Sensors Converge

# Accelerating Sensor Development with Digital Twins

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# Melding The Physical & Digital

**Simulating Excellence Through The Integration of Physics & Data, Digital Prototyping/Twinning**

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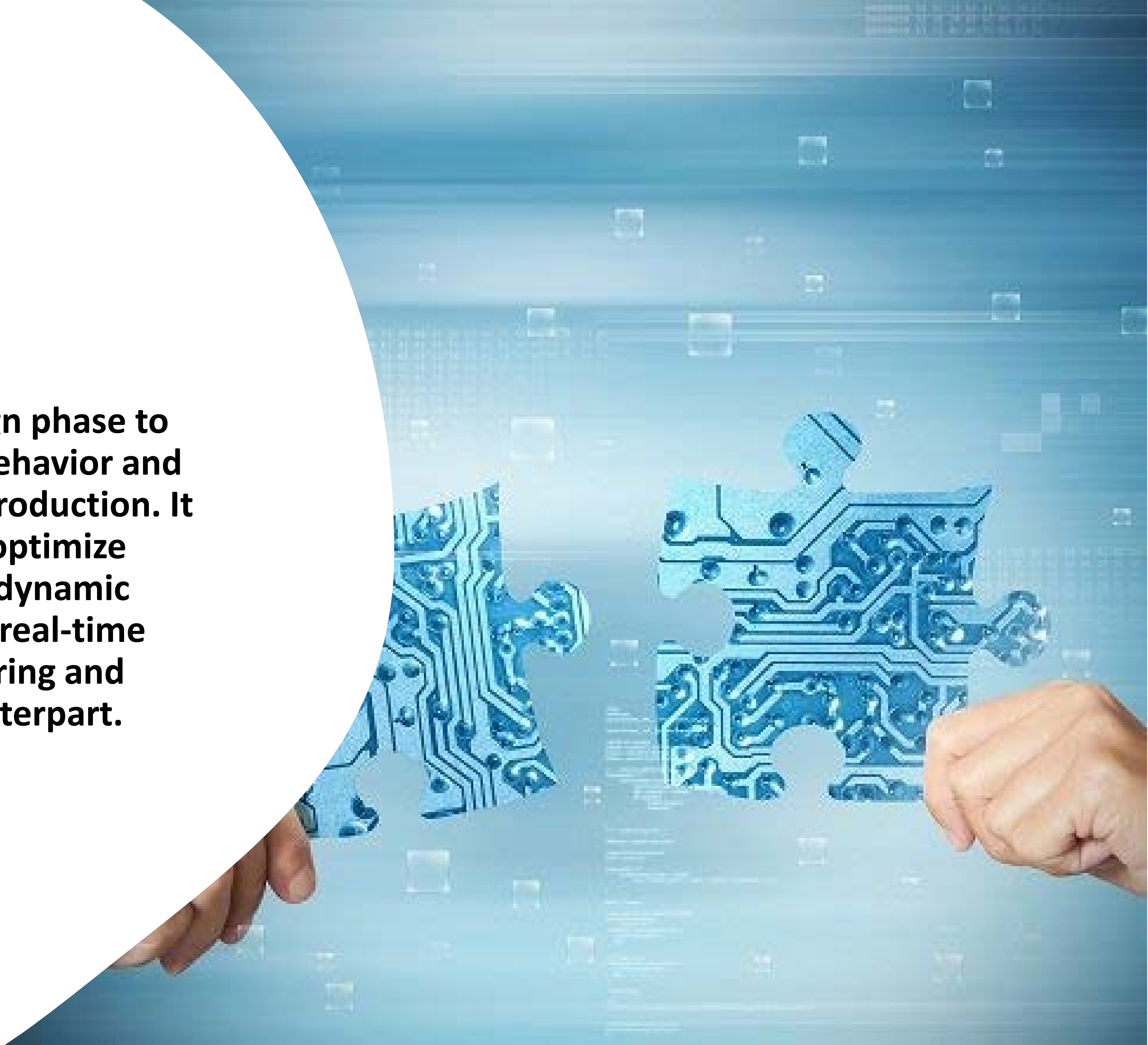
- A digital prototype is a virtual representation used in the design phase to simulate and validate product behavior and characteristics before physical production. It helps identify design flaws and optimize performance. A digital twin is a dynamic virtual replica that incorporates real-time data, enabling real-time monitoring and optimization of its physical counterpart.



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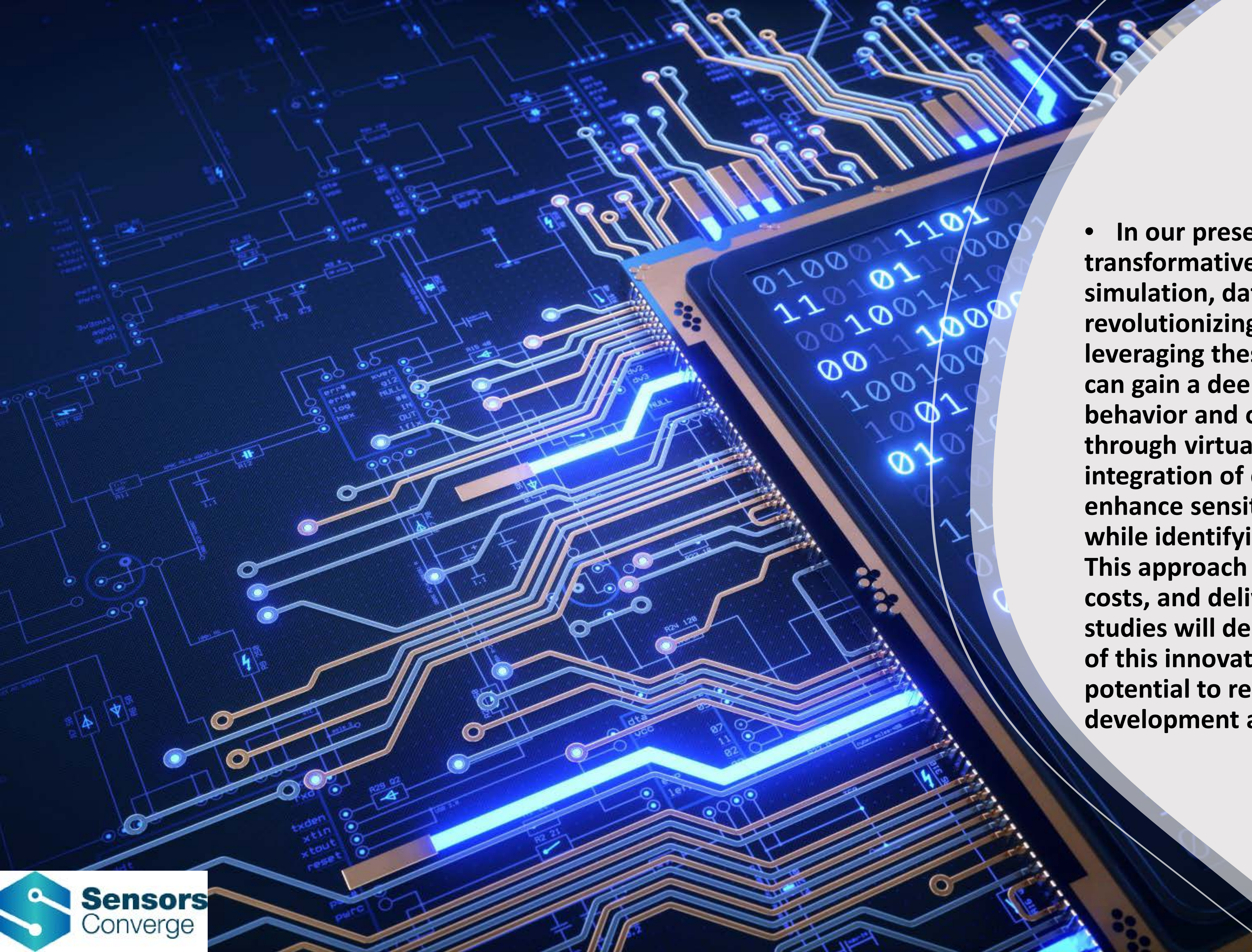

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- In our presentation, we will showcase the transformative potential of high-fidelity simulation, data fusion, and digital twinning in revolutionizing sensor development. By leveraging these cutting-edge technologies, we can gain a deeper understanding of sensor behavior and optimize their performance through virtual replicas. Through the integration of data fusion techniques, we can enhance sensitivity, accuracy, and calibration while identifying optimal sensor placement. This approach accelerates iterations, reduces costs, and delivers feasible solutions. Our case studies will demonstrate the tangible benefits of this innovative approach, highlighting its potential to reshape the landscape of sensor development and calibration.

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Leveraging digital twin technology, data-driven physics-based simulation, and data fusion techniques we can address:

## Industry Challenges:

### 1. Performance Optimization:

Current Challenge: Achieving reliable long-range communication while operating on low power.

Current Approach: Iterative testing and optimization based on empirical data and limited simulation.

### 2. Power Consumption and Battery Life:

Current Challenge: Achieving low-power operation for extended battery life.

Current Approach: Power management techniques, hardware optimization, and limited simulation.

### 3. Sensitivity and Accuracy:

Current Challenge: Ensuring accurate sensing for reliable data collection and analysis.

Current Approach: Calibration techniques, empirical testing, and limited simulation.

### 4. Cost Optimization:

Current Challenge: Developing low-cost sensor solutions without compromising performance.

Current Approach: Component selection, manufacturing optimization, and limited simulation.

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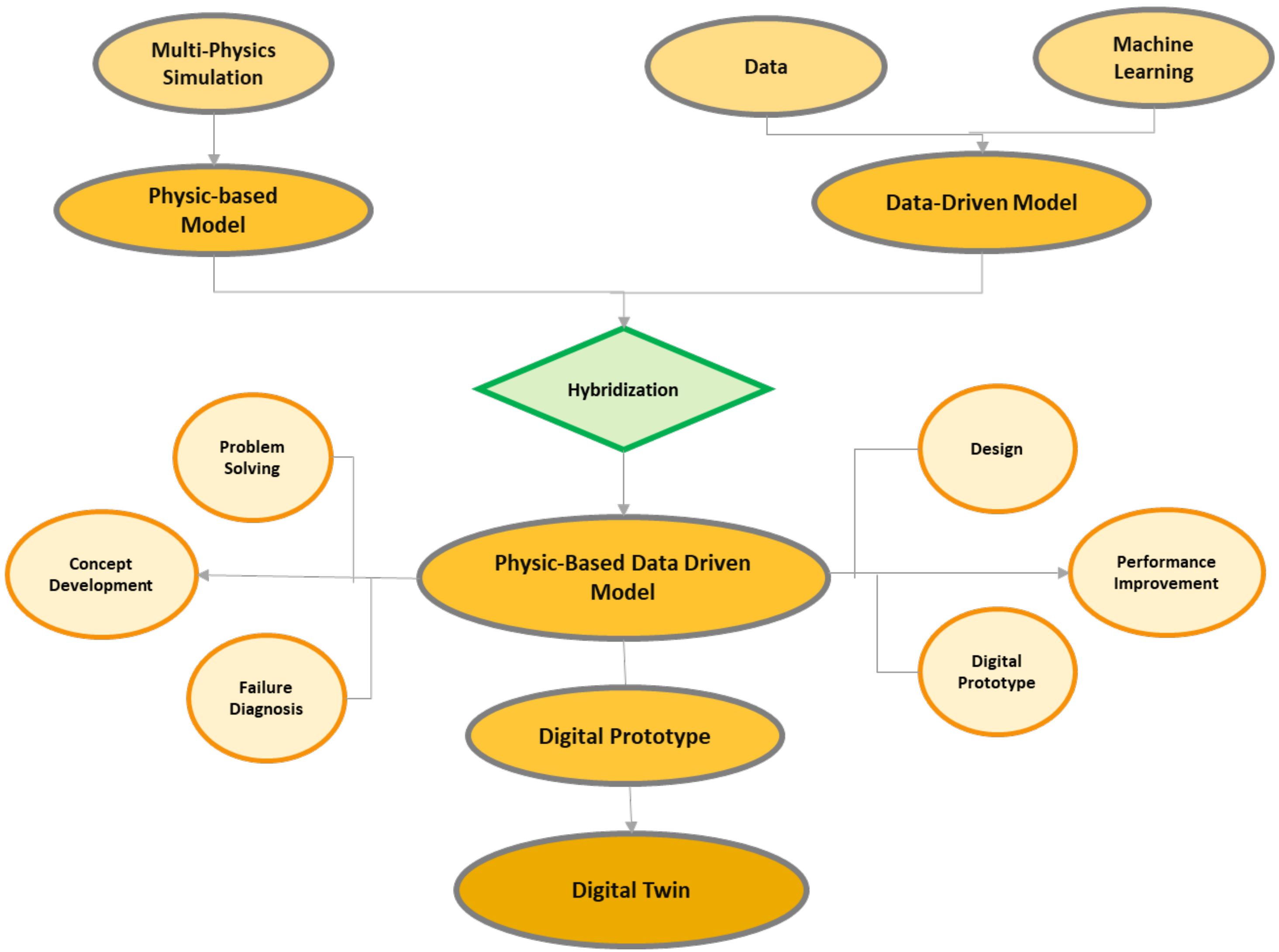
- The Road Map to Digital Twin begins with building the core block of data-driven physics-based simulation, which serves as the foundation for developing a robust digital prototype. By integrating real-time data streams and advanced analytics, we can enhance the prototype's capabilities and evolve it into a comprehensive digital twin, enabling continuous monitoring, analysis, and optimization of the physical system for enhanced performance and informed decision-making.

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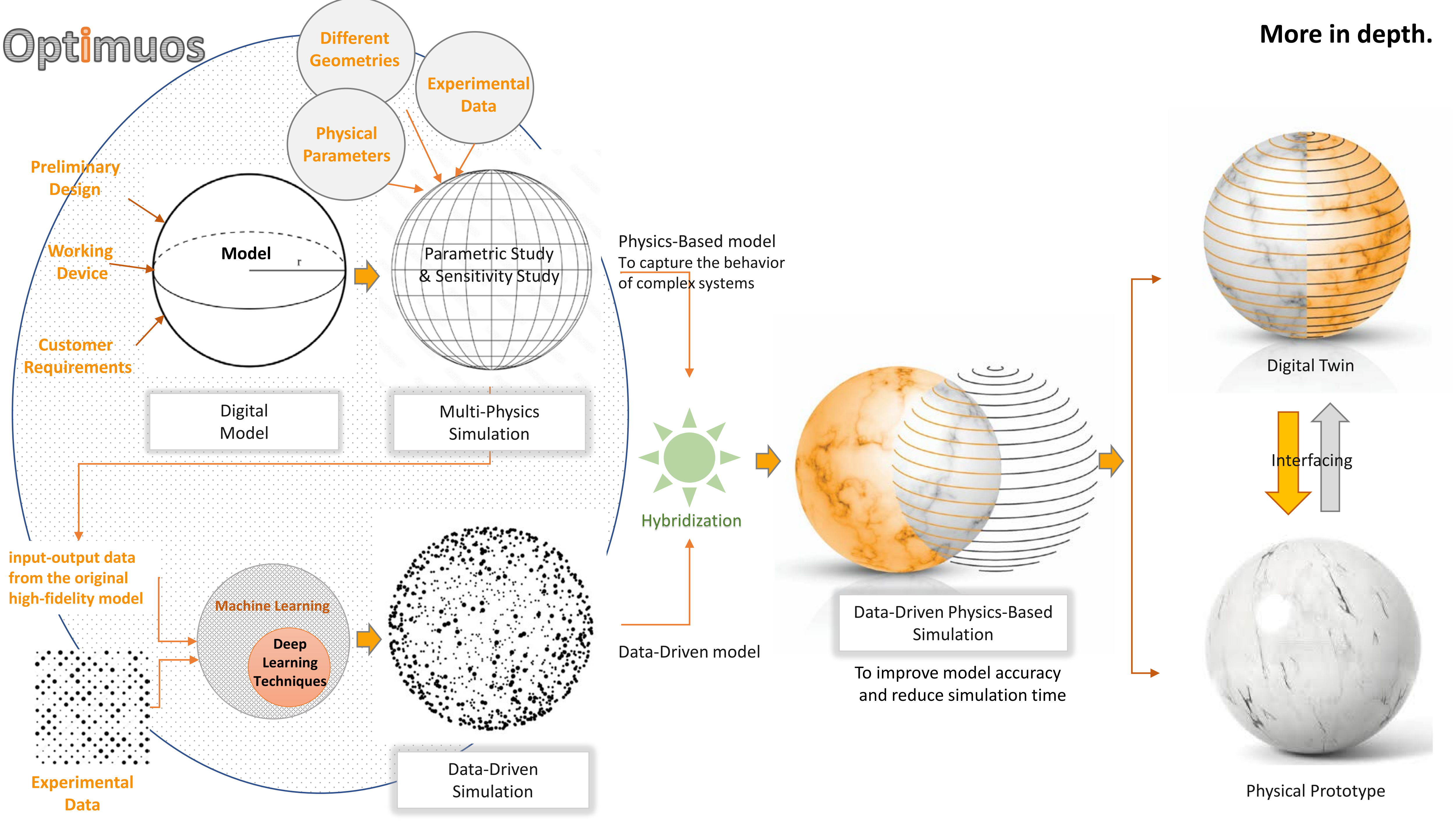
# More in depth.



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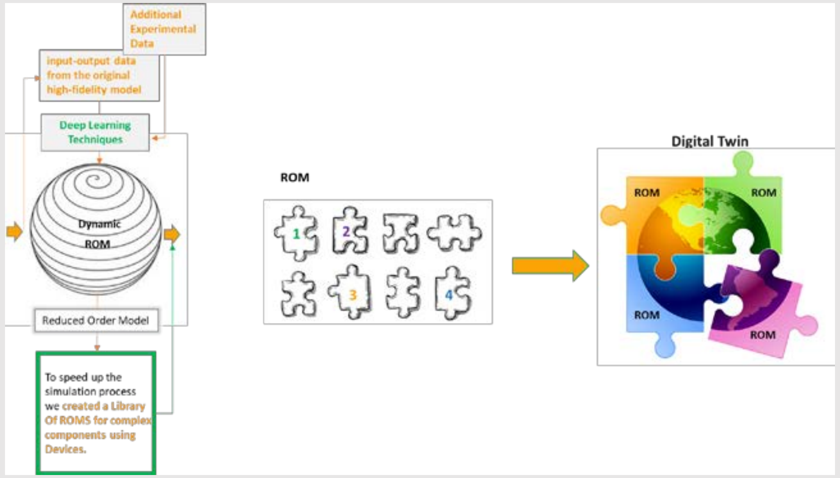
# How to Leverage our method for Design and Optimization

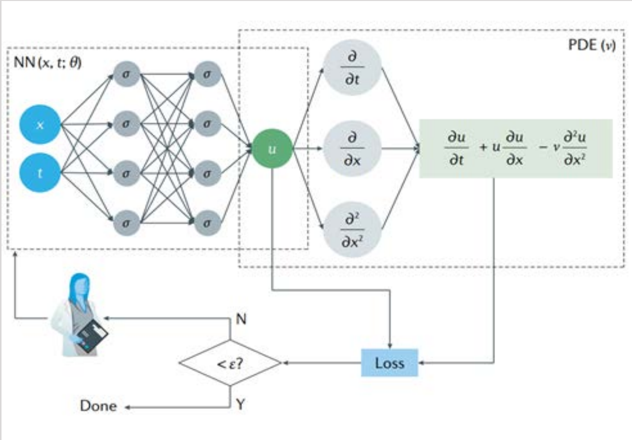
## Multi-Fidelity Physics-Based ROM Construction (MFP-ROM)

- Allows for efficient and accurate modeling of complex systems with large numbers of variables.
- Integrates physics-based simulation and experimental data to create a more accurate and reliable model.
- Enables faster design iterations and optimization of system components and processes.
- Provides a cost-effective alternative to traditional high-fidelity simulations.
- Enables real-time monitoring and control of system behavior.




## Physics-Informed Neural Networks (PINNs)

- To combine noisy data and mathematical models using neural networks.
- PINNs can solve problems that cannot be solved by existing algorithms due to noisy data, complex mesh generation, or high-dimensional problems governed by parameterized PDEs.
- PINNs can solve expensive inverse problems with hidden physics that require different formulations and elaborate computer codes.
- PINNs can design specialized network architectures that automatically satisfy physical invariants for better accuracy, faster training, and improved generalization.
- PINNs have been successfully used to solve Burgers' equation as an example of their capabilities.




## Physics-based modeling

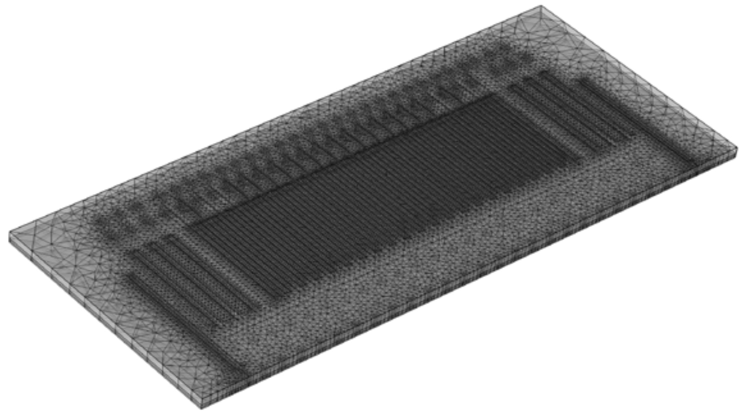
- can be used to develop a digital twin that accurately represents the physical behavior of a system or process in real-time.
- By integrating physics-based models with data-driven models, we can leverage the benefits of both approaches to improve accuracy and reduce uncertainty.
- Physics-based modeling can be used to simulate different scenarios and predict system behavior under various conditions, which can help in decision-making and optimization.
- With a digital twin, we can monitor and analyze system performance in real-time and identify potential issues before they become critical, enabling proactive maintenance and reducing downtime.
- The digital twin can be used to design and test control strategies, allowing for optimization and improvement of system performance.

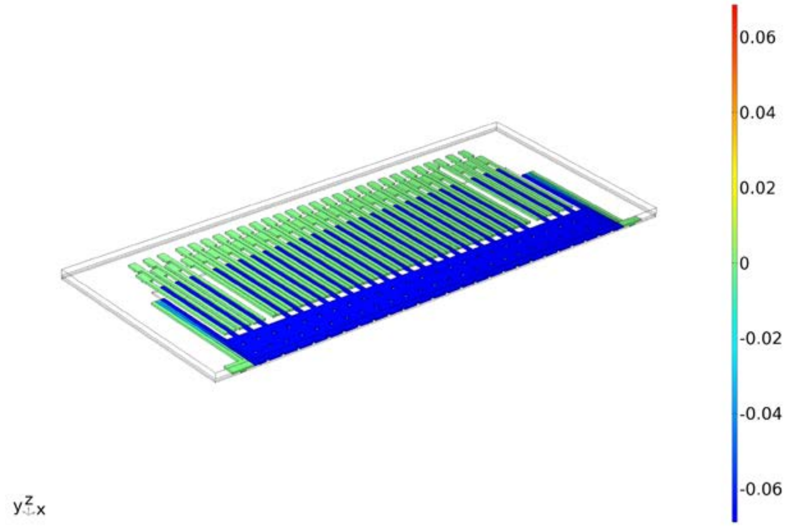
# Case Studies

Optimuos Why Incorporating Data Is Essential

- Example: Surface-Machined Accelerometer
  - Multi-Physics: Solid Mechanics, Electrostatics
  - Moving Mesh
  - Small components (sub millimeter)

- Simulations for 5 cases take 20 min
  - Ideal cases
  - No transient behavior captured
  - Only provides general behavior






- By hybridization with experiments data, high fidelity model can be achieved.

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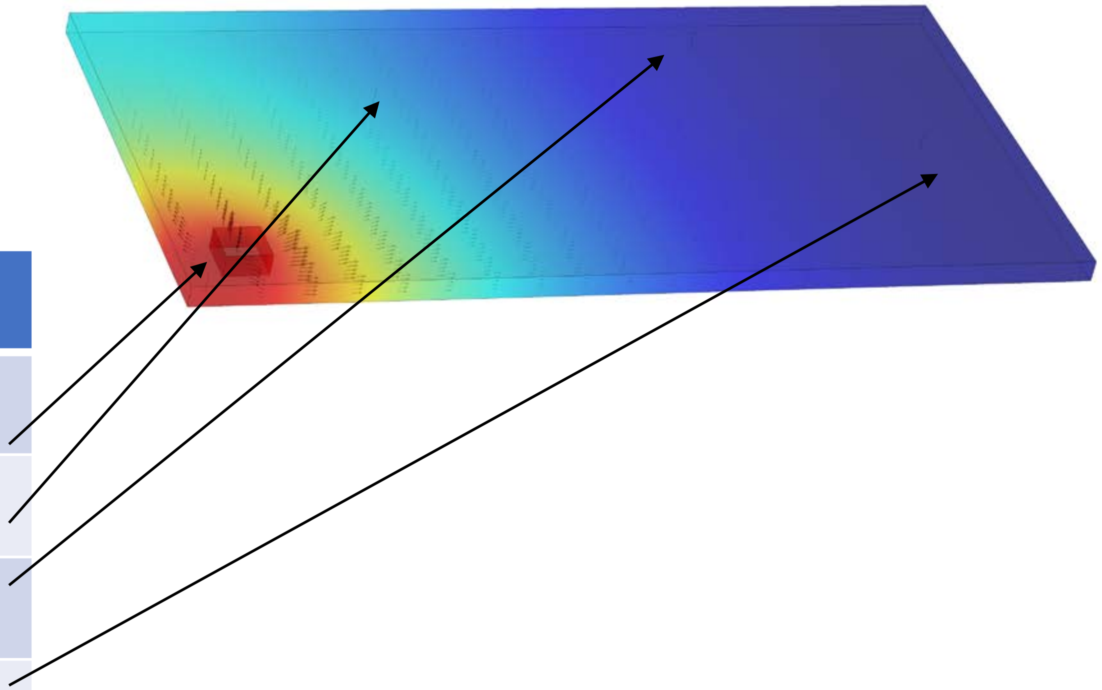
# Sensor Arrangement Optimization

## Case study: Implementation of data science on thermal sensors location and output.

- Aluminum Plate
    - 10 cm x 20 cm x 0.5 cm
- Heater size: 0.5 cm x 0.5 cm x 0.5 cm
    - Heater location can vary within the plate
    - Heat generation can also vary
- 4 Thermocouples placed in plate:

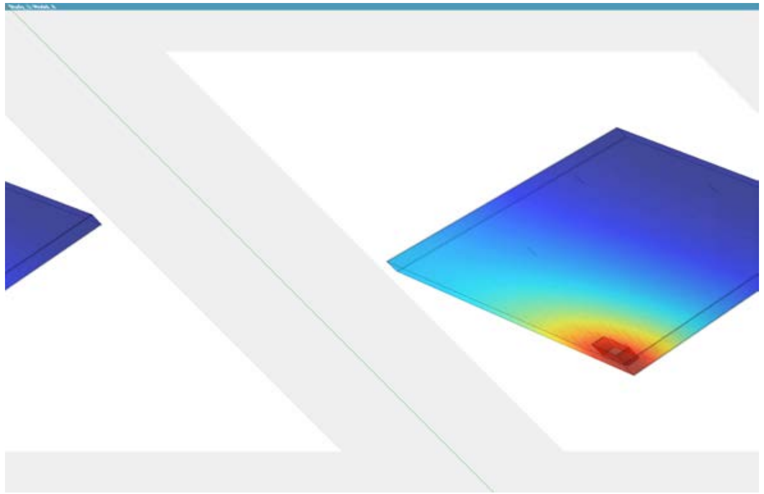
| Locations | x | y | z |
|---|---|---|---|
| T1 | 0.5 | 0.5 | 0.1 |
| T2 | 6 | 7 | 0.2 |
| T3 | 14 | 9 | 0.3 |
| T4 | 18 | 3 | 0.4 |

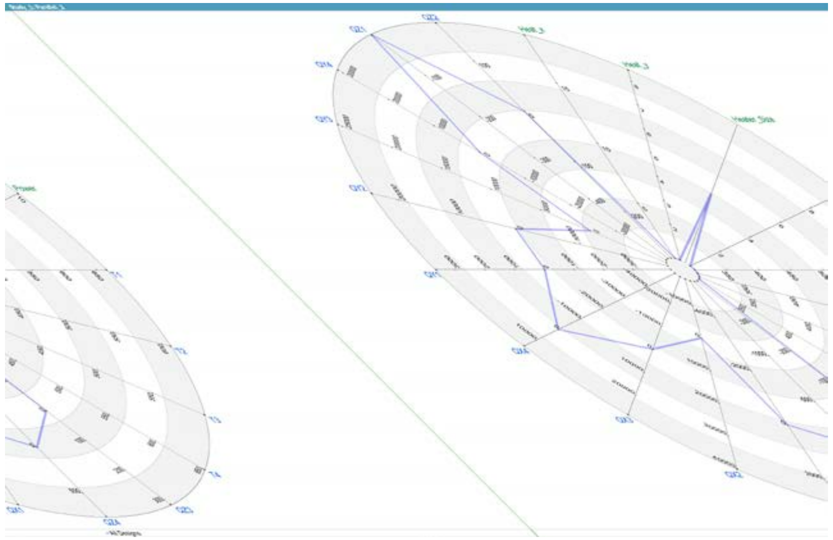


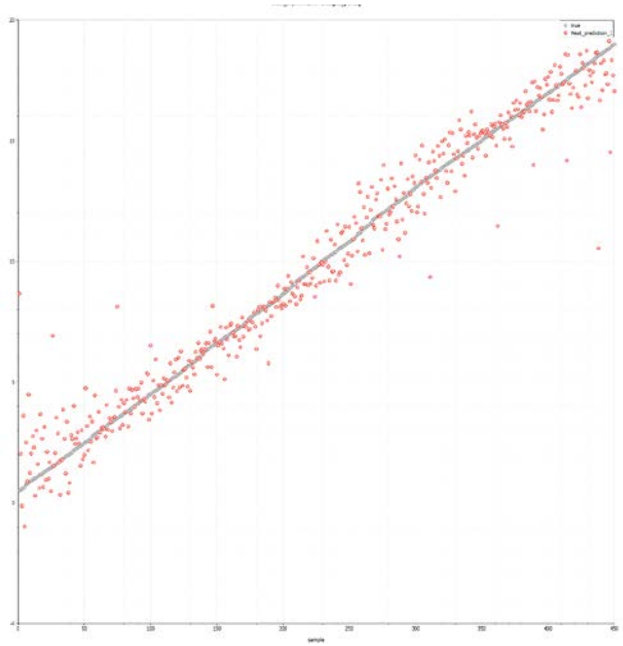
*Using data science and AI to detect the value power generation and location of heat source in a plate using thermocouples.*

# Optimuos Sensor Arrangement Optimization

*Data Fusion by combining DoE data  and experimental data*







Using DoE to generate data for the Neural Network
(500 different cases)

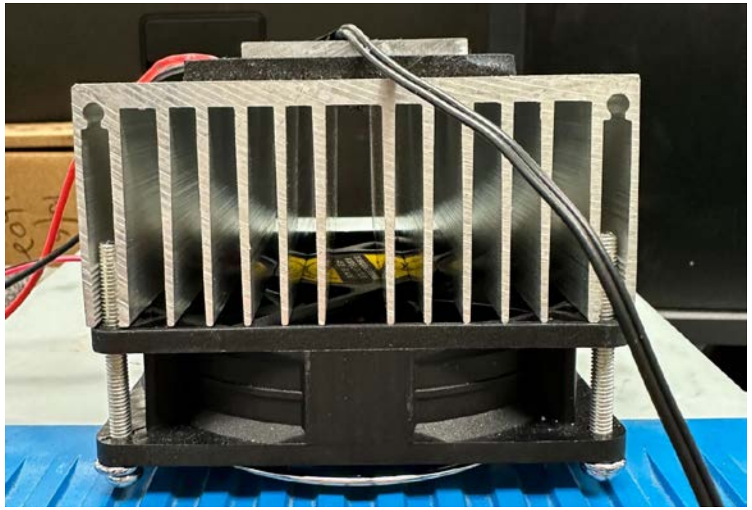
When input 4 measured values of temperature, power and location of the heat source is found within 99% accuracy.

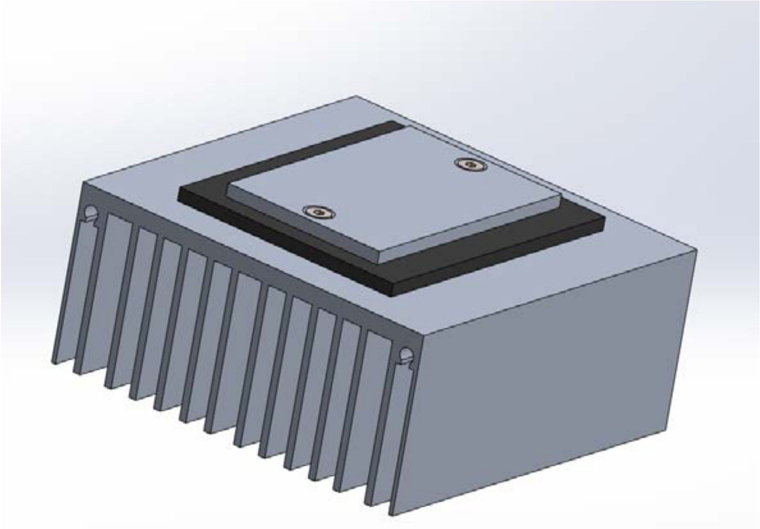
# Optimuos Sensor Calibration Using Digital Twin

## Case study: Heat flux sensor calibration using digital twin

*Hardware*

- Components:
  - Aluminum Heat Sin
  - Peltier Plate
  - Insulation
  - Fan
  - Aluminum top plate
- Sensors
  - Temperature sensors at top plate and air
  - Heat flux sensor between Peltier plate and top plate





*Creating digital twin by combining simulation and data to accurately calibrate heat flux sensor.*

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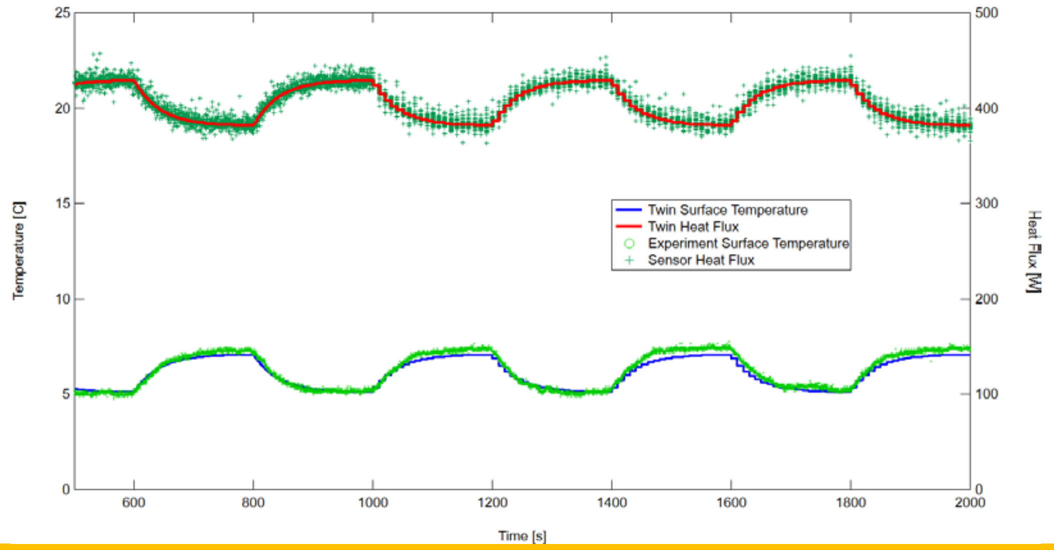
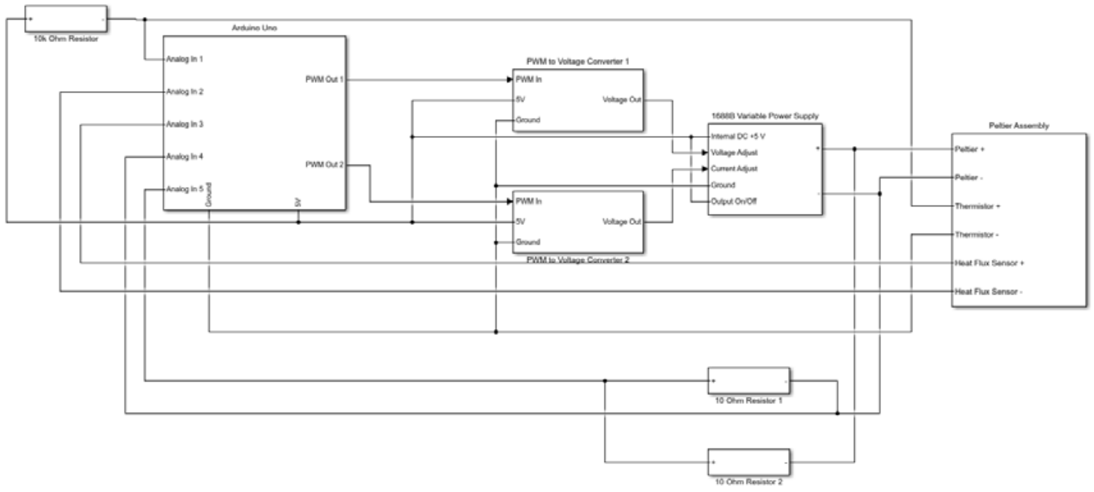
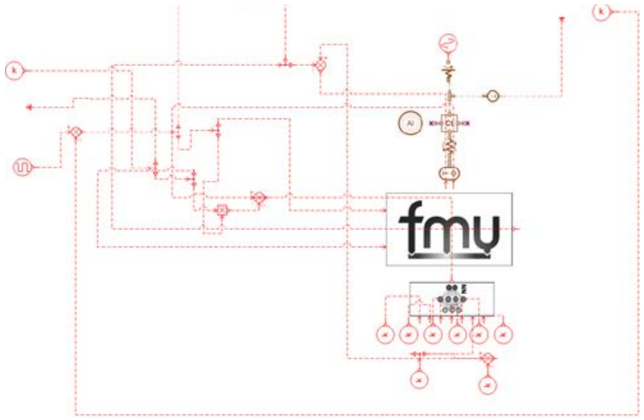
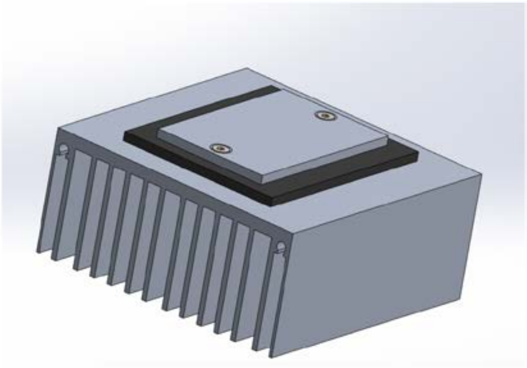
# Sensor Calibration Using Digital Twin

- Reduced Order Models (ROMs) of each component are built using hybridization technique.
- Digital twin first generation is fabricated.
- Digital twin was trained by set of data from experiments.
- Digital twin next generation behave identical to the system.
- Digital twin provides accurate heat flux calibration.



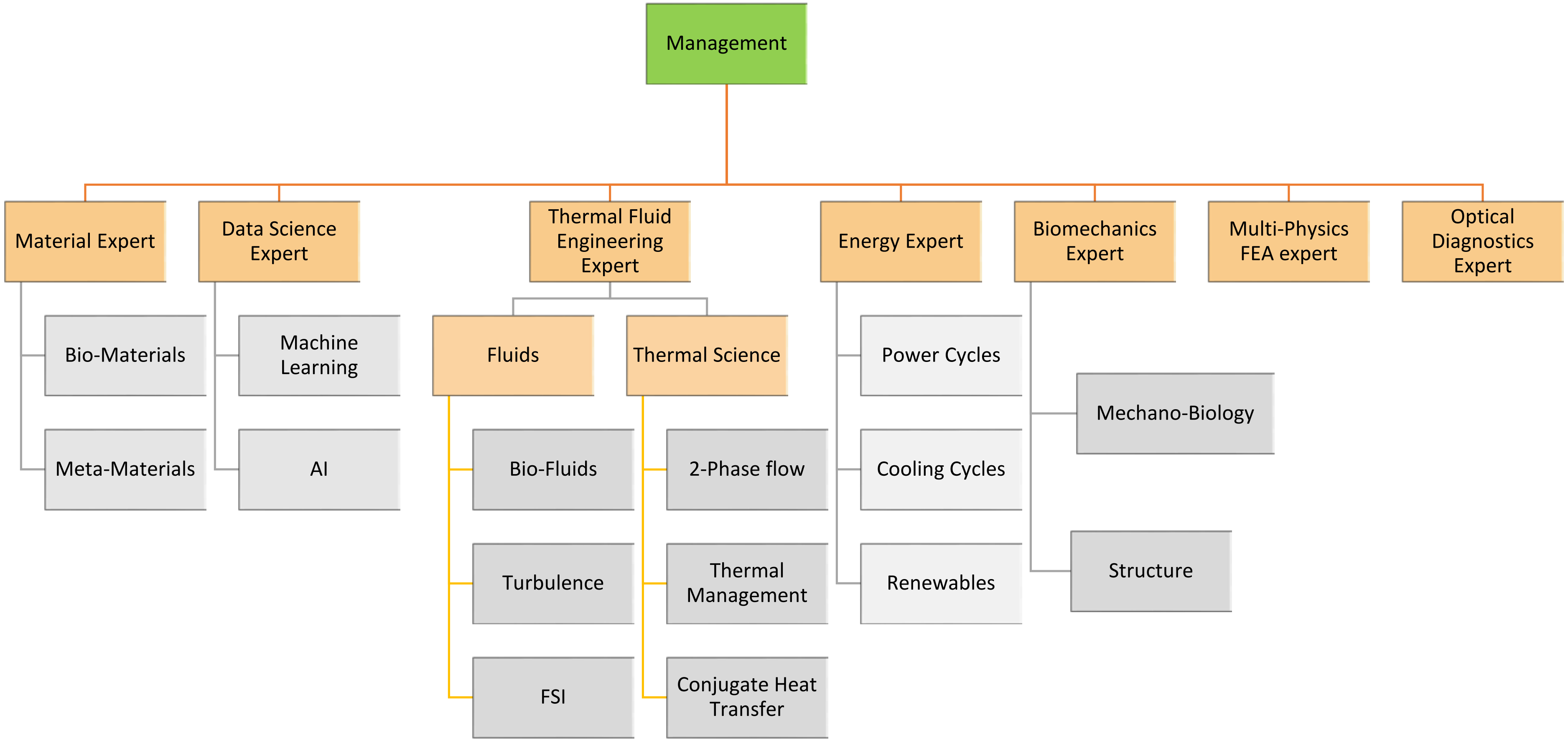



*Using data science and AI to detect the value power generation and location of heat source in a plate using thermocouples.*

# Who We Are



Management
Material Expert
Data Science Expert
Thermal Fluid Engineering Expert
Energy Expert
Biomechanics Expert
Multi-Physics FEA expert
Optical Diagnostics Expert
Bio-Materials
Meta-Materials
Machine Learning
AI
Fluids
Thermal Science
Bio-Fluids
Turbulence
FSI
2-Phase flow
Thermal Management
Conjugate Heat Transfer
Power Cycles
Cooling Cycles
Renewables
Mechano-Biology
Structure

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# Thank You

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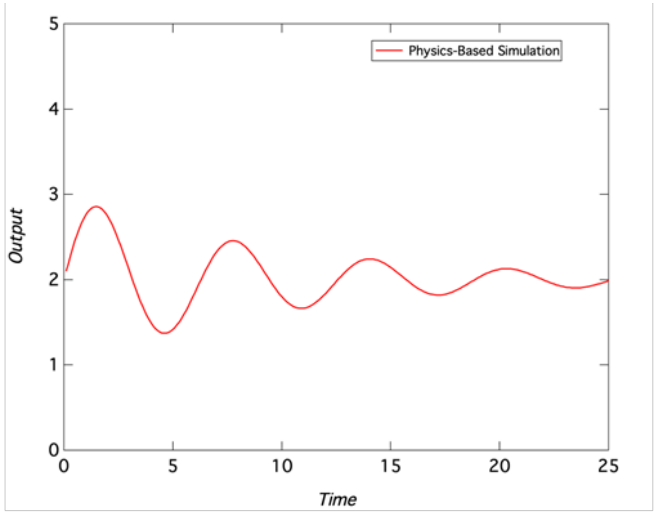
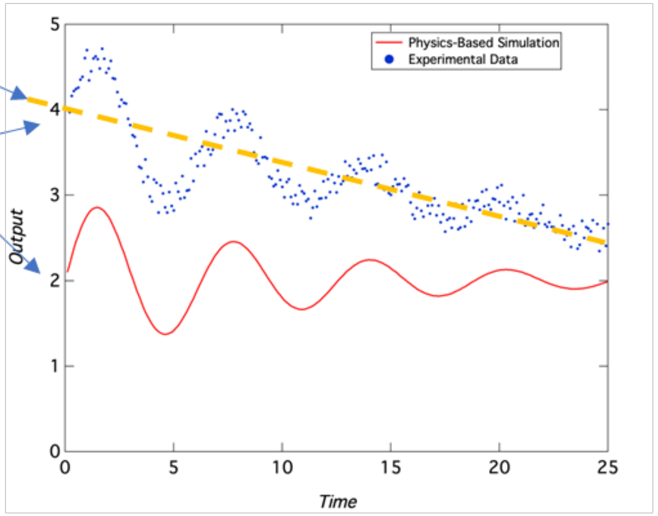
# Case Study




Drift in experimental data

Off-set of model vs. data

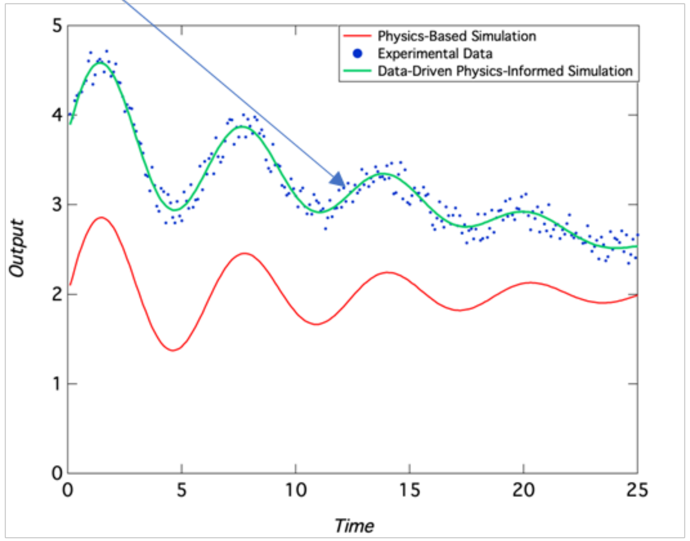



- Physics-based simulation can't capture the actual boundary and initial conditions
- Physics-based simulation can't capture behaviors that are not incorporated in the simulation either due to lack of knowledge or complexity.

Hybridization

Data- Driven Physics-informed simulation

- High-fidelity simulation
- Includes complexities and dynamic response




Reduced Order Model of the component

High-fidelity, low computation time of overall system model

***Automation Within Automation removes human error and the time needed for human inspection and subjectiveness of the supervisor.***