Boston Dynamics

AI, Autonomy, and Digital Twin For Radioactive Environments

How Modern Robotic Solutions Are Changing The Nuclear Sector

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BIOGRAPHY:

Boston Dynamics Team - FRTR Spring 2024

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Robots: Born in Nuclear

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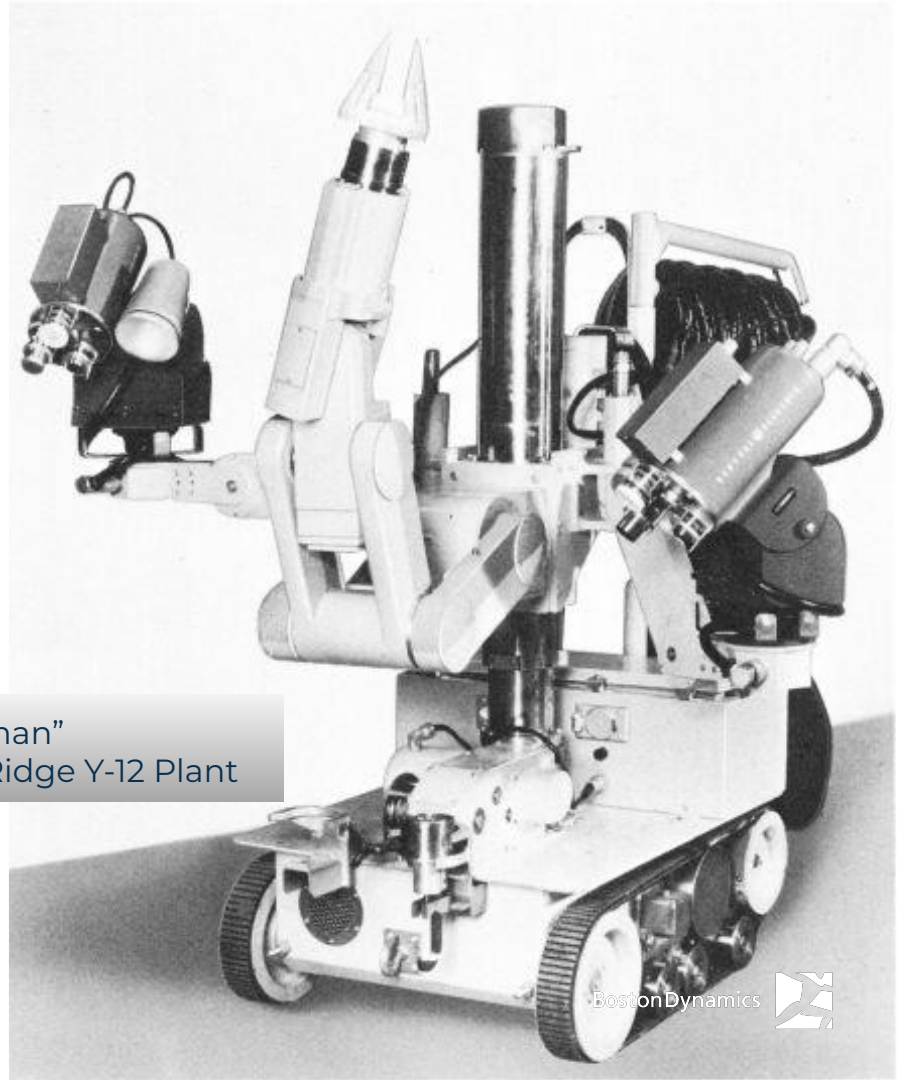
“Traditional” Mobile Robots for the Nuclear World

- ROVs for tele-presence and remote manipulation
- Highly specialized to a specific task or subset of tasks
- Born out of necessity for the hazardous environments unique to the industry
- Full dependency upon highly skilled human operators



“Herman”
Oak Ridge Y-12 Plant

Modern Mobile Robots

Evolving the Landscape of Interacting with the World

- Human-level mobility
- Intelligent perception
- Super-human sensors
- A.I.-assisted manipulation
- Un-tethered operation
- Autonomy, not just repetition

“Intelligent Mobility”

- Uniting perception and kinematics
- Abstracting the movement from the operator
- Applying what we already know about kinematics to machine learning

Reinforcement Learning

Stepping is easy, but walking is hard!

- Model predictive controls are excellent for well-understood low-dimensional problems
- Machine learning agents can iterate in simulation to build algorithms quickly
- A hybrid system brings the best of both worlds to moving rigid bodies through the places we go

Where that Mobility Takes Us

Navigation

Heightened situational awareness that the robot is able to leverage without direct supervision

Terrain

High-level movement direction with the robot handling stairs, obstacles, and tripping hazards

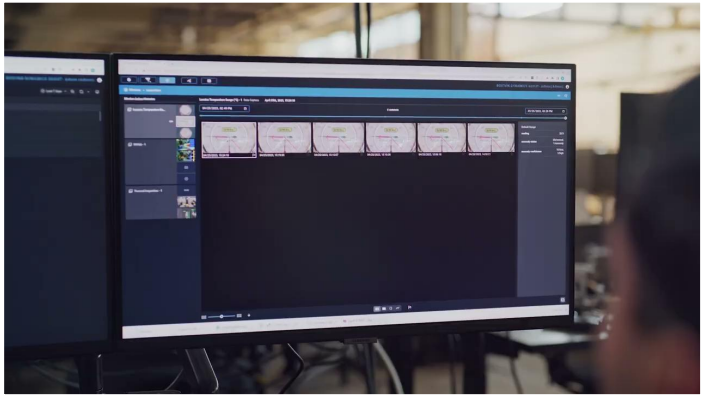
Time on Target

Get in close without going excessively slowly around challenging environments

Inspection

Getting a better viewpoint can be done with a tap, rather than significant amounts of control inputs

Automation Beyond Repetition

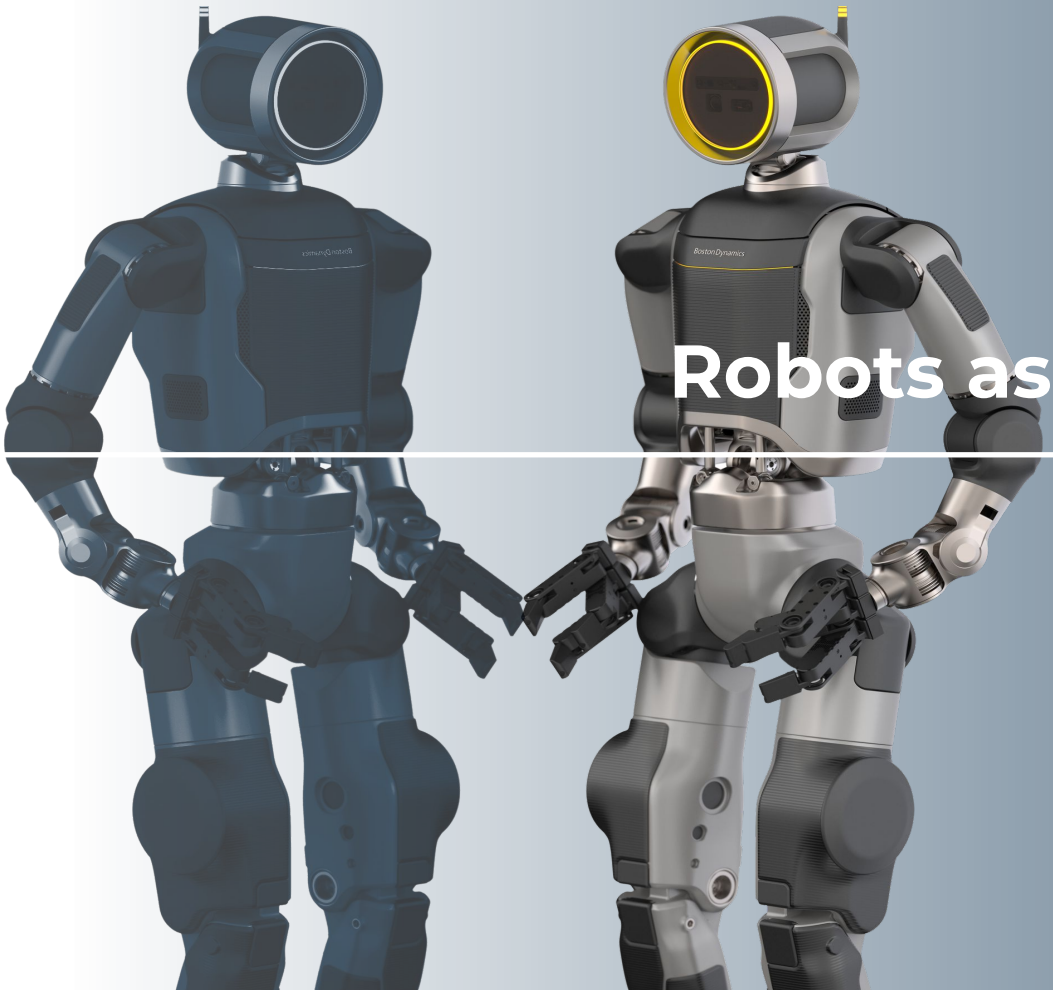


Surface contamination sweeps

- Detecting and marking locations of alpha contaminants on walls, containers, and vehicles
- LANL, Framatome

A.I. and data analysis

- Visual: Gauge Reading, Valve positions
- Acoustic: Anomaly detection, Gas leak detection
- Thermal and Radiation trending
- Digital twin creation



Robots as Twin Builders

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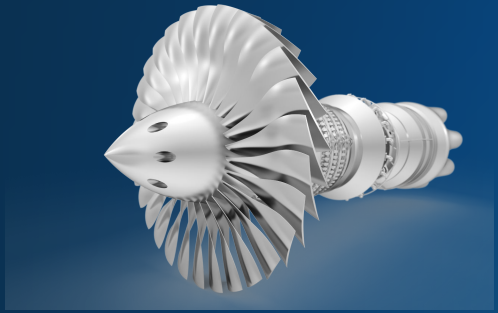
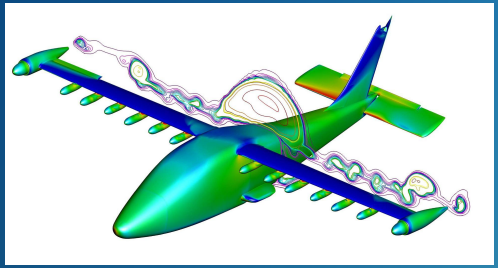
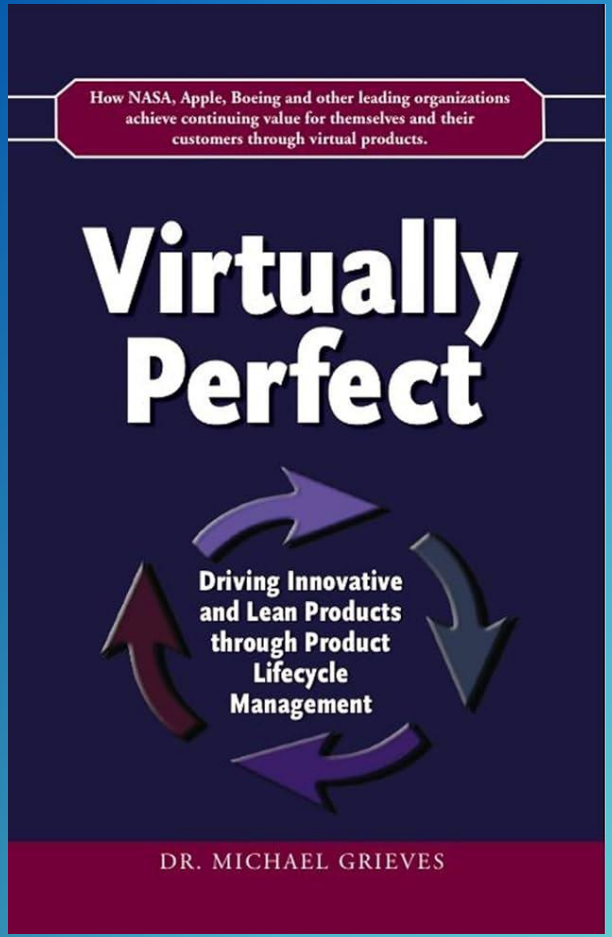
The digital twin originated as the conceptual model underlying **product lifecycle management (PLM)**.

It was pioneered by the aerospace industry in their late 90s/early 00s application of advanced CAD, simulation, and sensors to their design and operation processes.



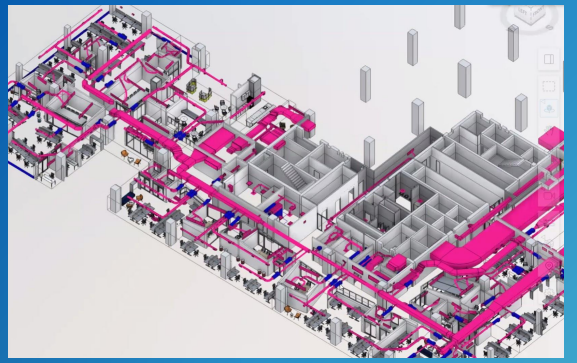




Defining the Site Twin

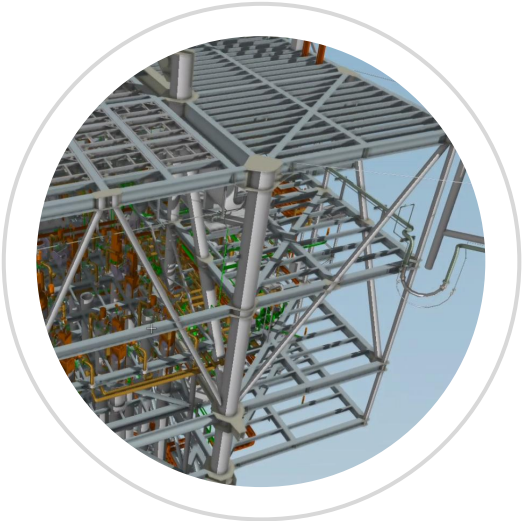
A site twin is a dynamic, virtual model of an environment and its assets that **reflects, predicts, and controls** the current state of its physical counterpart.

Current data is sent to the virtual twin from the physical twin via real-time data flow from sensors, and feedback is sent to the physical twin from the virtual twin via predictive simulation and real-time control interfaces.



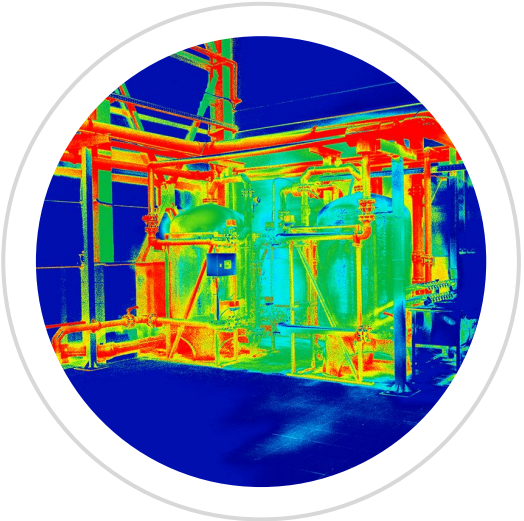
From Product Lifecycle to Facility Lifecycle

Design & Construction



Operations

Decommissioning



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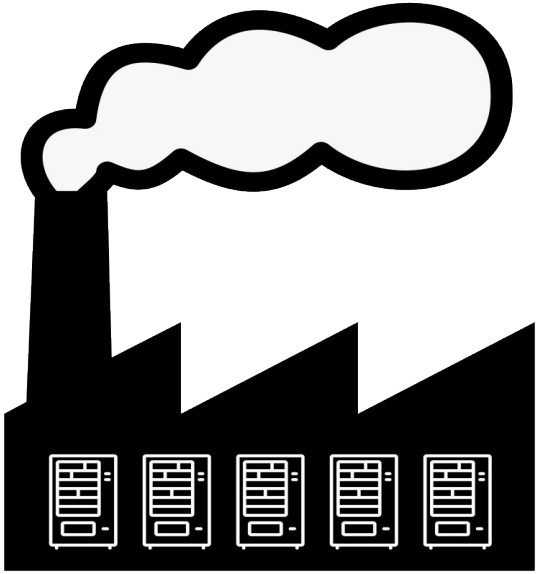
Twin Components

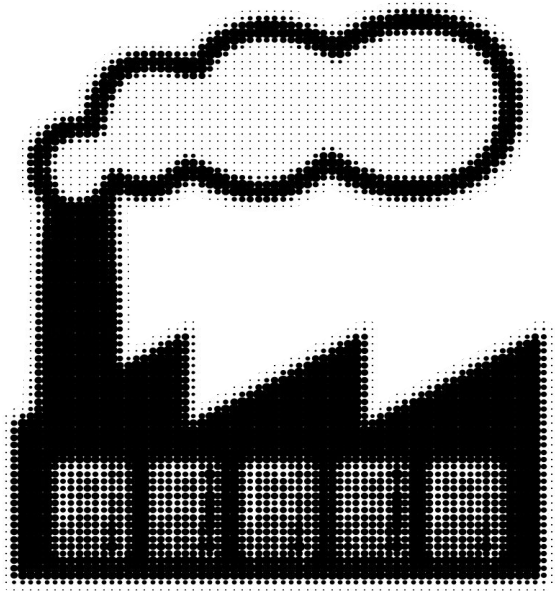
Physical Environment



Physical Assets

Communication Channels

Virtual Model



Virtual Assets

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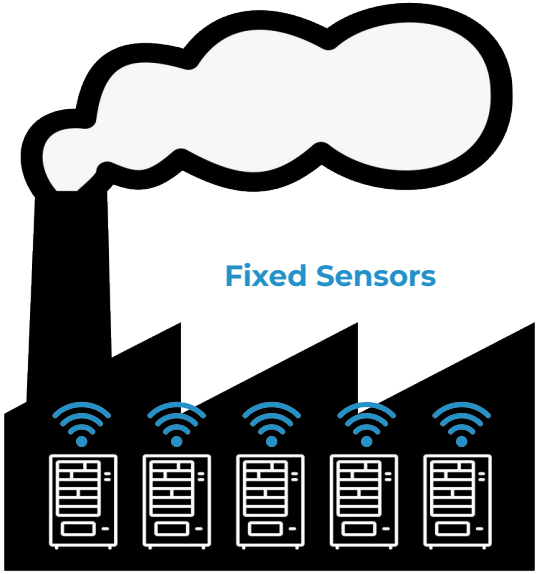
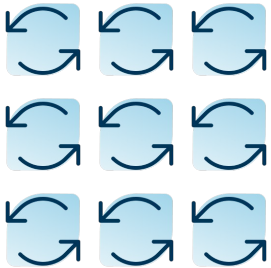
Fixed Sensing/IoT

Physical Environment



Physical Assets

Communication Channels



High Frequency

Virtual Model

Virtual Assets

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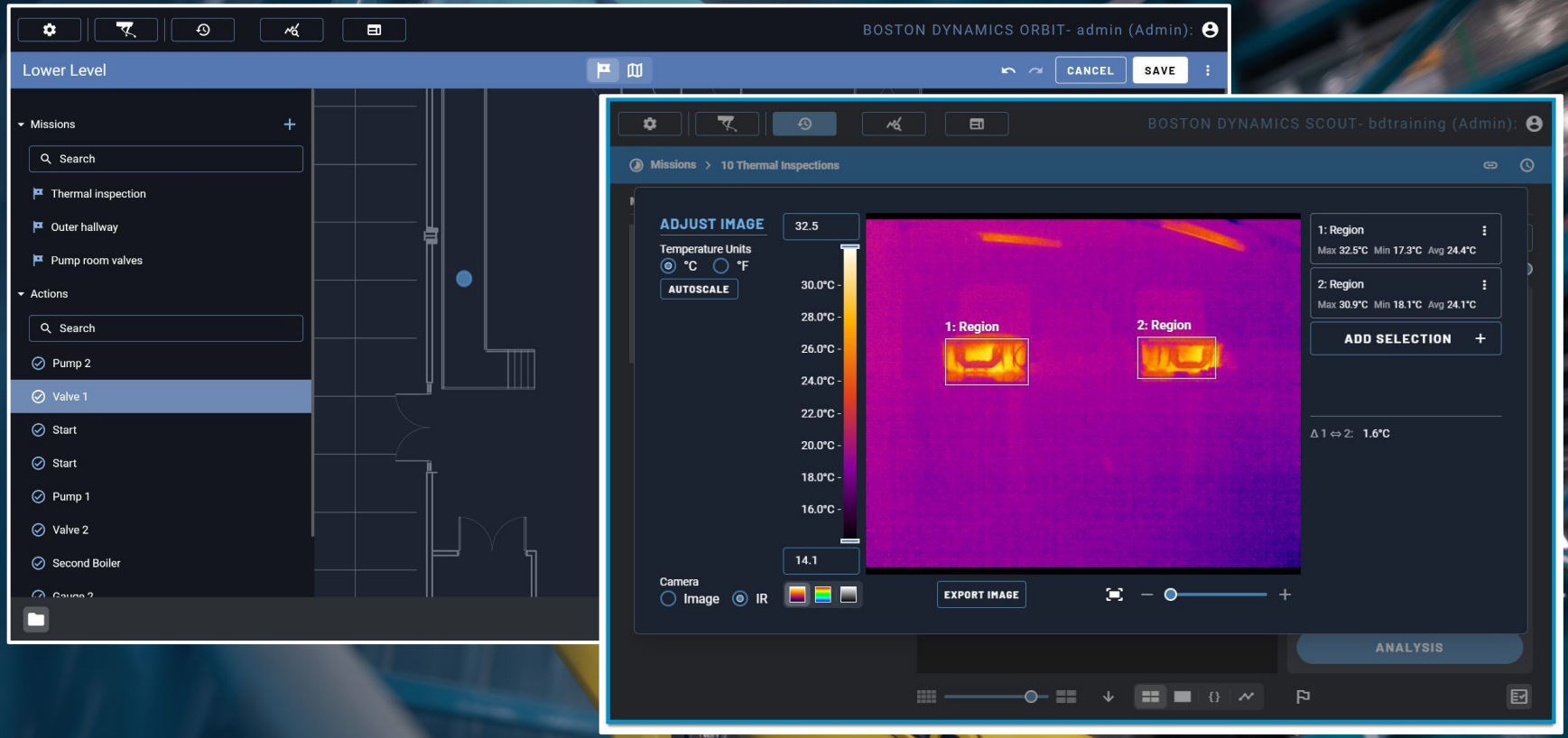
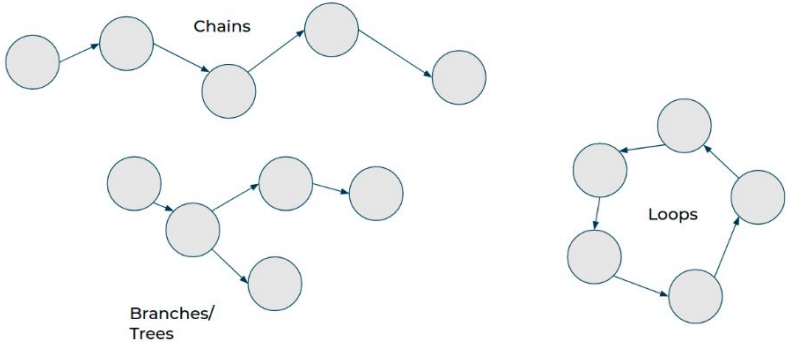
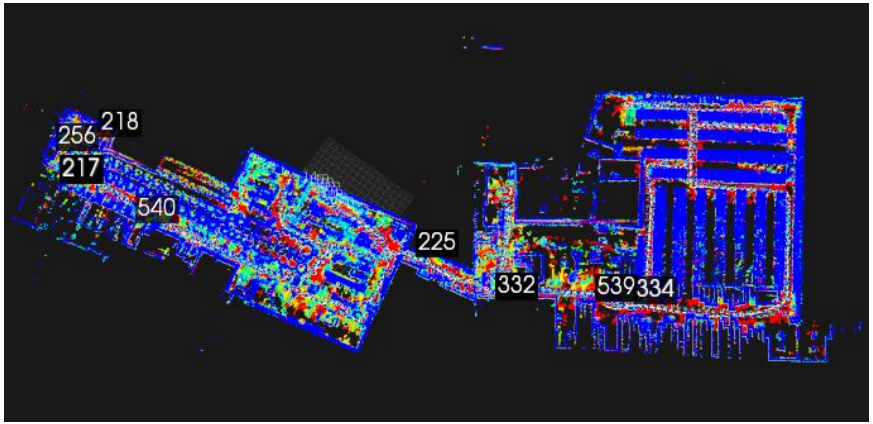
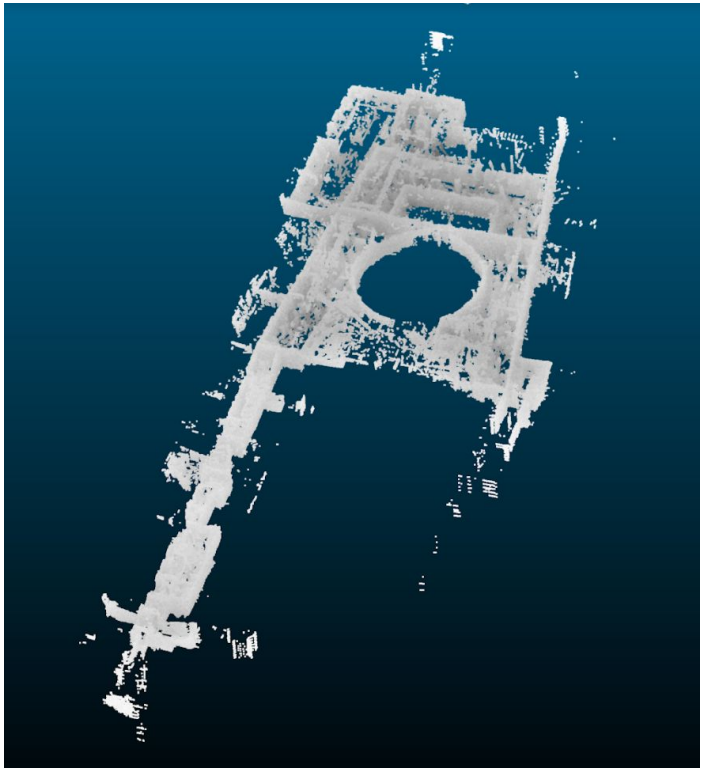
Remote Sensor Data



Robot Navigation Maps







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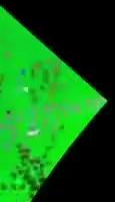
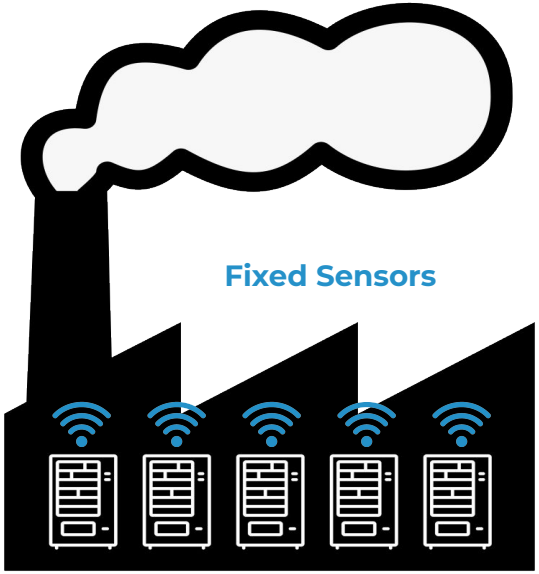
Autonomous Reality Capture



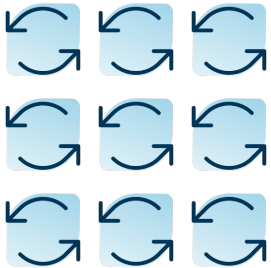
Fixed Sensing/IoT

Physical Environment



Physical Assets

Communication Channels



High Frequency

Virtual Model

Virtual Assets

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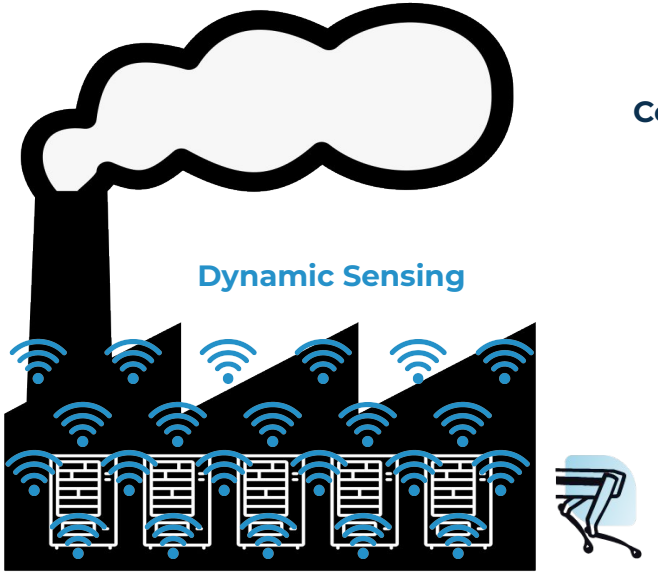
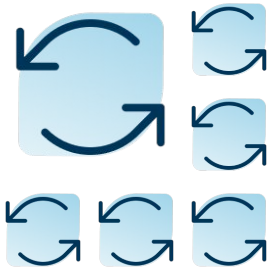
Dynamic Sensing/Mobile IoT

Physical Environment



Physical Assets

Communication Channels



Adaptive

Frequency

Virtual Model

Virtual Assets

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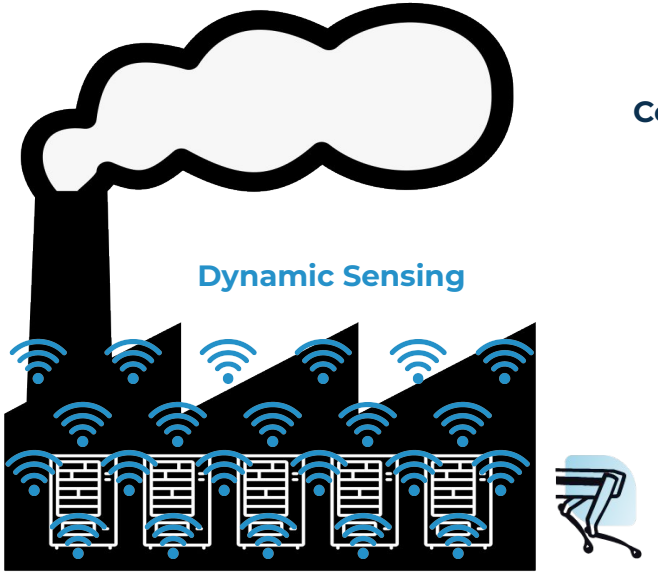
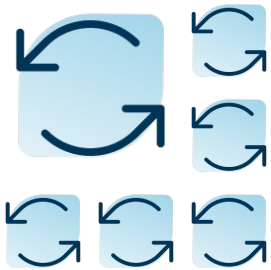
Dynamic Mapping

Physical Environment



Physical Assets

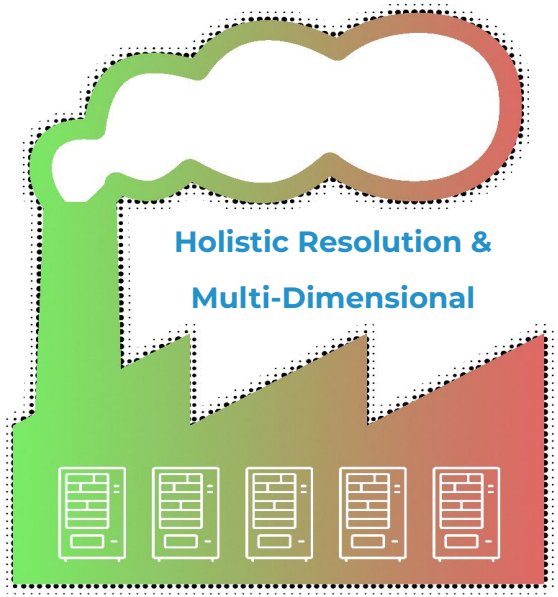
Communication Channels



Adaptive

Frequency

Virtual Model



Virtual Assets

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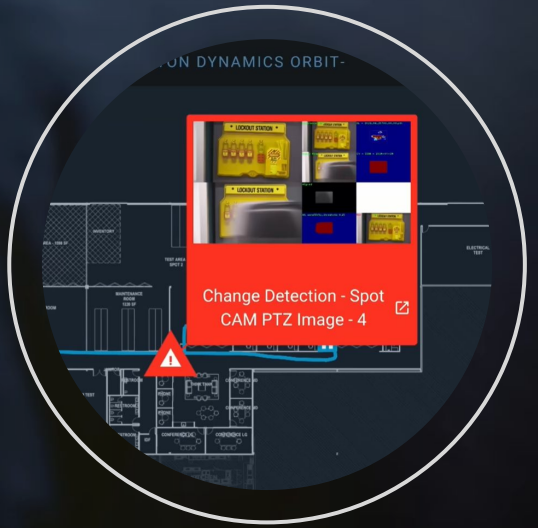
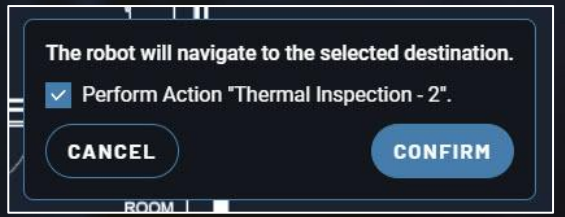
Site Twin Interfaces

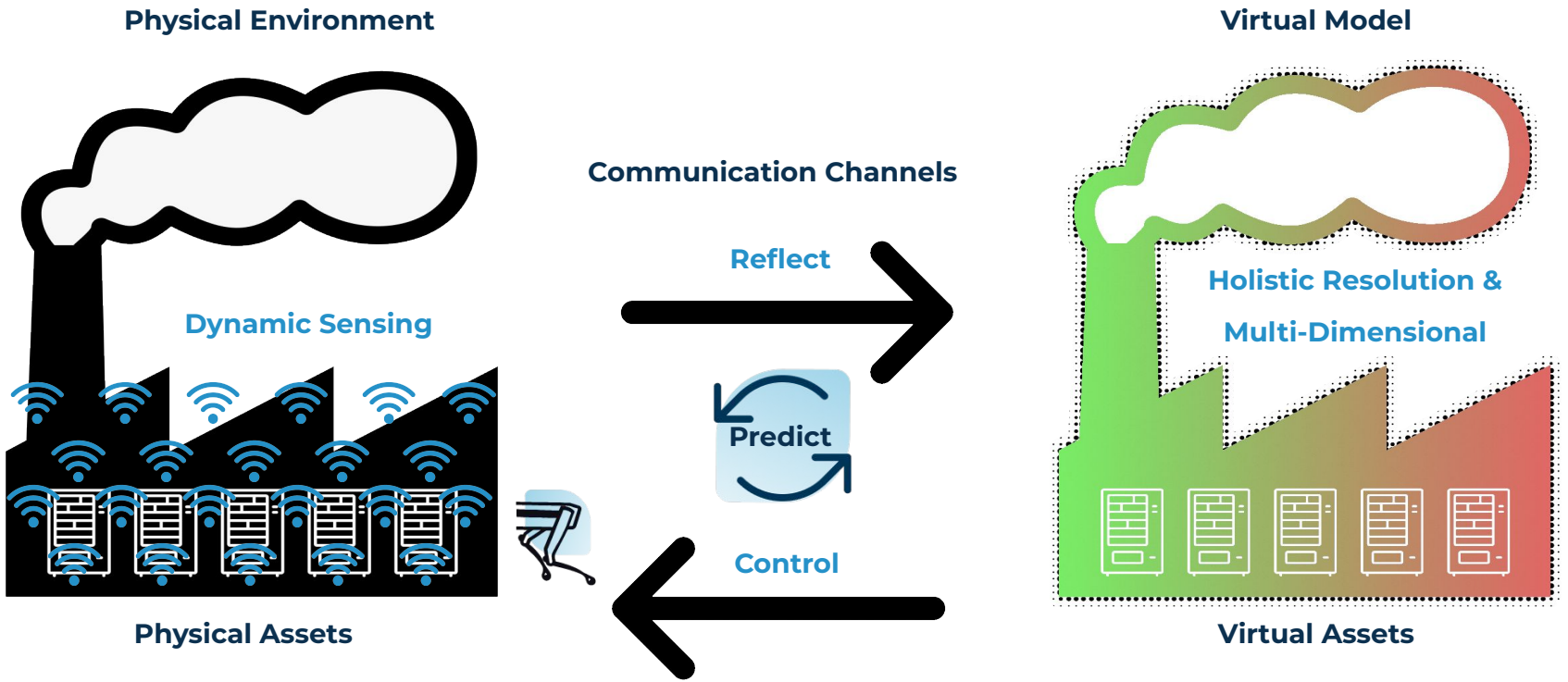
- Robot Location
- Asset Status
- Alerts



Site Twin Interfaces



Dynamic Mapping



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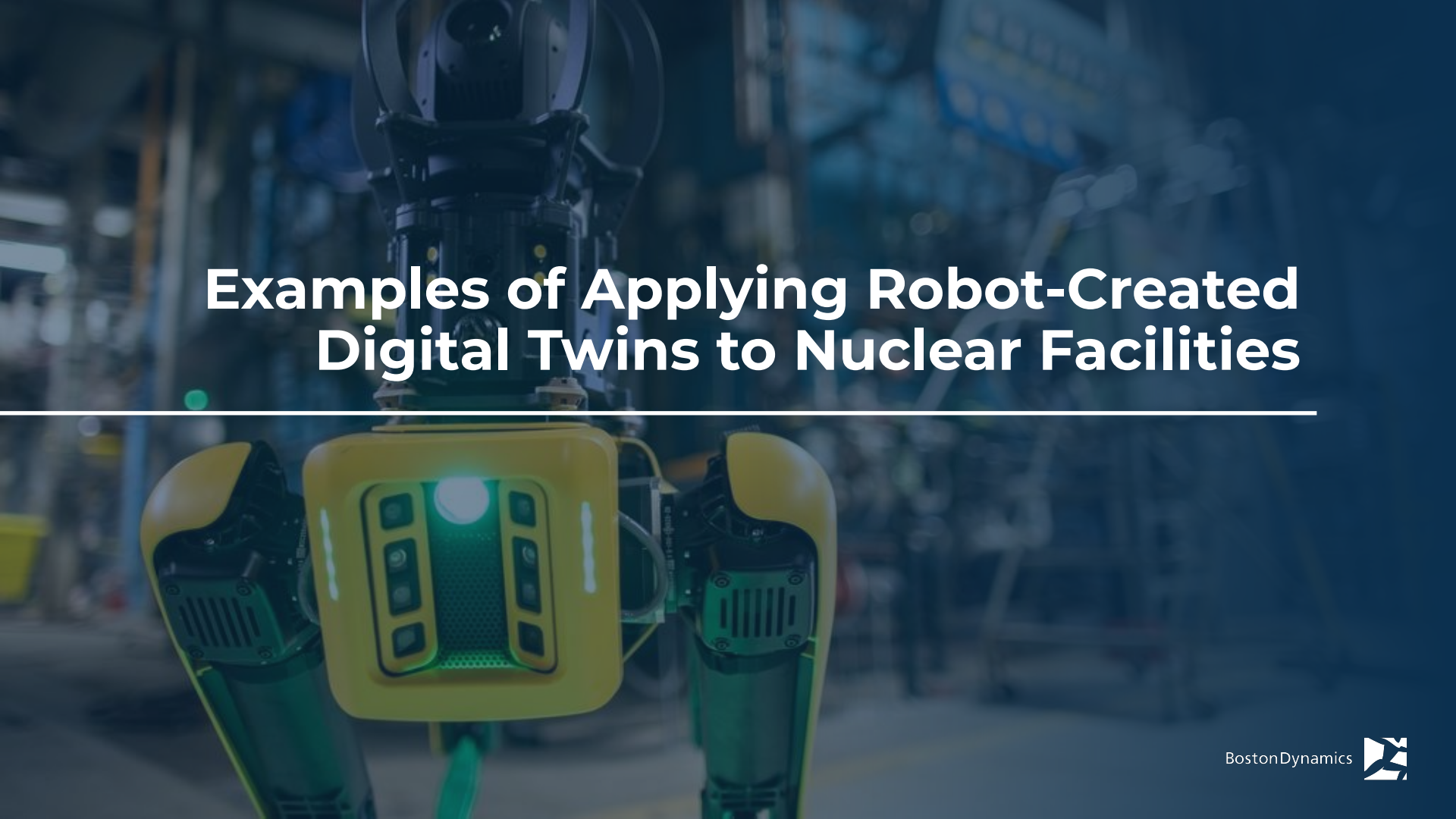
Examples of Applying Robot-Created Digital Twins to Nuclear Facilities



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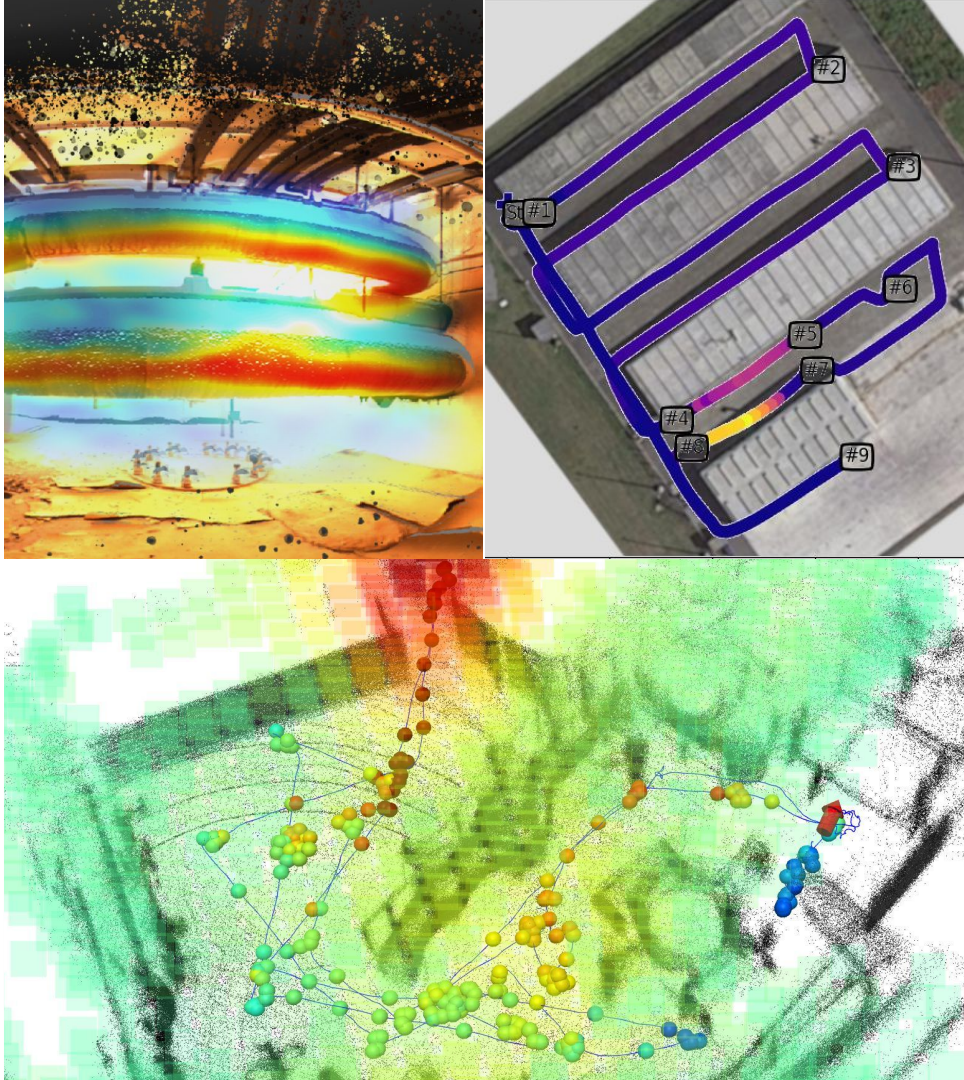
Digital Twins for Radiation Mapping

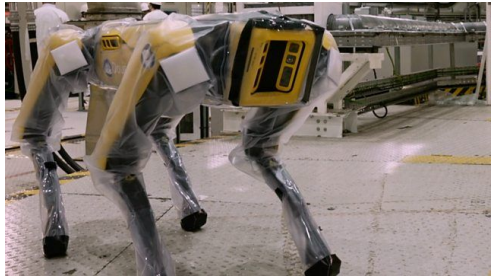
- A natural blend of existing technologies
  - Localization
  - Mapping
  - Dose rate estimation
  - Source characterization
  - LiDAR
- Clockwise from top left
  - Radiographic dose rates
  - ISFSI dose rate mapping
  - 3D point cloud w/ dose rate colorization

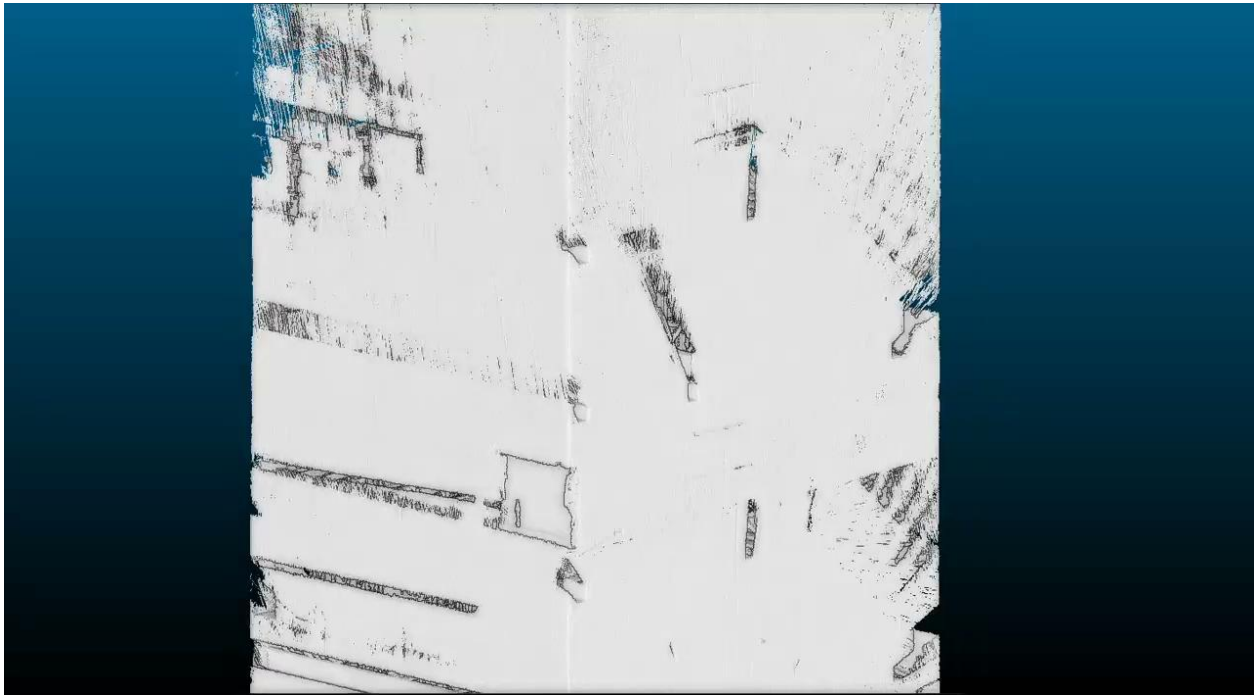


Case Study: Dounreay

- UK NDA decommissioning project of fast breeder reactor facility
- Entry to various fuel processing facilities that have been sealed for decades
- Surface swabs, visual inspection, radiation and 3D digital twin scans

Case Study: Dounreay

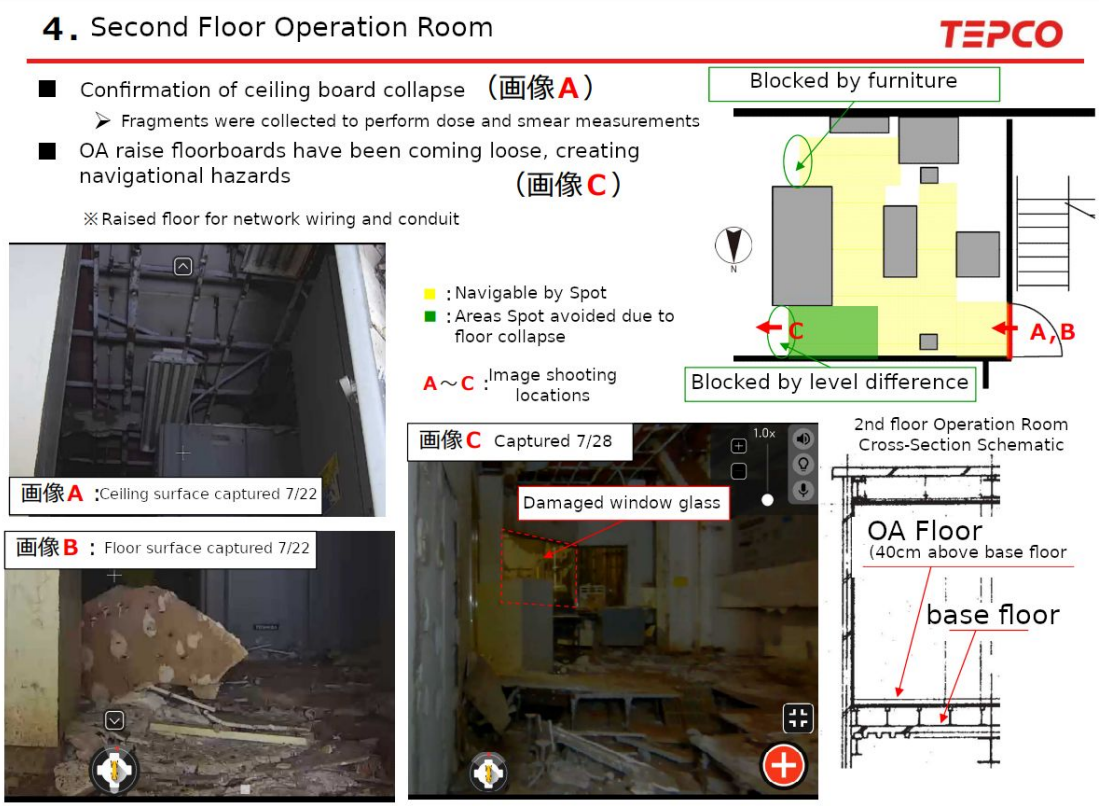




Case Study: Fukushima Daiichi

Fukushima Daiichi Unit 2 Fuel Handling Control Room

- Visual Surveys
- Navigational hazards
- Route planning



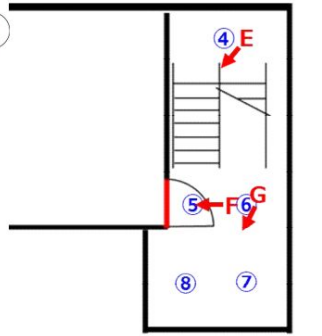
Case Study: Fukushima Daiichi

- Stair Climbing
- Comprehensive dose rate assessments

Reference 4: Situation around the 2nd floor staircase

TEPCO

- No major damage to walls, ceilings doors, or stairs
- The second floor has a higher dose rate than the 1st floor, with 4.10 mSv/h at measurement point 6



FHM 2nd floor schematic

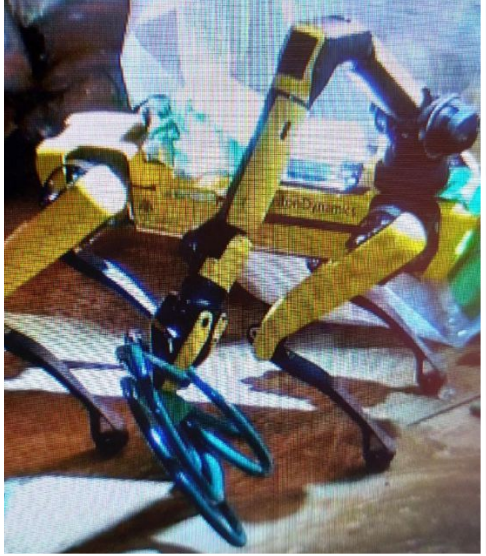
④～⑧ : Dose Measurement Points
E～G : Image capture locations

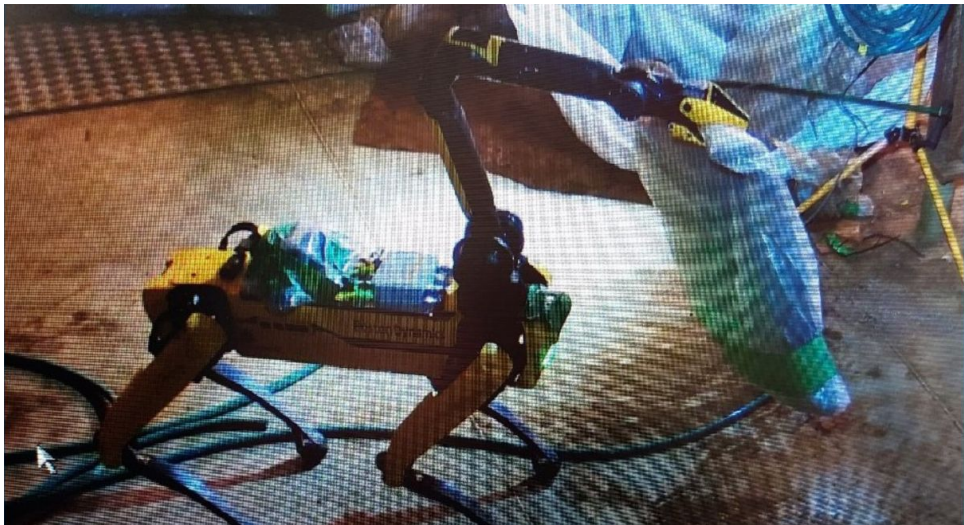
Measurement Points	Gamma Dose Rate mSv/h	
	July 6 ※1	Aug 1 ※2
④ Stair Landing	12.9	11.2
⑤ In front of CR door	36.0	27.2
⑥ Near 2nd fl. CR door	41.0	27.3
⑦ Near 2nd fl. CR door	36.8	40.1
⑧ Near 2nd fl. CR door	31.0	24.6

※1 : Measured at 1500mm above floor
※2 : Measured at 50mm above floor

Case Study: Sellafield

- Spot has moved enough waste to fill 18 Plutonium Contaminated Material (PCM) drums with 12 hours of work.
- 14 PCM drums worth of PPE waste *prevented*
- Phase 2 currently being developed–scope includes SPOT using shears to cut up discarded air hoses





Case Study: US Nuclear Site

Multi-robot Operation to Conduct NRC Downposting and Decommissioning Planning

- Highest recorded gamma dose for Spot w/o interruption: 2000 REM (20 Sieverts)
- Hundreds of radiation readings taken, full radiation digital twin created.
- Supporting other UGVs, removing debris, surface tests, dose, visual surveys, and device retrieval

Thank you!

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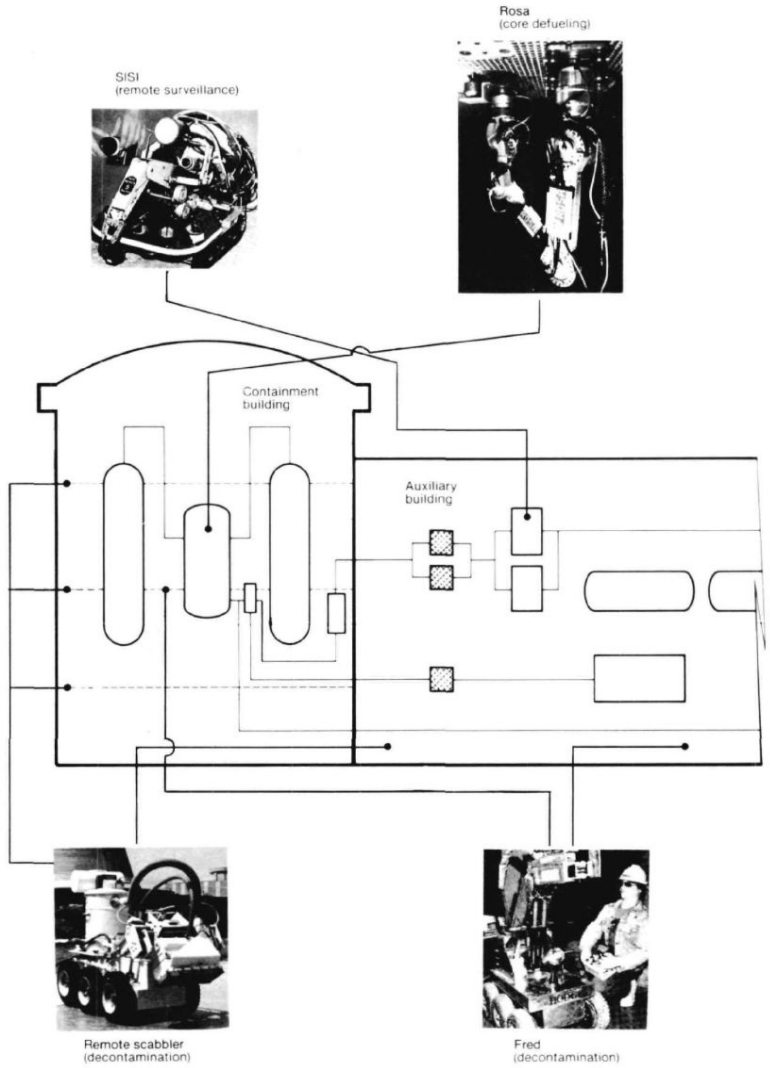
Rosa
(core defueling)
SISI
(remote surveillance)
Containment
building
Auxiliary
building
Remote scabbler
(decontamination)
Fred
(decontamination)