

Artificial Intelligence and Machine Learning

- Solver acceleration
- Solver settings
- Top-down methods
- Bottom-up methods
- Reduced order models
- Generative AI

Cloud, Platform, and User Experience

- Cloud Enabled
- Cloud Native
- Platform, Collaboration
- Open APIs and developer ecosystem
- Common user experience

Digital Engineering

- Model Based System Eng.
- Requirements & architecture Connections
- Safety, security, & software
- Digital twins
- Simulation process & data management
- Mission engineering

Building new pillars of technology on more than 50 years of innovation …

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AI/Machine Learning

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AI/ML Approaches to Simulation: *Solver Acceleration and Solver Settings*

Bottom-Up Methods

Organic ML Initiatives

- ML-based fast high-fidelity solvers
- ML-enabled enhancements
  - Starter meshing
  - Sub-modeling
  - User-Experience
  - Solution steering / settings
- ML-services across physics
  - C++ based deployment model

Top-Down Methods

Fast, Accurate, Predictive

- Design Optimization
  - Performance
  - Operation
- Model Calibration
  - MIL-SIL integration
- Virtual Validation
  - Digital certification
- Lifecycle Exploration
  - Digital Twins

Reduced Order Models

ROMs, Twins, Cloud

- 0-3D Reduced Order Models
- Multi-Fidelity models
  - Physics + Data
- Digital Twins
  - Analytical, Data-driven, Hybrid
- Feature extractions from data
- API and UX for ecosystems
  - Partner, customer solutions
  - Cloud services
  - Autonomy and Swarms

Generative AI

Large Language Models

- Generative design and optimizations
- Make solvers easier to use
  - Setup-tuning, AI-Bots:
- Improve customer interactions
  - Virtual agents
  - AnsysGPT

Top-Down: AI/ML Using optiSLang + Ansys Solvers

- **AI/ML integrated in optiSLang PIDO toolbox and workflows**
  - MOP (Metamodel of Optimal Prognosis): Workflow for automatic detection and training of best possible metamodel out of large range of surrogate models including
  - AI/ML (Neural Network) integrated into metamodel competition = auto ML
  - AMOP (Adaptive Metamodel of Optimal Prognosis): Framework for automatic refinement

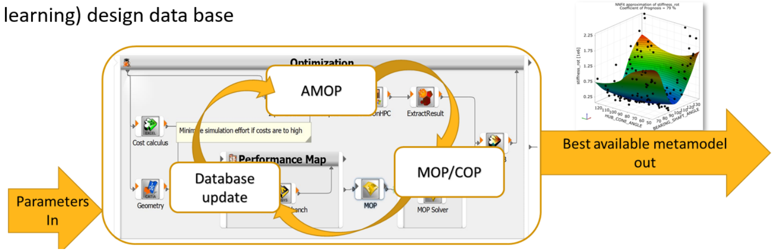
→ Automatic generation of best metamodel training and verification regarding forecast quality of response variation

→ Based on the most efficient (self learning) design data base

→ Simulation Platform physics and vendor independent

→ After Simulation workflow setup democratize as App

→ Enables EVERYBODY to use it



Thermal MetaModeling – optiSLang + Icepak

Package Material Level

As-is process/Challenges

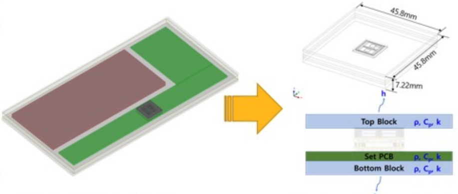
- Sensitivity analysis of thermal material properties of mobile AP
- Fast and Accurate equivalent virtual thermal testing model → Simple Model
- Trial & Error approach for fine tuning material → Expensive!
- Too many trials (1000+) need to be performed for 10+ parameters
- Challenges:
  - Significant manual effort for 1000+ trials
  - Accurate simple model for transient thermal analysis
  - Reduced Dependency on package type

Ansys Value Stream

- Robust workflow integration and optimization with optiSLang-AEDT Icepak
- Reduced input BC conditions and material properties (h,K,CP and Den)
- Sensitivity analysis with thermal material parameter of components.

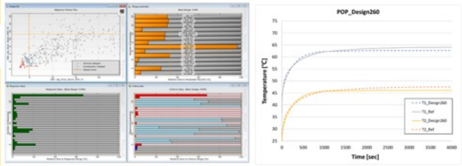
Outcome

- Extract optimized equivalent properties of Simple model that is well matched with reference data
- Automatic DOE reduction to reduce the overall time for optimization.
- Reduced time for optimization and increased accuracy
  - 2~4 Weeks → 4~5 Days



Full set model of smartphone

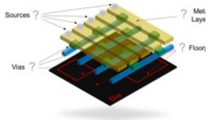
Simple model with equivalent thermal material property

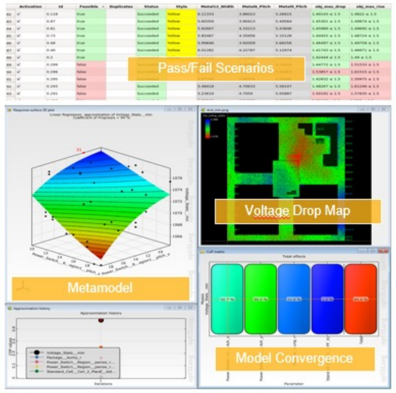


"Thermal Model Simplification of Mobile Device with Adaptive Metalmodel of Optimal Prognosis (AMOP)", V. Krishna, et al., iTherm, 2022

Power Integrity MetaModeling – optiSLang + RHSC

SoC Level





/OptiSLang Power Integrity Parameters Analytics

1 **/Seascape** - Elastic Computing & Database
PDNs prototype generation (Python based), Analysis & Metrics Storage

2 **/RHSC** - Power Integrity Solvers to generate hierarchical CPMs
Voltage Drop, Electro Migration, Effective Resistance

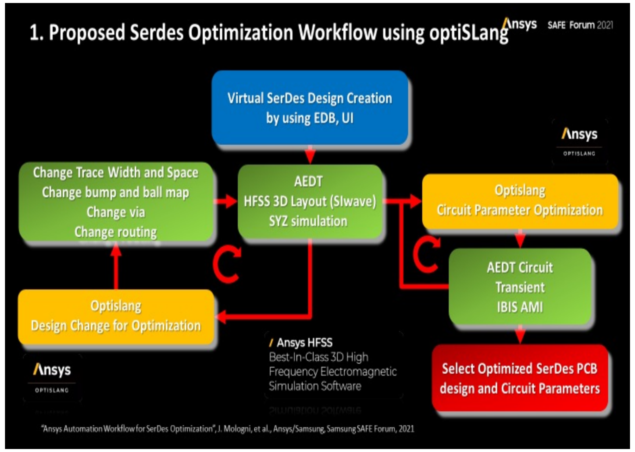
3 **/optiSLang** - Parameters generation & Sensitivity Analysis
MetaModel, Pre-processing of parameters, Post-processing of Simulations

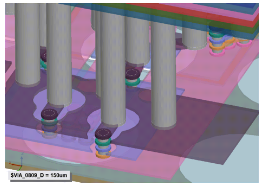
Proof of Concept

- **Design Case:** 5nm, 80mm2 design, 3 big Macros, 10M Instances
- **PDN:** 12 Metal Layers and Constant power distribution
- **Variables:** Metal6 & Metal9 pitch, Metal12 width, PowerSwitches
- **Criteria:** Static Voltage Drop
- **Metamodel:** Analytics of **958** PDN scenarios (total runtime: **1Hour**)

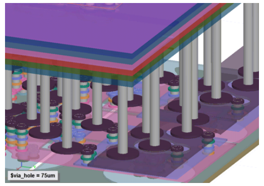
SoC Power Delivery Networks Exploration & Analytics

EMag MetaModeling – optiSLang + HFSS + AEDT Circuit Simulation

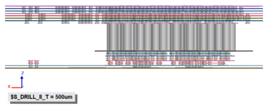




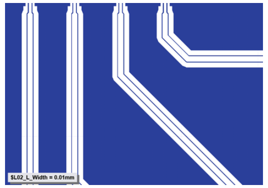
Via pad



Drill size



Stack-up thickness



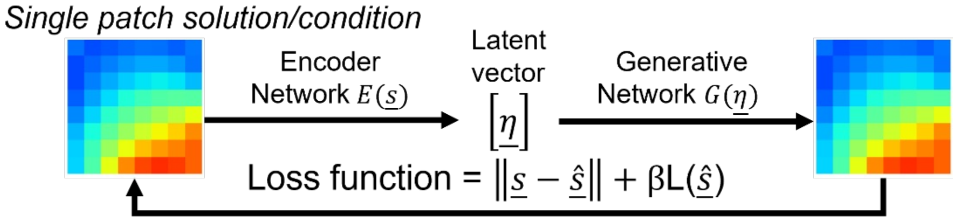
Trace width

Bottom Up: ML-based Fluids Solver

Motivation:
- Geometries and physics have lots of patterns!
- Do we need to solve from scratch?

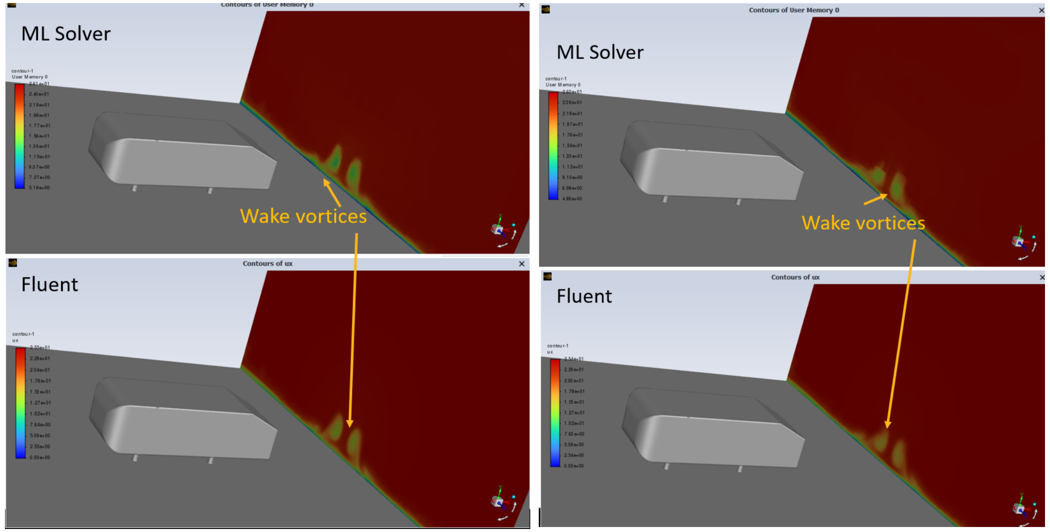
Key insights:
- Learn lower dimensional representation (η) of solutions on subdomains
- Learn how these patches connect in η space
- Deploy trained networks to solve on entire domains iteratively

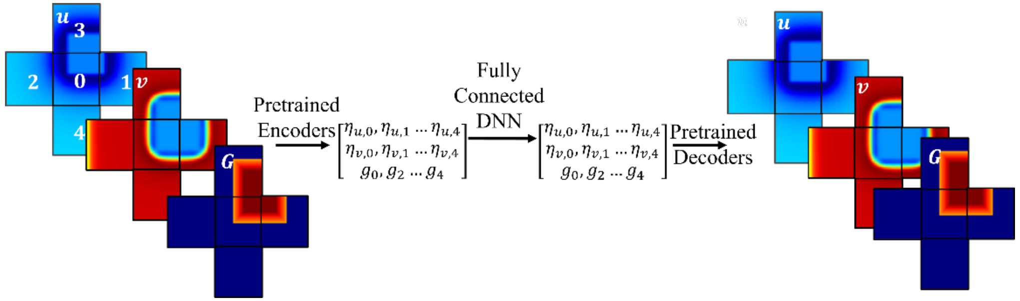
What is new
- Faster solve (100X speedup)
- Lower memory footprint (1/1000 of Fluent)



Learn lower dimensional (η) of solutions on subdomains

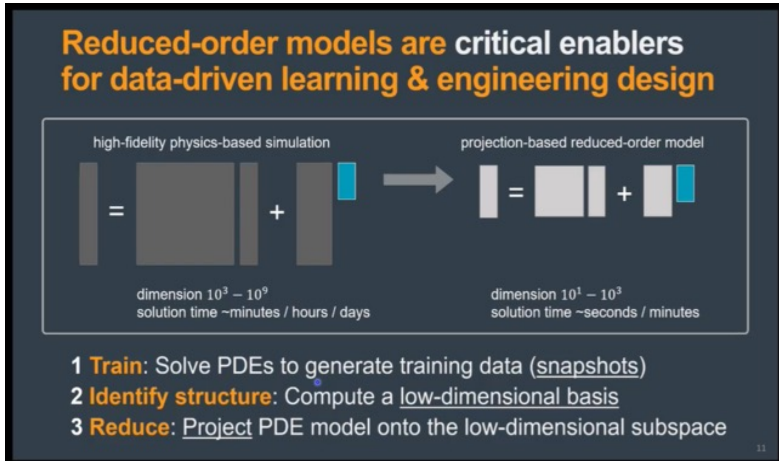
ML Solver: Ahmed Body Improved U-Velocity Profiles





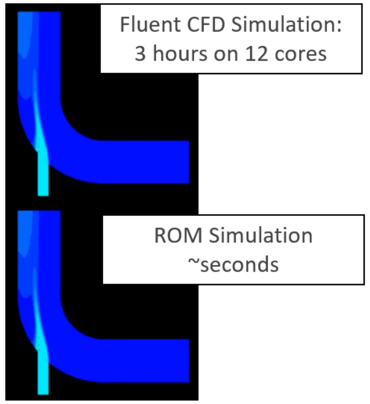
Learn how these patches connect in η space.

Reduced Order Models (ROM)



ROMs are compact, auto-generated representations of full-3D models that are useful for control design/validation

- ROMs are usually compute and license intensive to create but fast once built
- ROMs have well-defined inputs and outputs (electrical ports, parameters, etc)
- ROMs match the steady-state and/or dynamic responses of the original model, within specified tolerance
- Benefits
  - Reuse: Easily and automatically generate accurate & validated component models
  - Process Compression: Simulate accurate models in 1/10th to 1/100th of the time
  - System Verification and Optimization: Perform rapid design optimization and tradeoff analysis at system level



INCREASED PHYSICS USAGE

ROM Type	Training Data Generation		ROM Extraction		Consumption Format	Ease of Use	Complexity
	Type of Data Required	Source Tools	ROM Technique	Tools			
Response Surface	Parameter Sweep/DoE	All/Any	Lookup table + interpolation	OSL, MC, TB	FMU for Scalars, Twin for Fields	Integrated end-to-end workflow	No states/steady-state only
LTI/LPV/State-space ROMs	Response to step inputs	Mech, CFD and EM	State-space Model with Interpolation	TB, Fluent	FMU for Scalars, Twin for Fields	Mostly integrated. Manual transfers.	Linear or weakly non-linear and stateful
DynaROM	Response to various input waveforms	All/Any	Nonlinear ODE	TB	FMU for Scalars, Twin for Fields	Experience needed to generate training	Non-linear and stateful

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Digital Twins

What is a Digital Twin?

Past, Present, Future, Simulate!

digital twin CONSORTIUM : "Virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity"

Track the past, provide deeper insights into the present, predict and influence future behavior

25% average margin for aftermarket services compared to **10 %** for new equipment

Increase Revenue

costs high as **$800M** per year – an amount equal to as much as **3%** of productive revenues

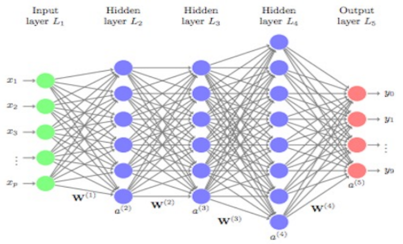
Reduce Costs

1.65B industrial assets under condition monitoring by 2025

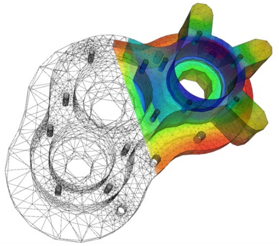
Gain Competitive Edge

Sources:
1. "Industrial aftermarket services: Growing the core.", McKinsey.com
2. "Controlling Warranty Costs by Preventing No Fault Found", WIKA Group
3..Total addressable market (TAM) and compound annual growth rate (CAGR) information throughout presentation is based on third party study completed by Evaluserve Inc. in 2019 commissioned by ANSYS. Study was based on customer and industry expert interviews and review of industry analyst reports and commentaries. Refer to Cautionary Statement for a discussion of factors that could impact future financial results.

Digital Twin Challenge: Accuracy, Time & Cost



Data-Driven Modeling

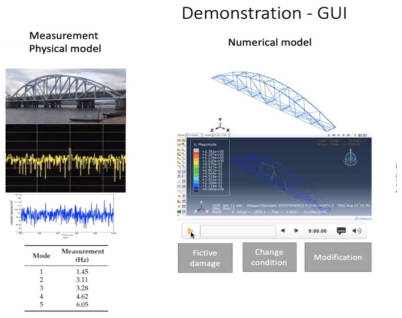


Model Development

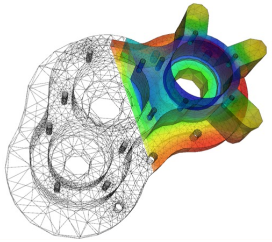
Design & simulation information not readily available / usable

Large volumes of process data required for training

Insufficient accuracy, limited by observed data



Simulation-Based Modeling



Model Development

Difficult to accurately model the as-operated performance of equipment

Lacking ability to incorporate available data into models

Long, expensive time scales to develop & deploy

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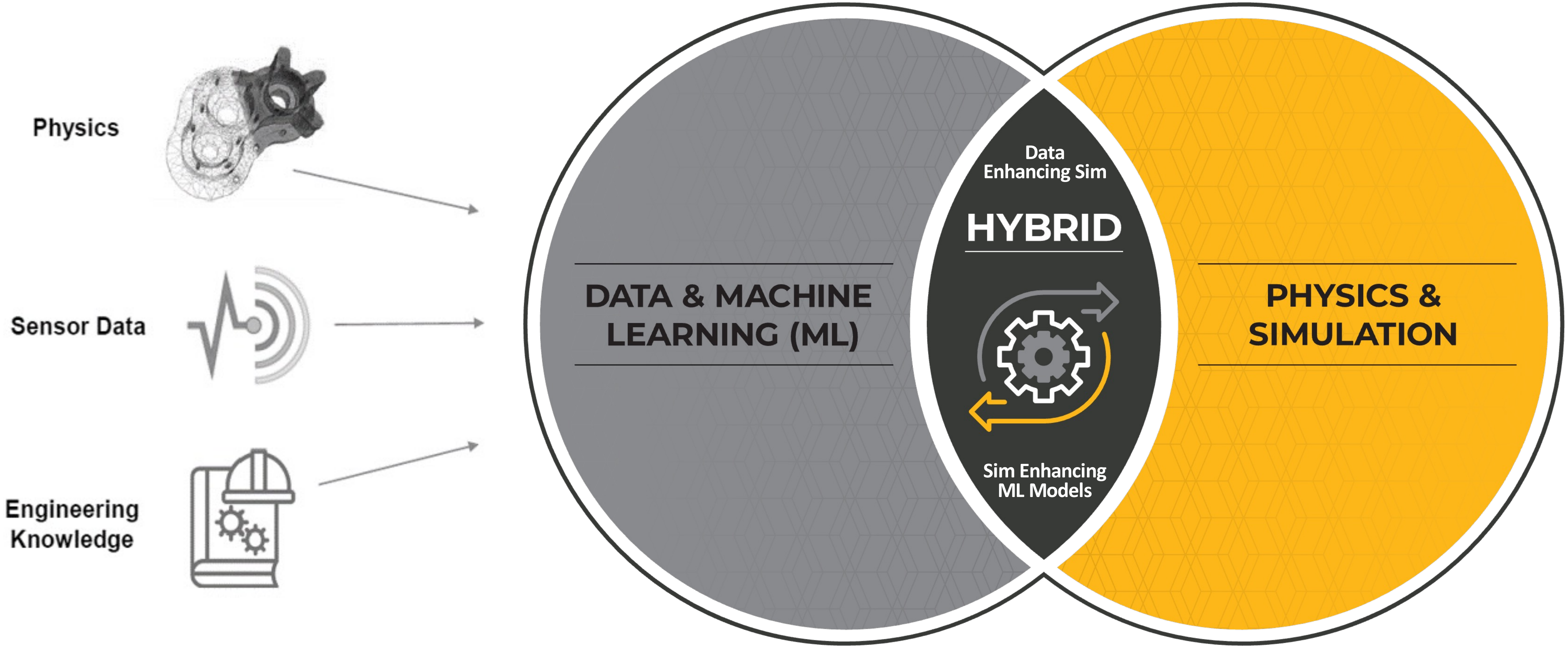
Hybrid Digital Twins: Combining simulation and data



Hybrid Analytics combines data and physics to build Hybrid Digital Twins

Elements of the Digital Twin ecosystem

Simulation-Based and Hybrid Analytics — Ansys

Data-Based Analytics

IoT/Edge Platform

Assets and Infrastructure

Open Ecosystems and Key Announced Partners

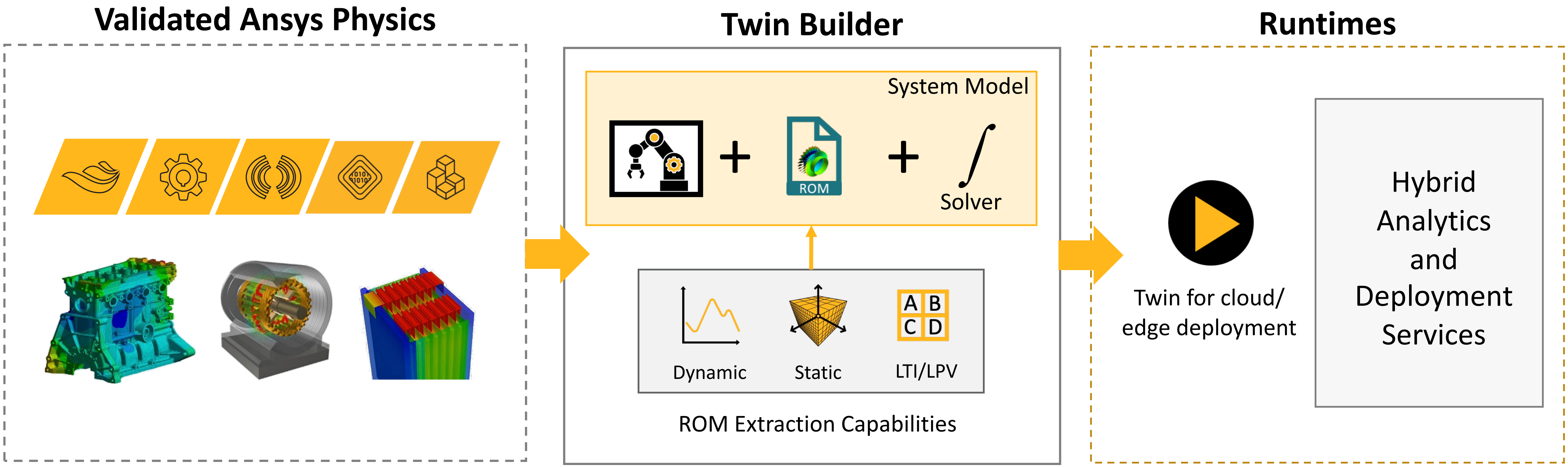
Microsoft, aws, Rockwell Automation, ptc

Customers are putting simulation at the center of their Digital Twin implementations

Simulation-Based & Hybrid Analytics

- Create virtual sensors to "measure" missing data
- Perform what-ifs before applying a solution
- Analyze accurate and deterministic predictions based on physical principles
- Explore causality and failure modes using physics

Our solution architecture fits seamlessly into our customers' stack



1. Best in class Reduced Order Modeling capabilities → Reuse
2. Hybrid Calibration → Accurate, evolving models
3. Unique runtime model and open architecture → Scalability

Rockwell Automation · aws · ptc

Digital Twin Partners

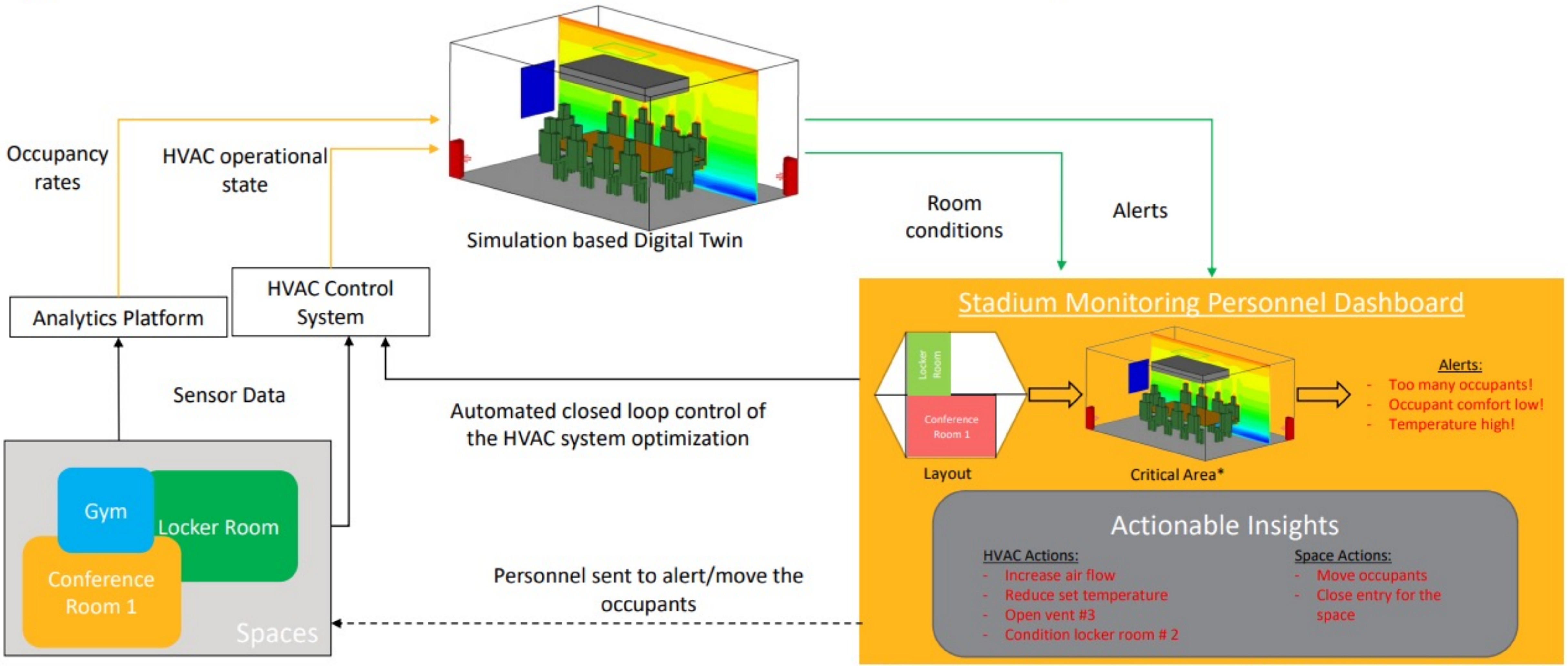
Typical use cases for Digital Twins

Virtual Commissioning and System Configuration

Predictive and Prescriptive Maintenance

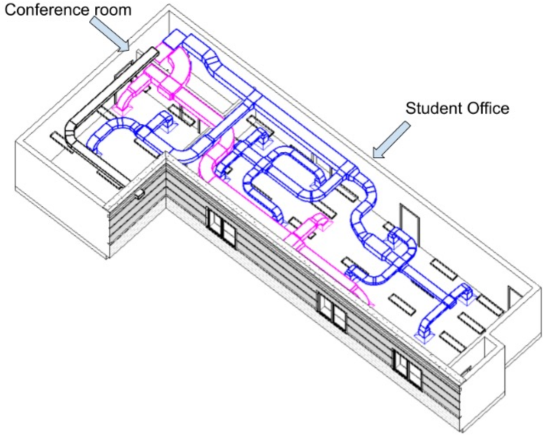
Production Optimization

Optimizing HVAC | Stadium Application with a Real Time Digital Twin

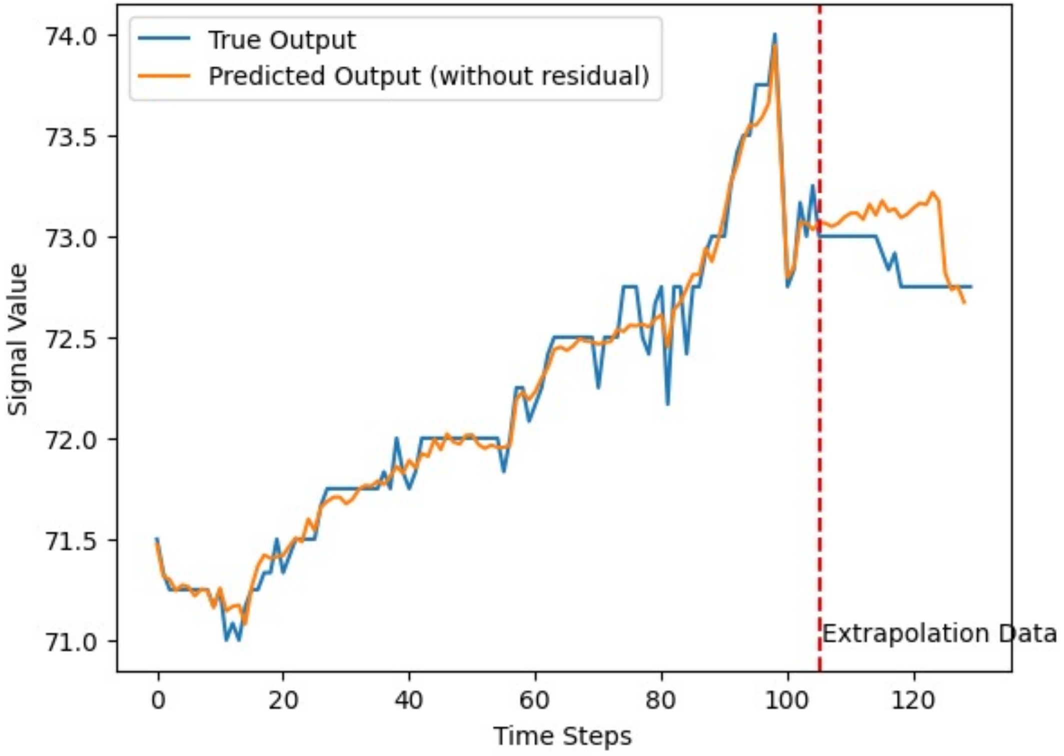


* - visualization will not be a part of .twin, however the data for viz will be provided by the twin

CMU Porter Hall HVAC Digital Twin



Training	Test	Extrapolation	RMSE (test)	RMSE (extrapolation)
1x83x7	1x22x7	1x25x7	0.11	0.24



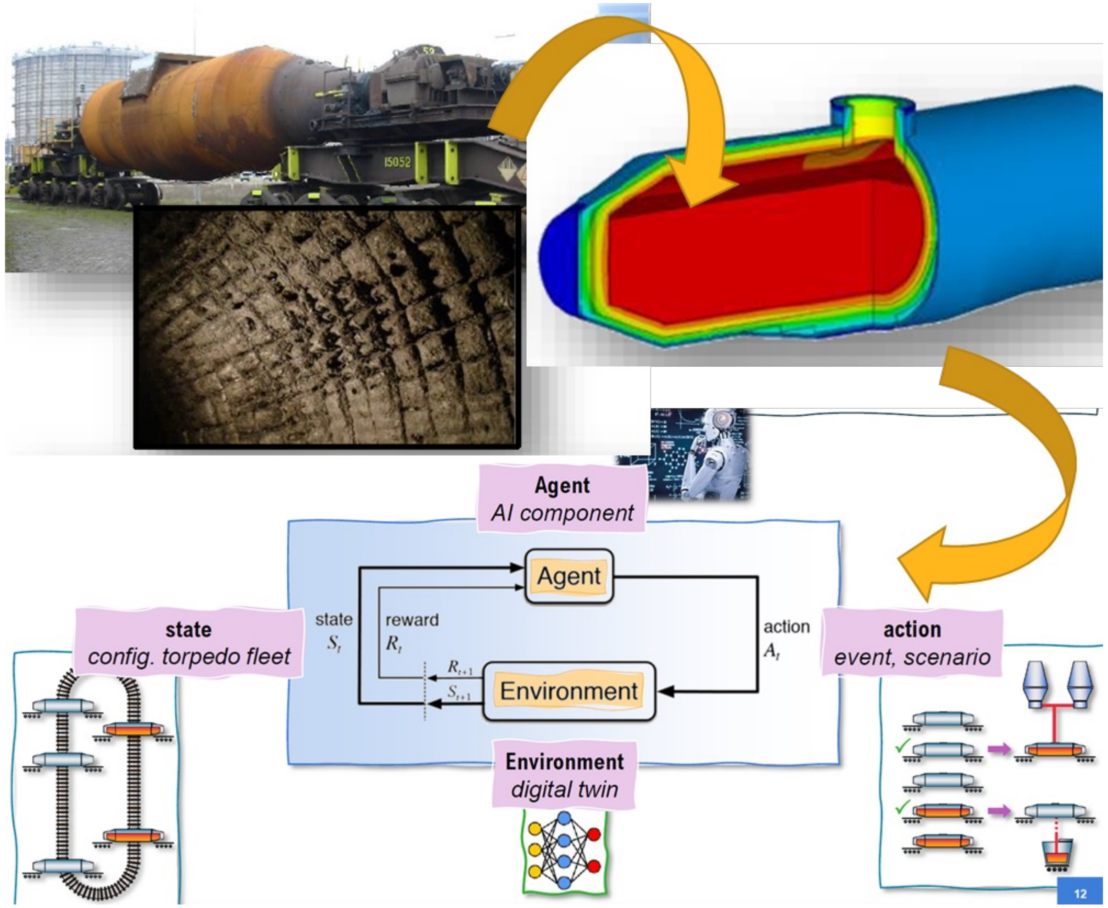
Component	Content	Method
Physical Space	Porter Hall office rooms & HVAC systems	/
Digital Space	Information model	Building information model (Revit model)
	Simulation model	Co-simulation model (Modelica & CFD model in Ansys Twin Builder)
		Hybrid Analytics model (Python-based ML model in Ansys Twin Deployer)

Energy efficiency optimization of iron & steelmaking by digitalization of thermal process management

Challenge: Torpedo refractory maintenance costs exceeded by several M€. Higher hot metal temperatures help with yield losses and CO2 emissions but lead to higher wear of insulation of torpedo car linings and higher energy usage.

Solution: A comprehensive (thermal) digital twin for the entire hot metal (HM) production route. AI based controls to optimize for refractory wear rate.

Result: Savings of ~M€ due to improved maintenance. Additionally, can optimize number of ladles and torpedo cars in use with respect to temperature and select best possible refractory lining



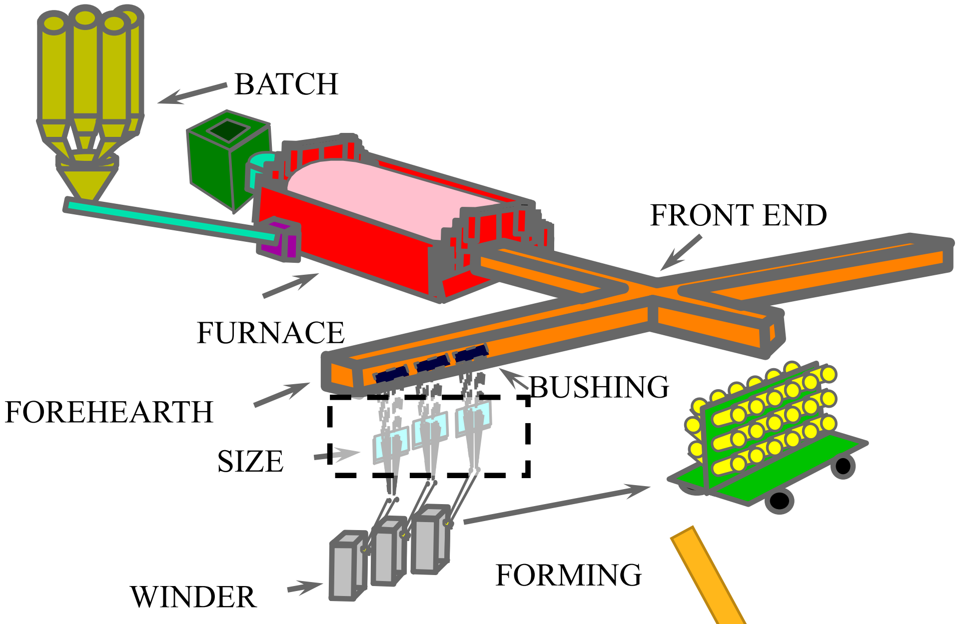
https://www.ansys.com/webinars/how-digital-twin-is-a-game-changer-for-tata-steel-nederland-to-achieve-their-targets

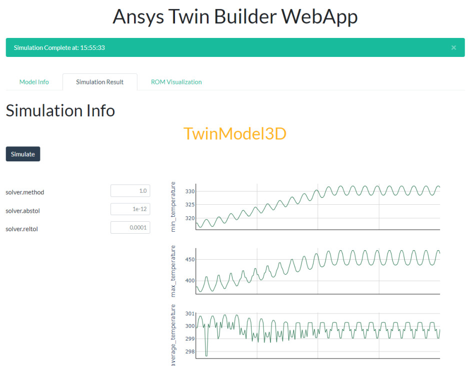
Improving production at global glass manufacturer

Challenge: For glass fiber manufacturing, consistent temperature (within 2-3 degrees at temperatures in excess of 1400C) in the glass flow path is vital to the quality of the output product. Positioning sensors along the entire flow path is infeasible.

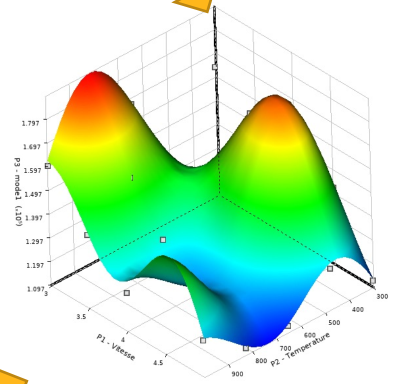
Solution: A reduced order model based digital twin to predict the entire temperature flow field of the forehearth. The reduced order model was created based on available non-linear CFD model and predicts temperatures

Results: Digital twin is deployed on the customer's asset, giving alerts to operators when temperatures are out of bounds. Twin runs in < 5 s, well under the budget allowed for the model execution. Real-time product optimization based on the temperature virtual sensor output in the pilot stage





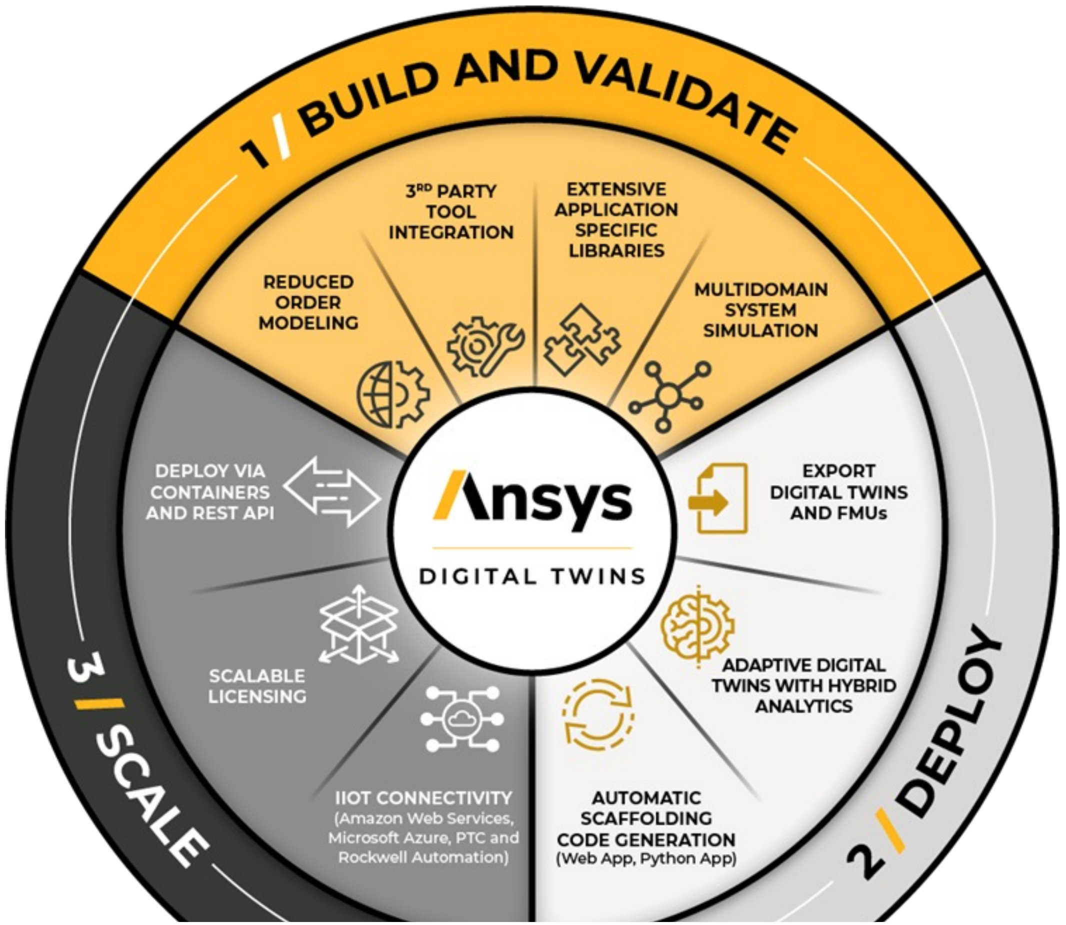
Operator Dashboard



Field ROM

Summary

- Simulation is at the center of virtual prototyping
  - Moving from hardware prototyping and testing to software prototyping and validation and verification
- Simulation allows our customers to grow top-line revenue and bottom-line savings
  - Rapid innovation, lower cycle time, lower risks, increase quality, manage complexity
- Ansys provides the broadest and deepest simulation platform in the industry with the leading physics solvers
- We discussed the latest technology trends for simulation including AI/ML, HPC, Cloud and Digital Twins
- Ansys has a robust Hybrid Digital Twin solution that combines the benefits of physics-based simulation with data-based ML techniques to create accurate, evolving representations of real-world assets.



Let's work together and capitalize on tools that can assist you in your ultimate goals and objectives faster.

Summary

- Building and Energy industry face increasing pressures:
  - Cost, time, safety, comfort, environment
- Virtual Building Design offers an attractive alternative
  - Validate proposed designs against regulations
  - Optimize buildings to maximize occupant safety and minimize operating / maintenance cost
  - Communicate and illustrate benefit to protagonists
- Simulation is at the center of virtual prototyping
  - Moving from hardware prototyping and testing to software prototyping and validation and verification
- Simulation allows our customers to grow top-line revenue and bottom-line savings
  - Rapid innovation, lower cycle time, lower risks, increase quality, manage complexity
- Ansys provides the broadest and deepest simulation platform in the industry with the leading physics solvers
- Ansys has a robust Hybrid Digital Twin solution that combines the benefits of physics-based simulation with data-based ML techniques to create accurate, evolving representations of real-world assets
- Simulation is key to Digital Twin implementations, providing critical capabilities such as virtual sensors, what-if analysis and causality and failure mode analysis
- Ansys has demonstrated successful deployment of Digital Twins via several real-world use cases

Ansys