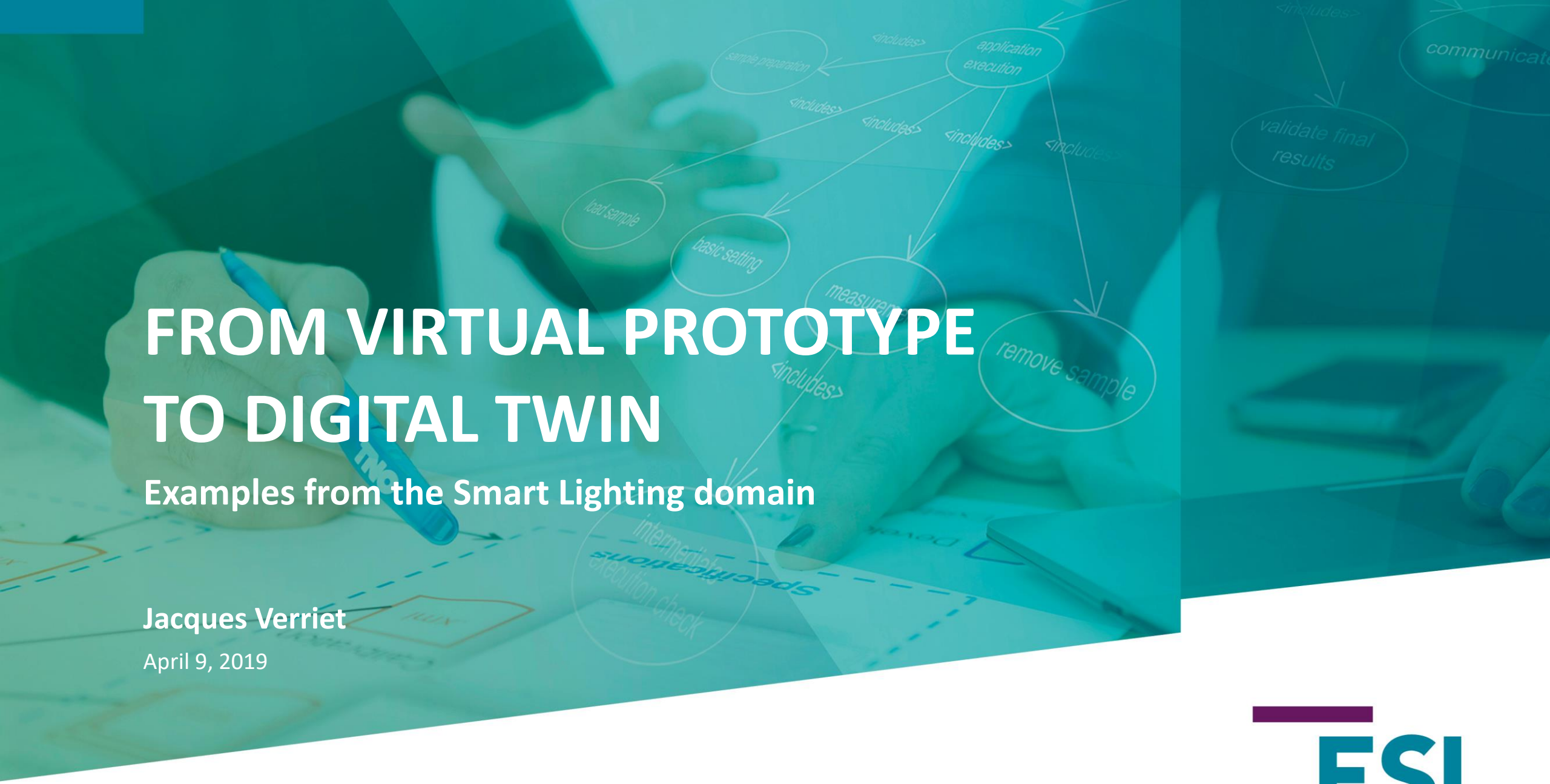


FROM VIRTUAL PROTOTYPE TO DIGITAL TWIN

Examples from the Smart Lighting domain

Jacques Verriet

April 9, 2019

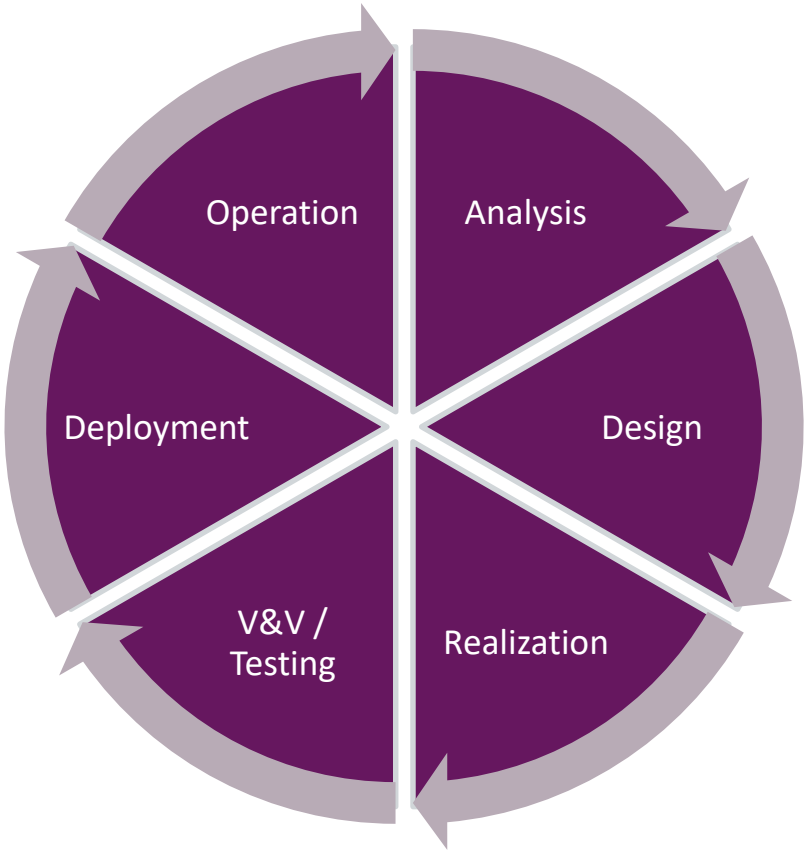
An initiative of industry, academia and TNO

ESI

OUTLINE

Analytic models used during

- Analysis and design ➔ Virtual prototype
- Realization, testing, deployment, operation ➔ Digital twin
- Operation (vision) ➔ Adaptive system



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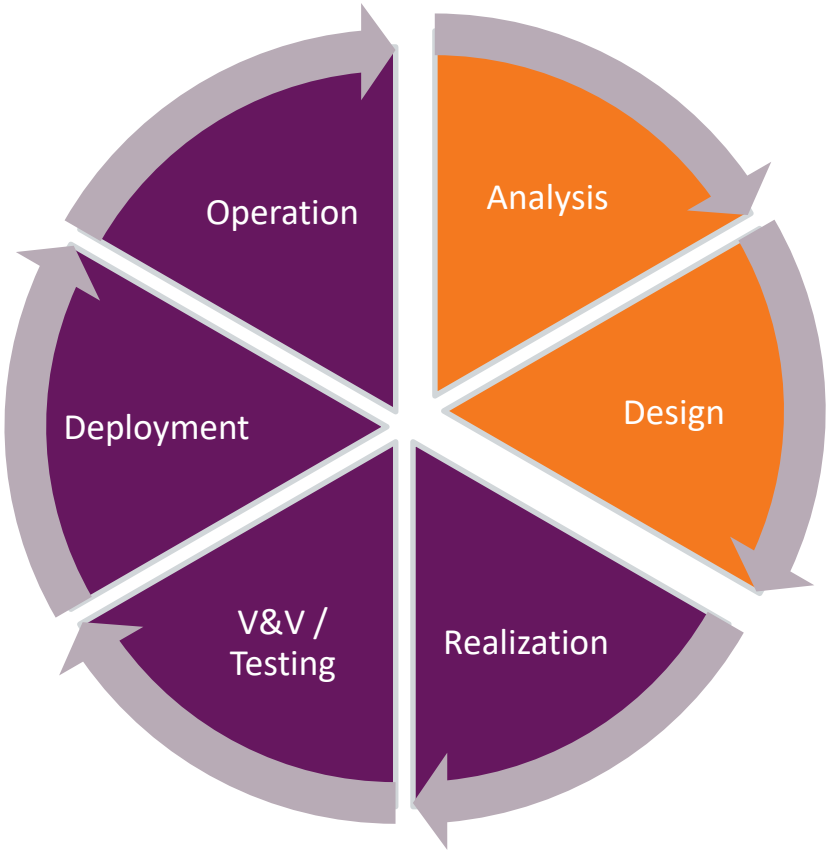
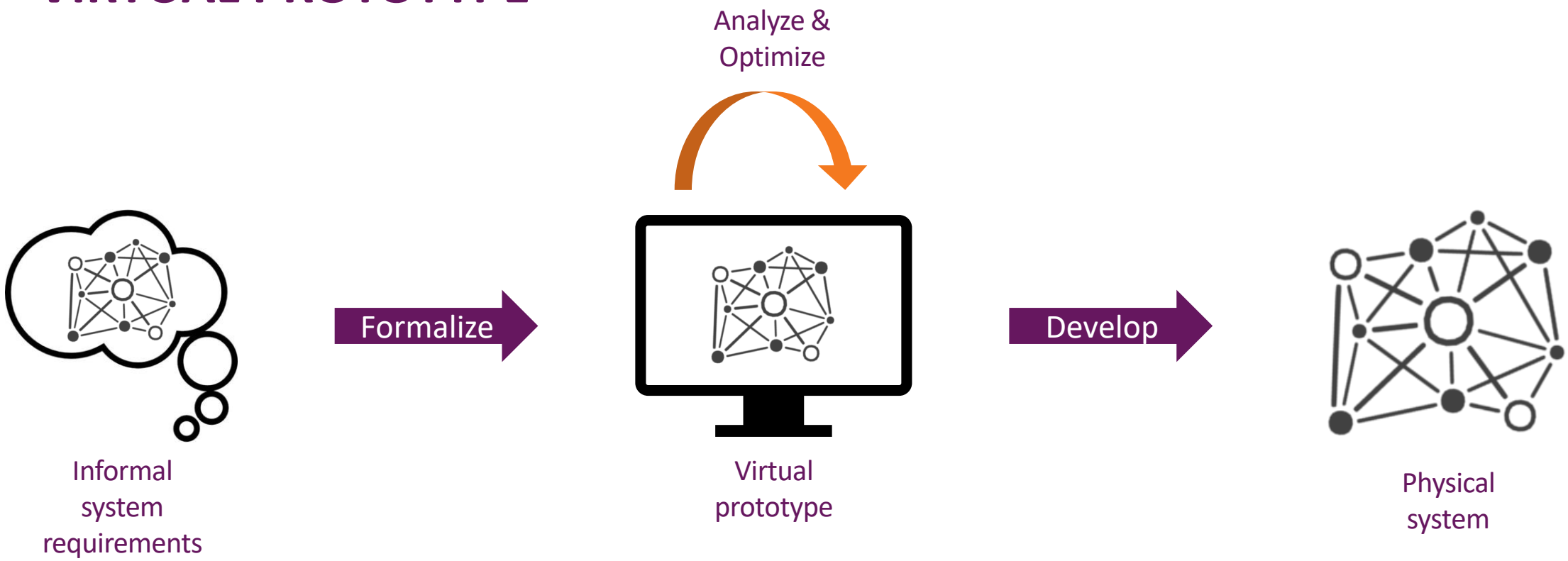


VIRTUAL PROTOTYPE



SMART LIGHTING CASE

- **Witte Dame** building
  - Landmark historical building
  - Former lighting factory

- Smart lighting system
  - Complete 5th floor
  - 367 light points
  - More than 1,300 behaviors

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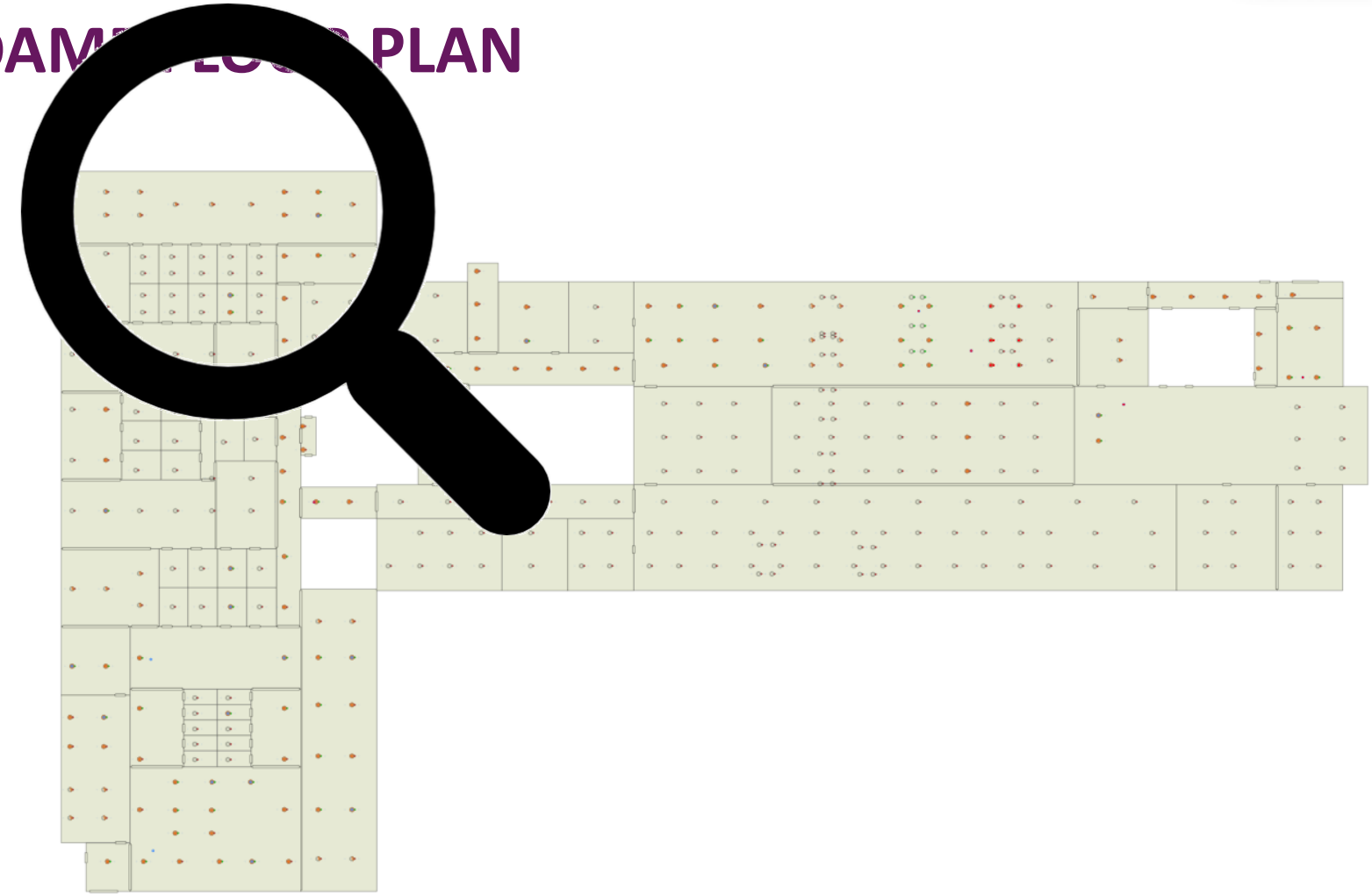
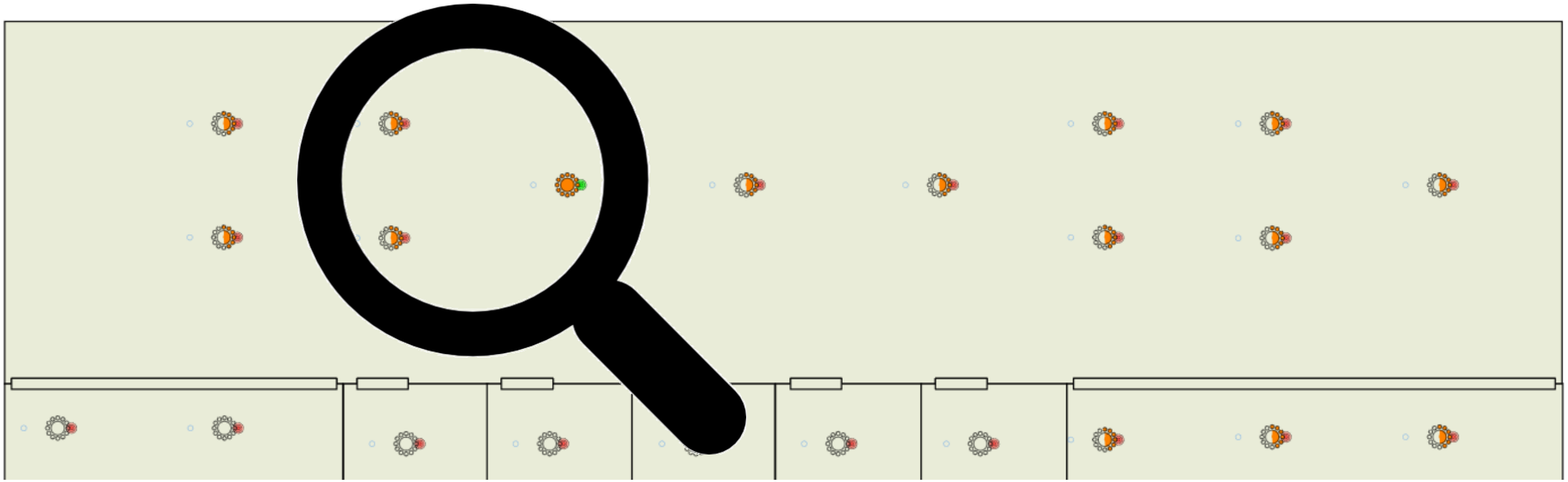
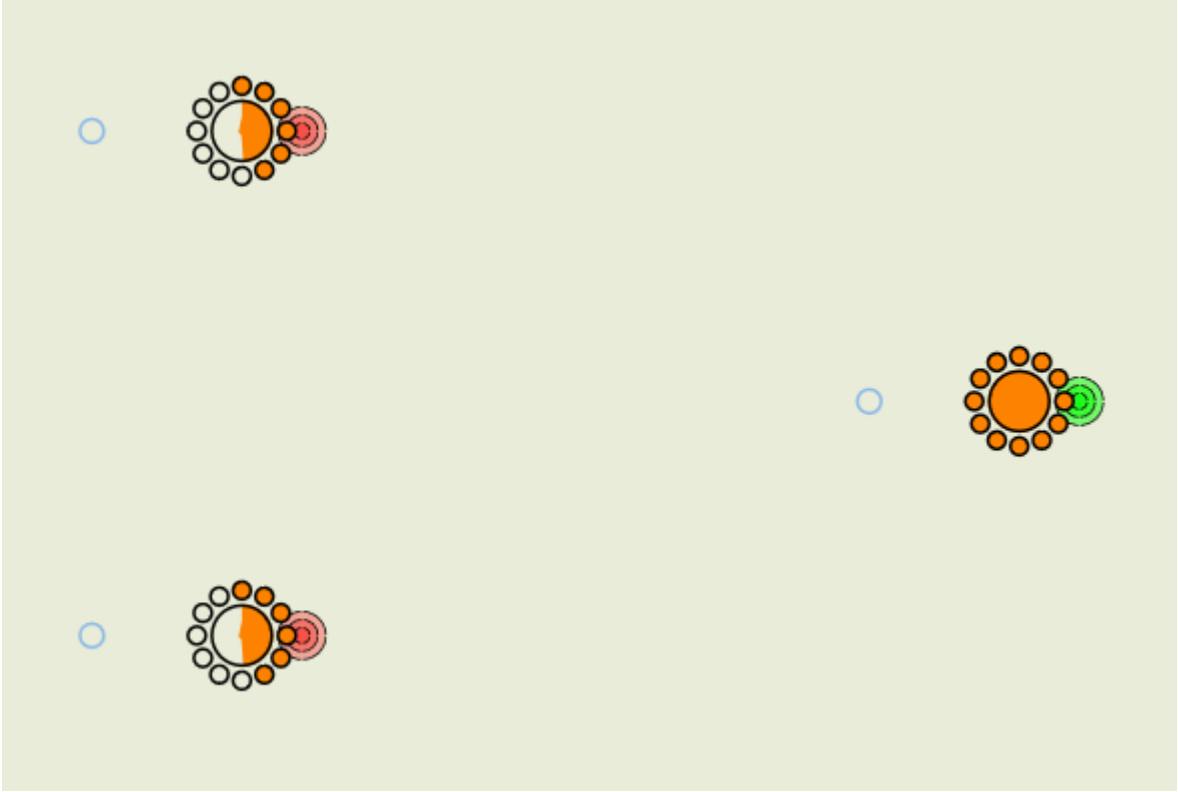
WITTE DAM[illegible] PLAN



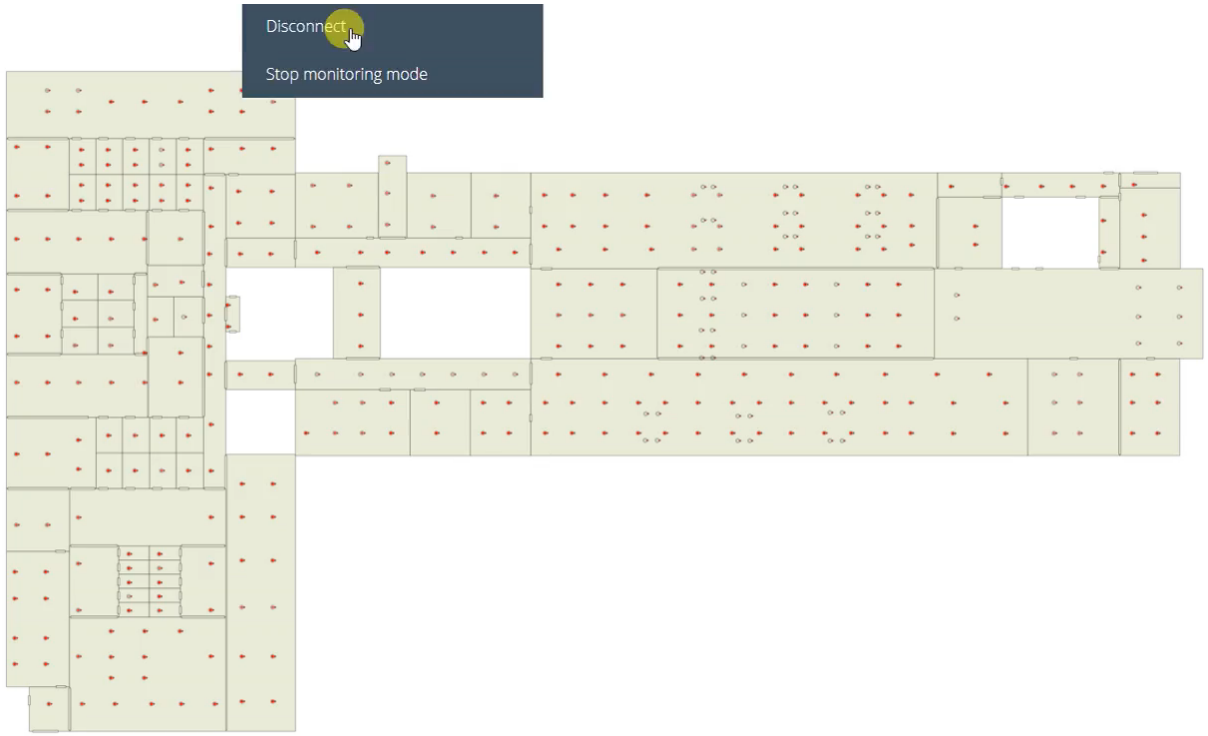
WITTE DAME FLOOR PLAN



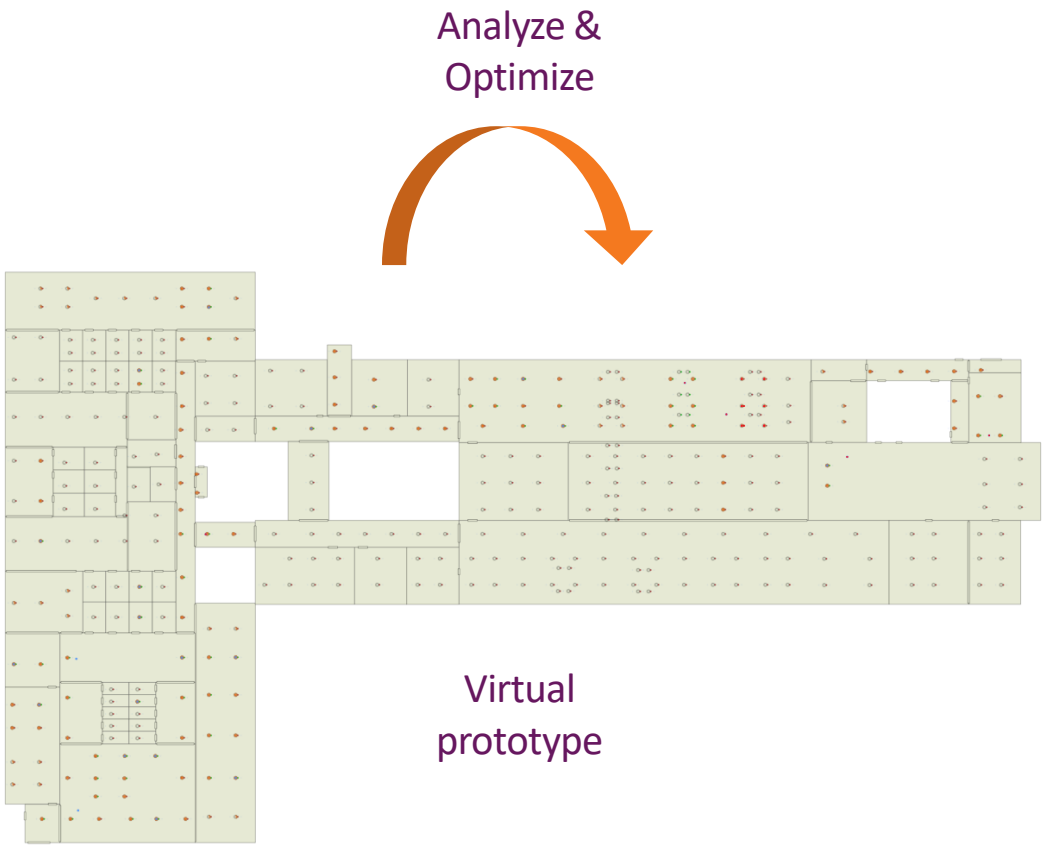
WITTE DAME FLOOR PLAN



VIRTUAL PROTOTYPE: INTERACTIVE SIMULATION

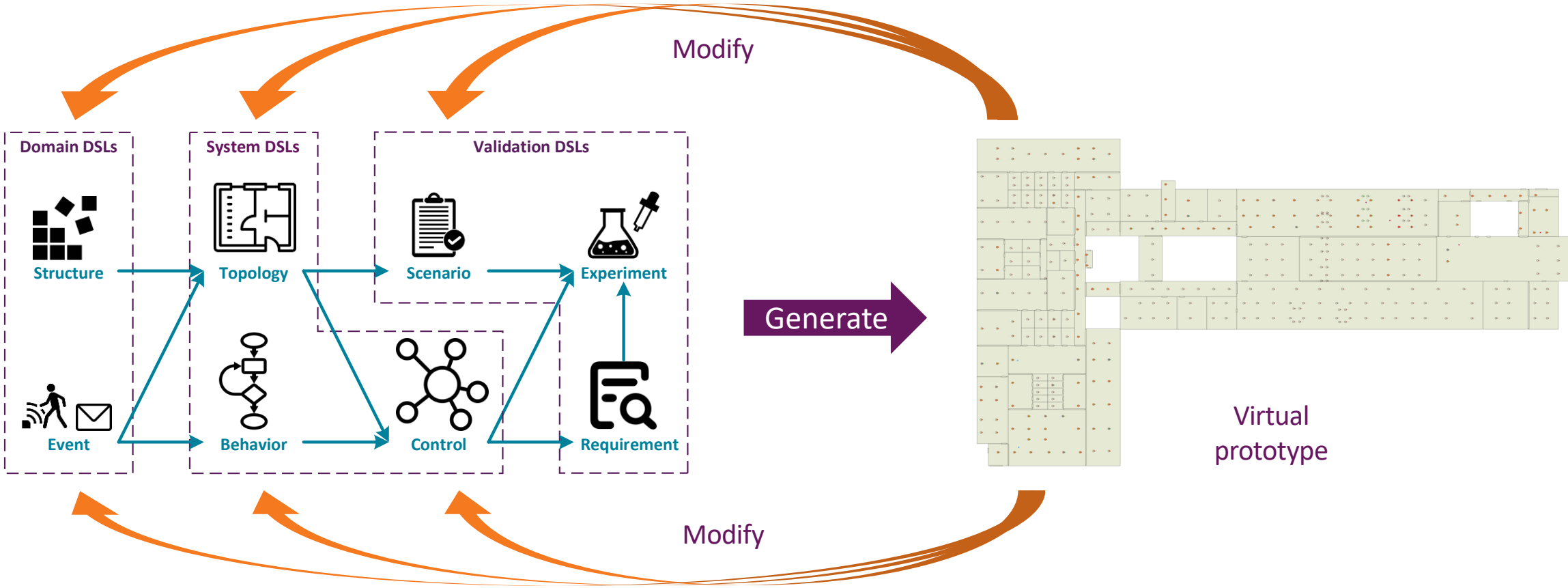


DESIGN SPACE EXPLORATION



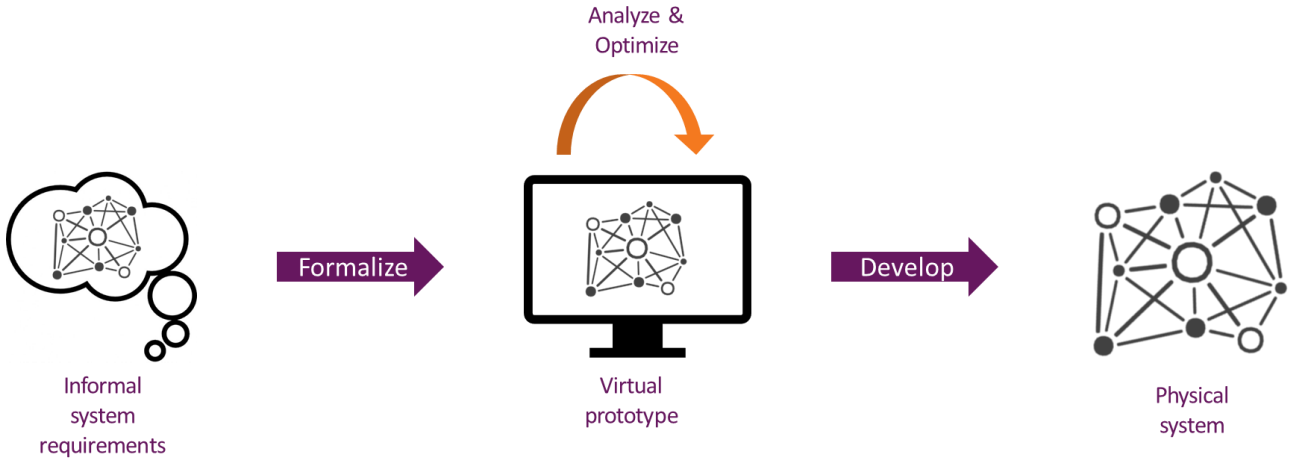
- Challenge
  - 1000's of **components** (sensors, buttons, light points, …)
  - 1000's of **interdependent controllers** (occupancy, daylight harvesting, …)
- But, few **types** of components and controllers

DOMAIN MODEL FOR DISTRIBUTION CONTROL APPLICATIONS



VIRTUAL PROTOTYPE SUMMARY

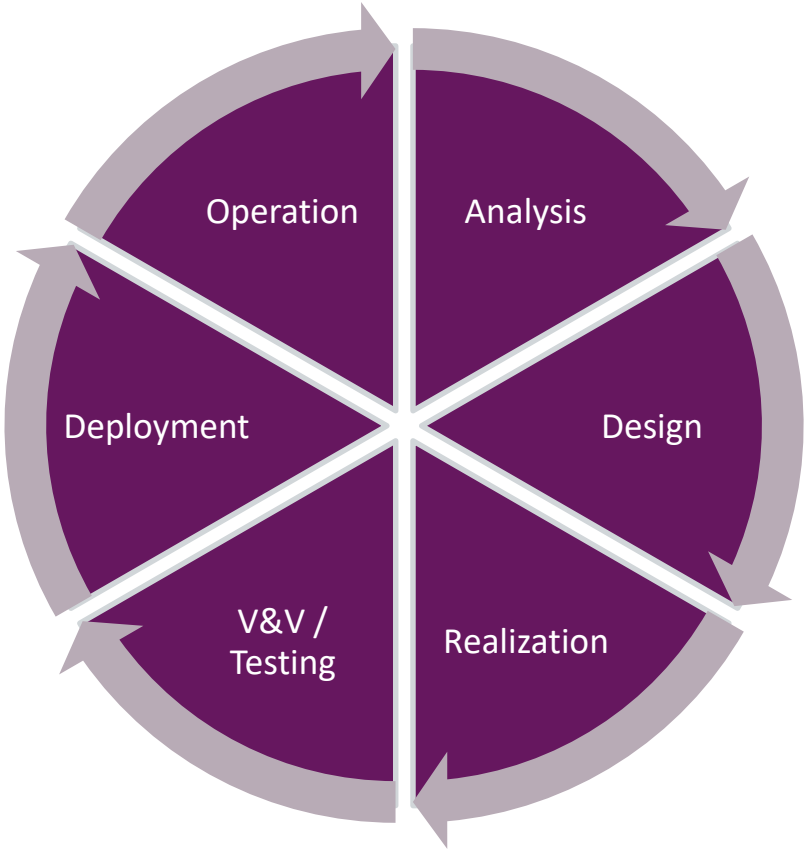
- **Executable virtual prototypes** are used to optimize system behavior in early development phases
- **Domain models** can be used to handle **system variability**
- **Design space exploration** is used to find a suitable system configuration



OUTLINE

Analytic models used during

- Analysis and design ➔ Virtual prototype
- Realization, testing, deployment, operation ➔ Digital twin
- Operation (vision) ➔ Adaptive system



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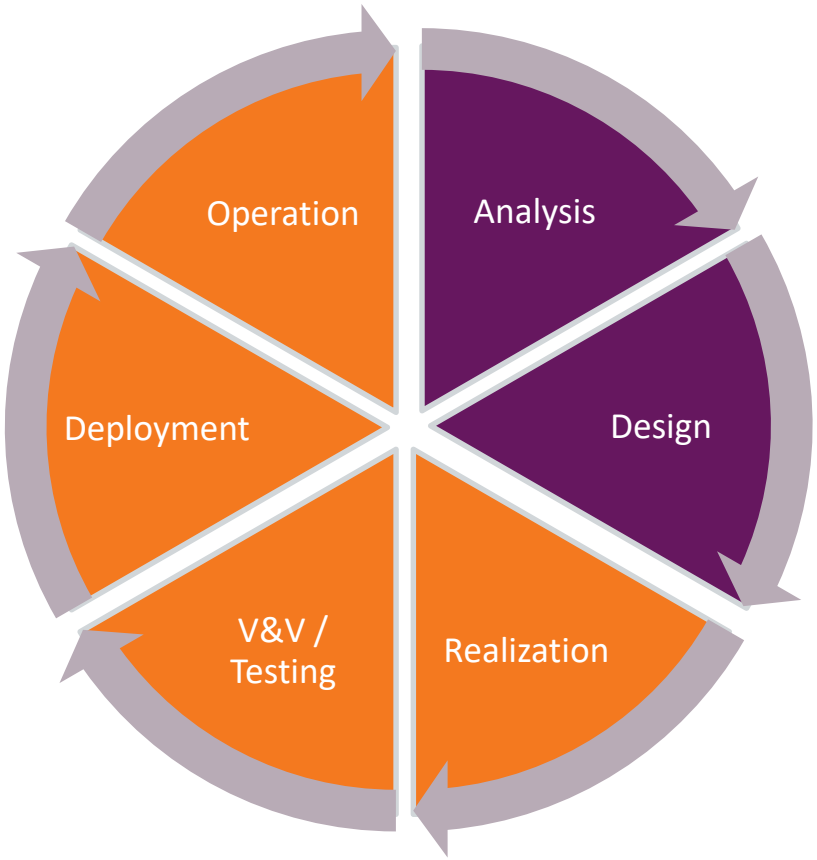
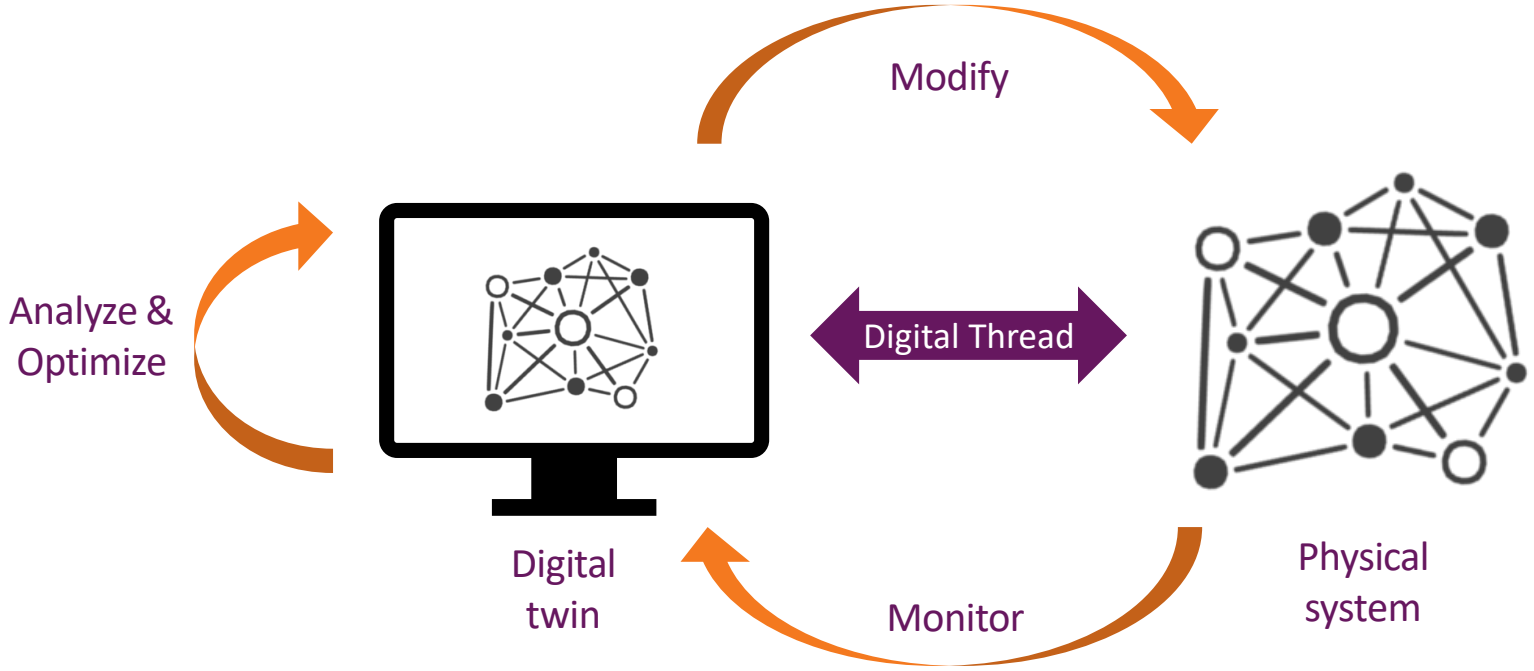


DIGITAL TWIN



SMART LIGHTING CASE

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  - Landmark historical building
  - Former lighting factory

- Smart lighting system
  - Complete 5th floor
  - 367 light points
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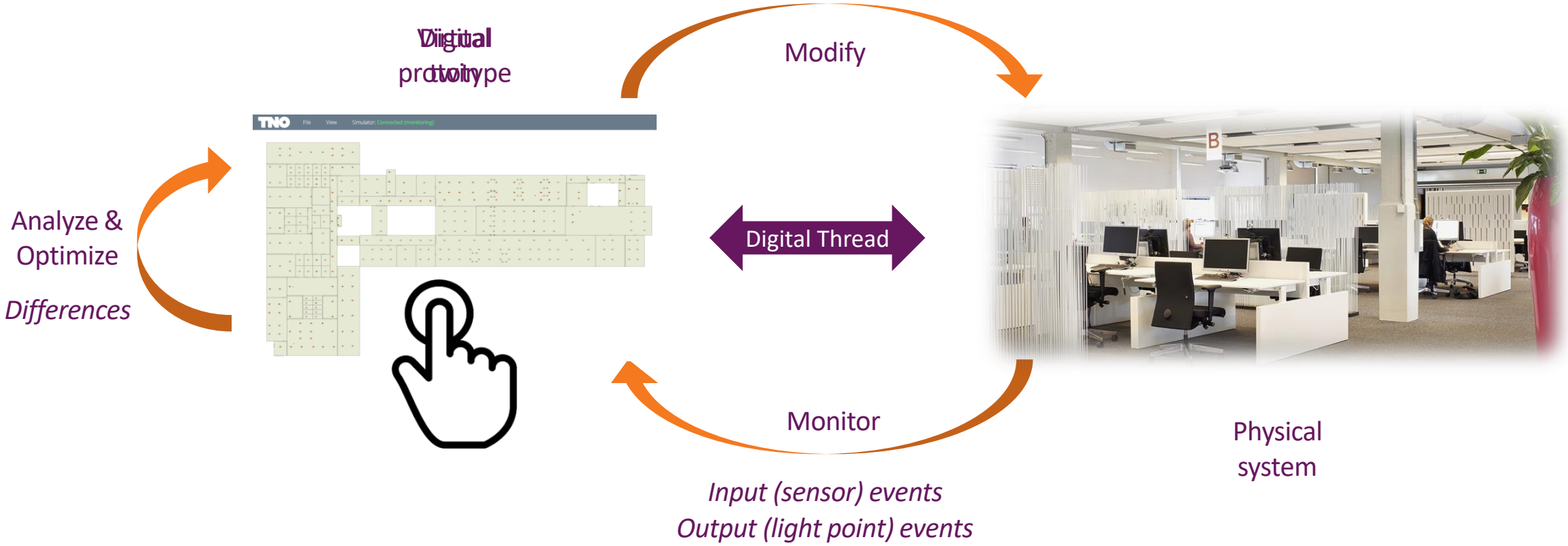
SMART LIGHTING SYSTEMS

- Challenge
  - 1000's of **components** (sensors, buttons, light points, …)
  - 1000's of **interdependent controllers** (occupancy, daylight harvesting, …)

- Humanly impossible to keep overview of the system behavior

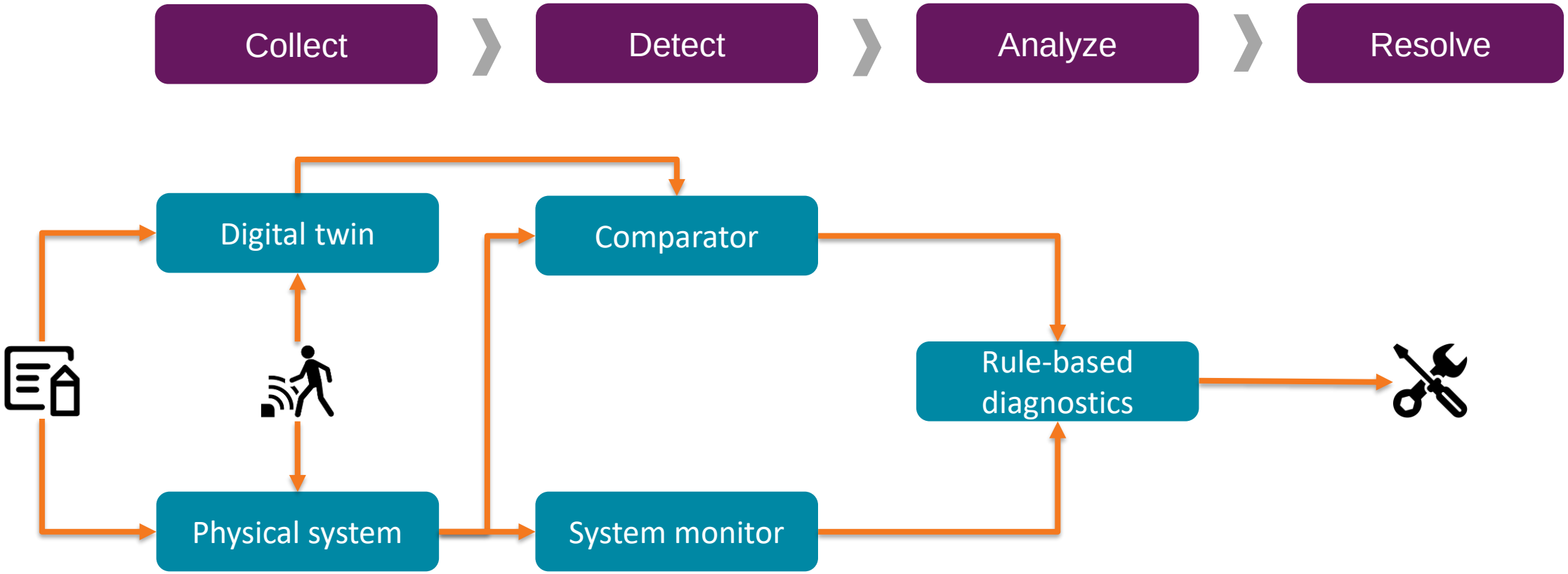
- **Automated monitoring** required
  - Reuse of **virtual prototype model** as **digital twin**

FROM VIRTUAL PROTOTYPE TO DIGITAL TWIN

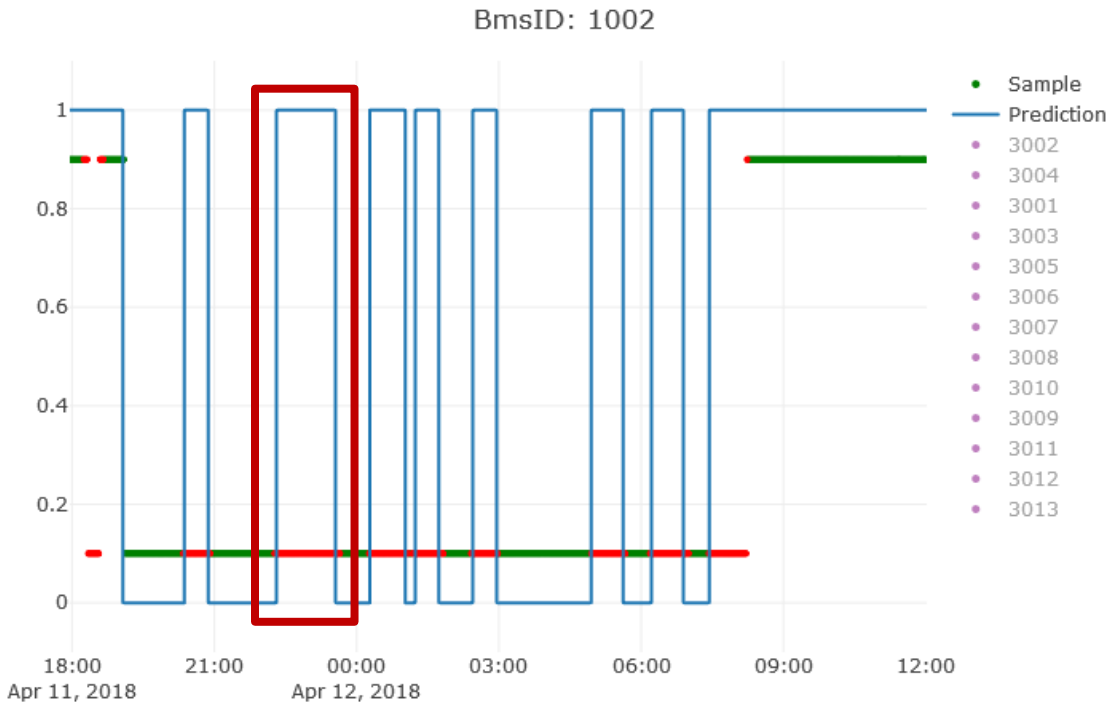


ROOT CAUSE ANALYSIS FOR SMART LIGHTING

ROOT CAUSE ANALYSIS FOR SMART LIGHTING

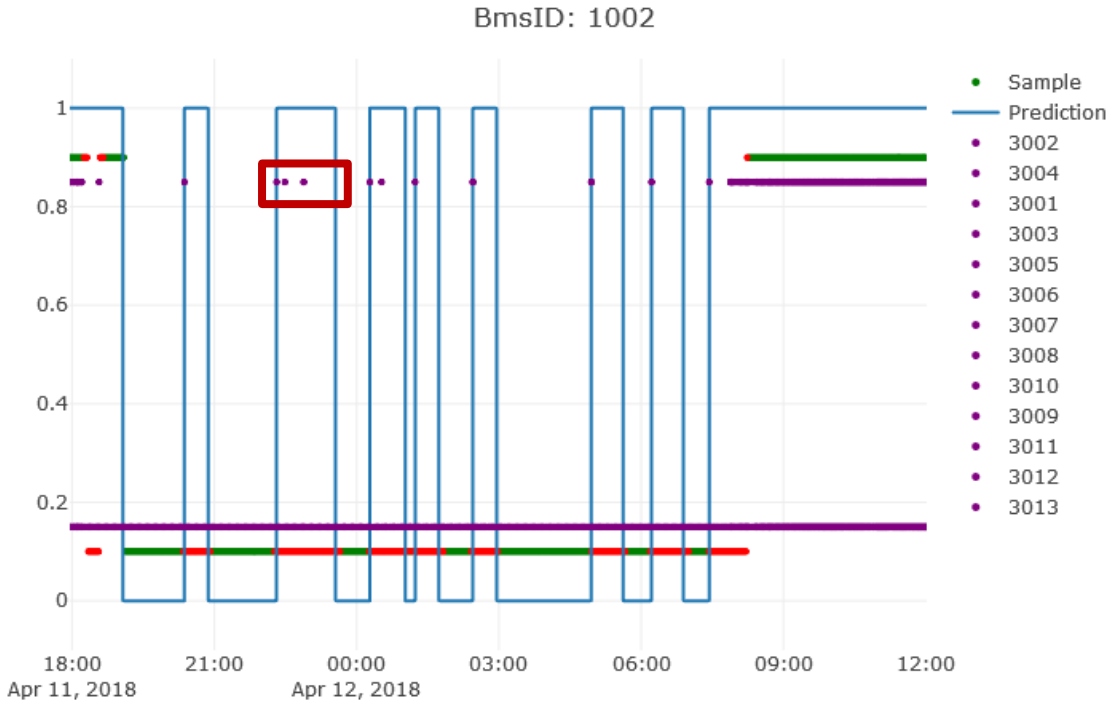


ANOMALY DETECTION



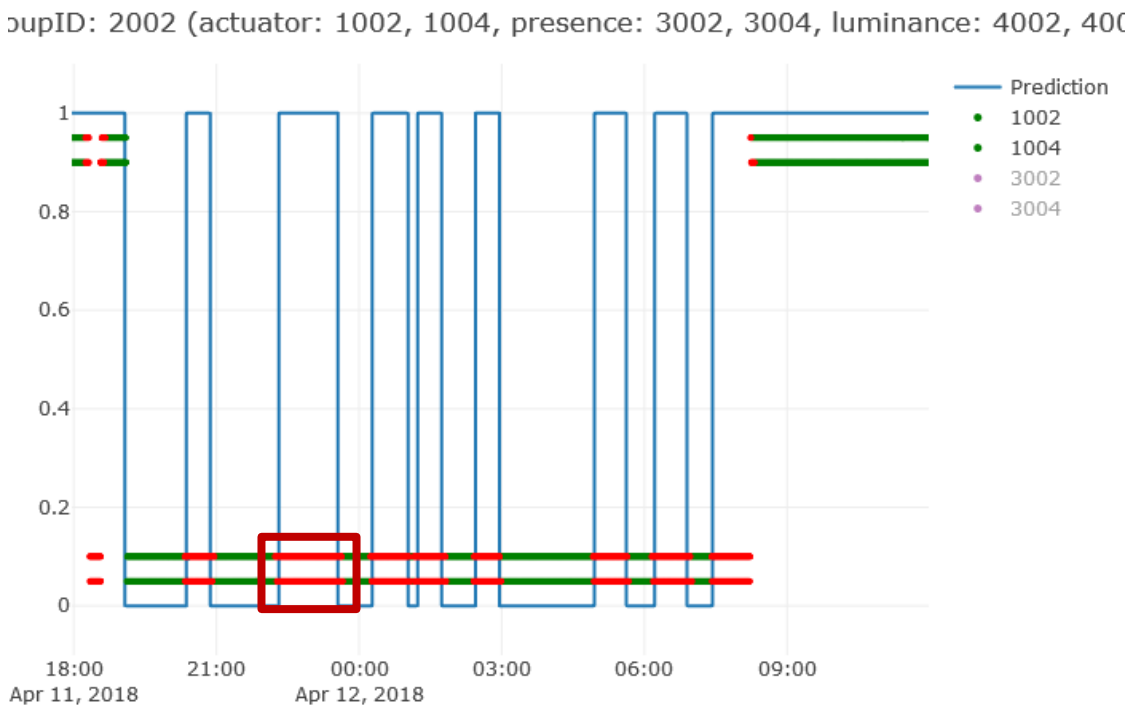
DIAGNOSTICS: RULE 1

1	Correctness of digital twin behavior	Is a sensor in the group reporting occupancy?	2	3	Is the digital twin behaving correctly?



DIAGNOSTICS: RULE 2

2	Group problem	Do other light points in the same group behave identically?	4	5	Is it an individual or group problem?

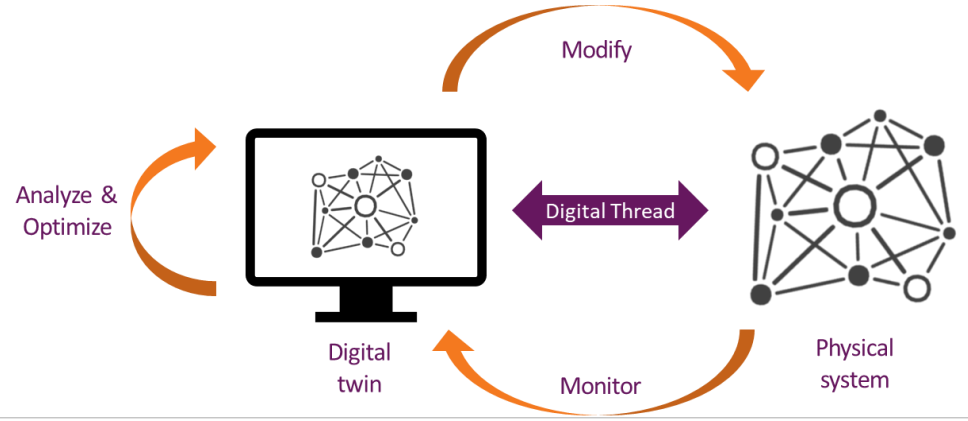


DIAGNOSTICS: RULE 3

4	Commissioning error	Have all behaviors of group 2002 been commissioned?	5		Commissioning error

DIGITAL TWIN SUMMARY

- An executable **virtual prototype** specifies the desired system behavior
- The virtual prototype can be coupled to the physical system to become a **digital twin**
- The digital twin can be used to **detect and analyze differences** between specification and realization
- After analyzing the difference, one needs to **modify** the physical system and/or the digital twin



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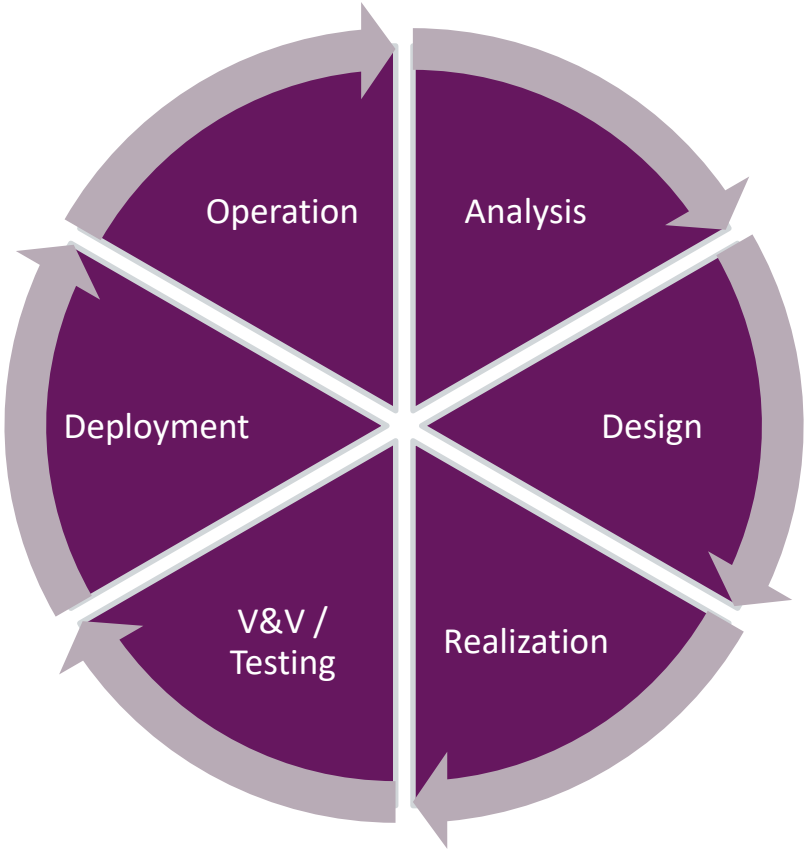

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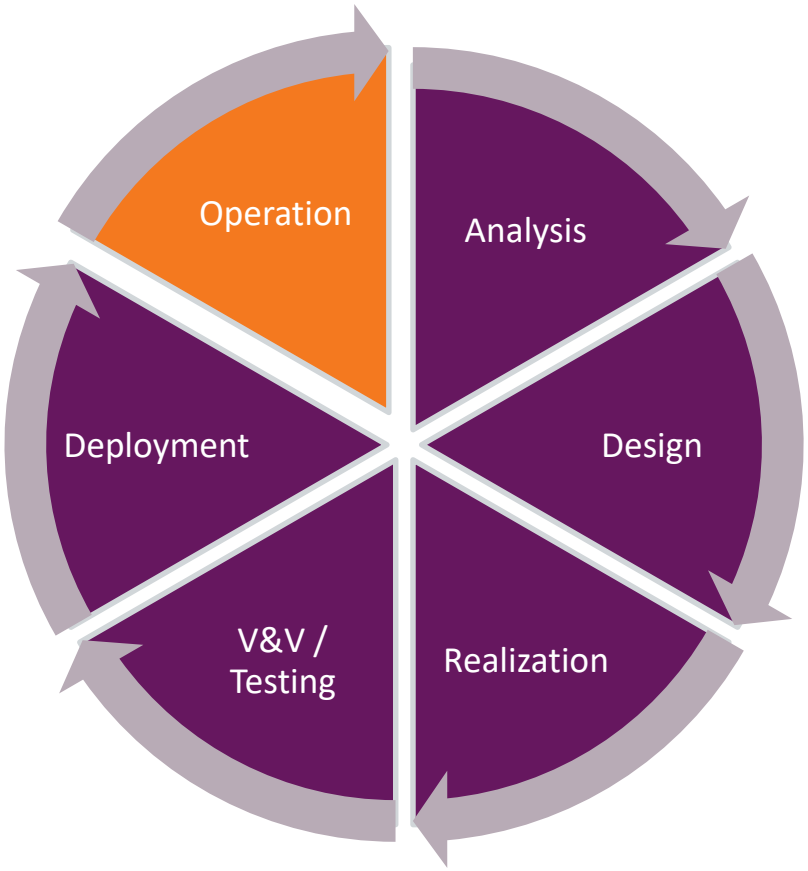
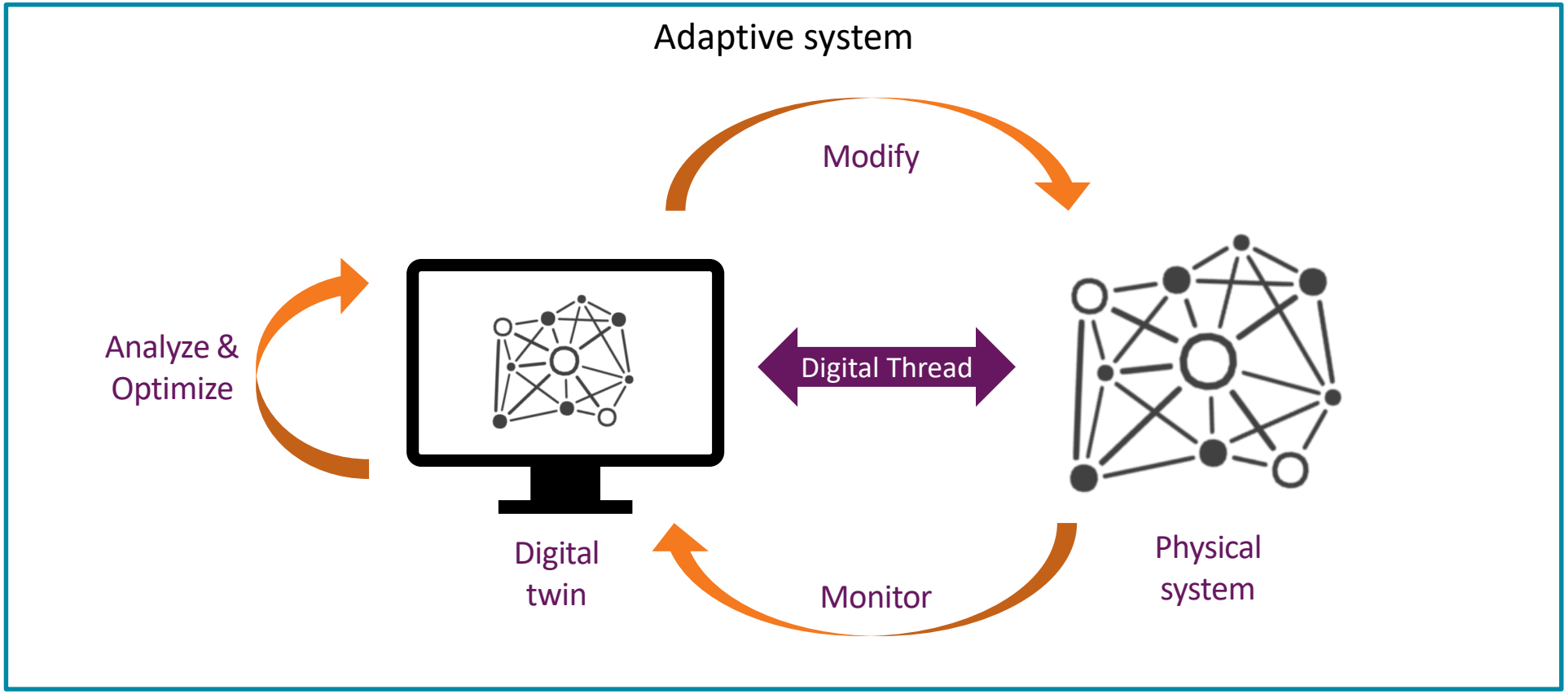
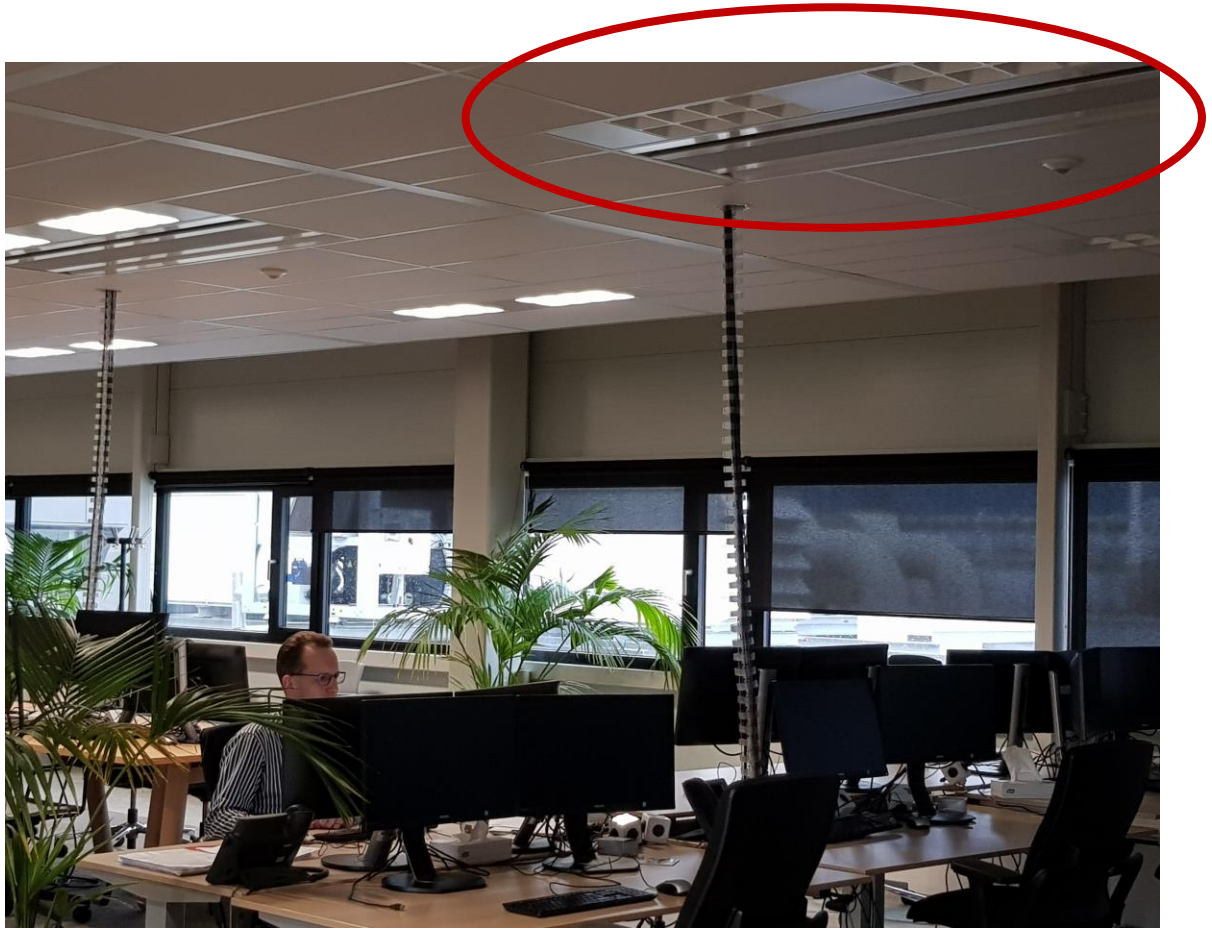


ADAPTIVE SYSTEMS

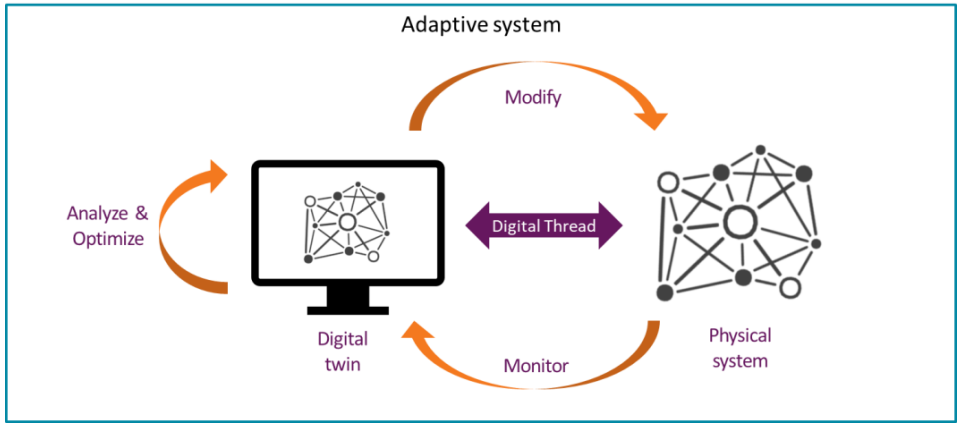


SMART LIGHTING ADAPTATION EXAMPLE



ADAPTIVE LIGHTING CONTROLLER: SCENARIO 1

- **Detect**
  - Lights switch on shortly after they have switched off
- **Analyze**
  - Occupancy sensor is not sensitive enough to detect all occupancy
  - Occupancy sensor is not operating at maximum sensitivity
- **Resolve**
  - Increase sensor sensitivity to detect smaller motions

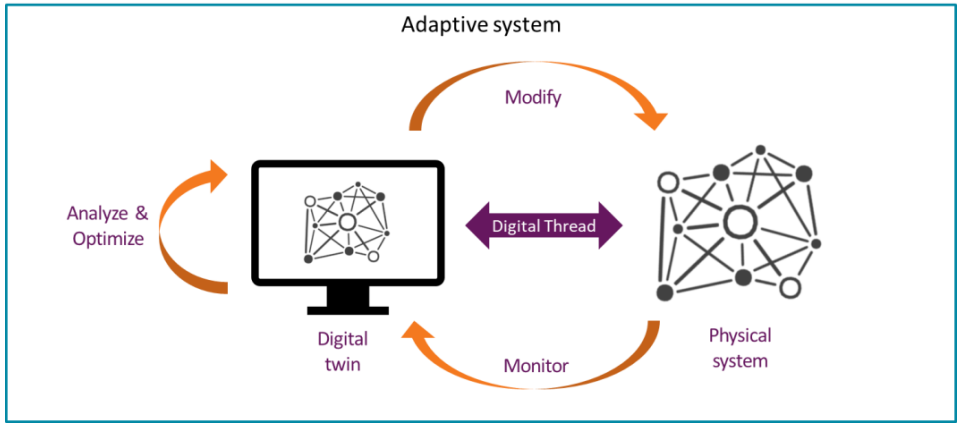


ADAPTIVE LIGHTING CONTROLLER: SCENARIO 2

- **Detect**
  - Lights switch on shortly after they have switched off

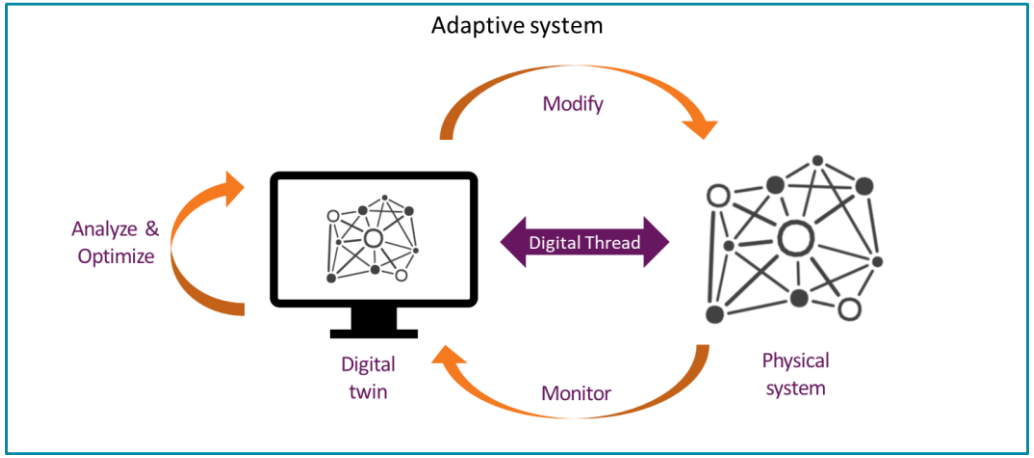
- **Analyze**
  - Occupancy sensor is not sensitive enough to detect all occupancy
  - Occupancy sensor is operating at maximum sensitivity

- **Resolve**
  - Increase time between last occupancy and switching off
  - Issue service call to replace/move/add occupancy sensor



ADAPTIVE SYSTEMS SUMMARY

- **Analysis** based on digital twins is currently done **manually**
- **Integration** of the digital twin in the physical system gives a **self-aware system**
- Self-aware systems may **adapt themselves** or **initiate service actions**



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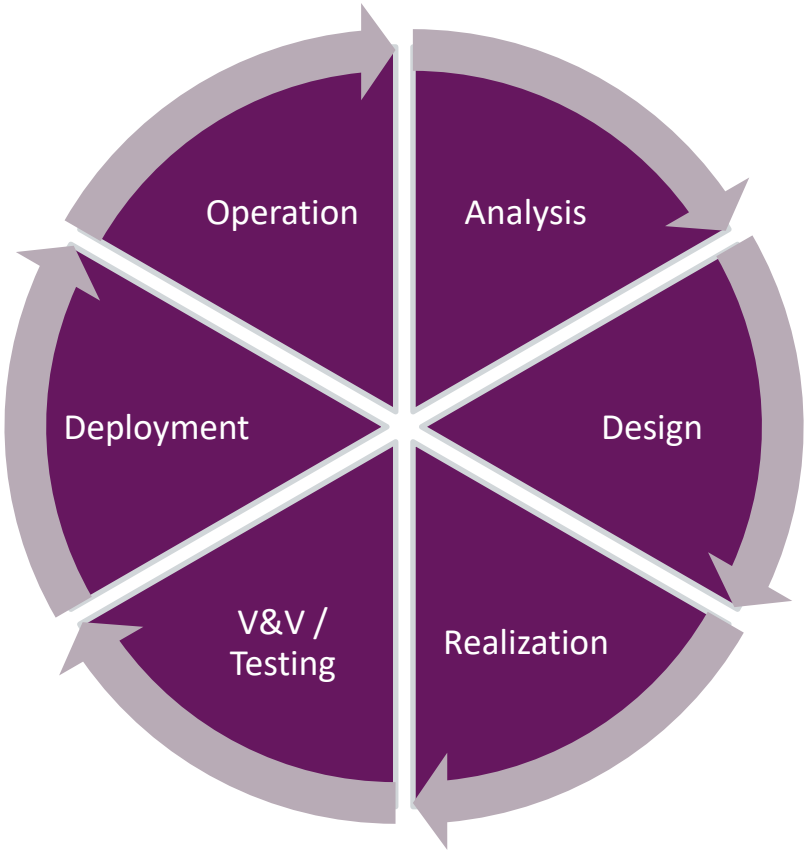

TAKEAWAYS

- **Executable virtual prototypes** can be used to formalize **system behavior specifications**
- These **virtual prototypes** can become **digital twins**,
  which are used e.g. to **detect and diagnose anomalous system behavior**
- By incorporating the **digital twins in the system**,
  the system become **self-aware** or even **self-adapting**

For more information, visit our **diagnostics booth** on the **demo market**