Digital twins and Ontology for Robot Assisted Decommissioning Operations

DORADO

EURATOM PROJECT DORADO

APPLYING DIGITAL TWINS AND DEDICATED ONTOLOGY FOR ROBOT ASSISTED DECOMMISSIONING OPERATIONS

Finnish Nuclear Symposium 2025, Espoo, Finland October 2025

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This project has received funding from the Nuclear Research and Training (HORIZON-EURATOM-2023-NRT-01), project #101165990.

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Contents

Introduction and project backgroud

Why digital tools:

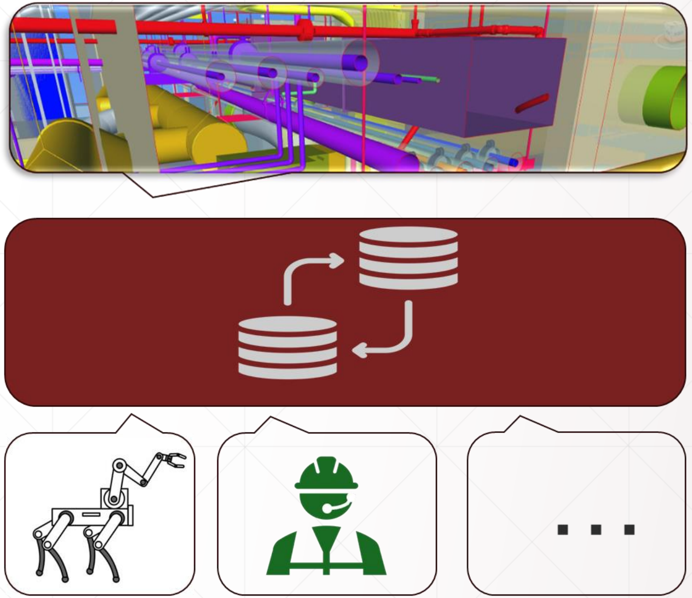
- The aim is to improve **safety** and **efficiency** while maintaining a realistic consideration of **costs**, and increasingly, **sustainability**.
- Legacy nuclear sites often present a unique set of difficulties:
  - Incomplete or Missing Data: Original design documents, operational records, and historical monitoring data may be lost or incomplete, making it difficult to understand the site's past and current conditions.
  - Unknown Radiological Conditions: Areas within the site may have undocumented or poorly characterized radiological conditions, posing risks to personnel.
  - Difficult and Hazardous Access: Many areas within legacy facilities may be confined, structurally unsound, or have high levels of residual contamination, making human access dangerous and time-consuming.
  - Lack of Accurate Spatial Information: Existing maps and drawings may not accurately reflect the current as-built state of the facility, hindering planning and execution of decommissioning activities.

The objective of DORADO

The opportunity
- BIM and Digital Twins are used at all steps of large projects;
- Digital Twins are not just simulations—they support remote operations, training, system integration, and even AI validation
- Flexible system requires field operators' data generation.

The challenge
- data fragmentation, low digital maturity, integration hurdles, and the need for trustworthy AI
- We need sandbox environments and cross-sector collaboration to accelerate safe deployment and regulatory readiness

Proposal by the DORADO project
- A platform to share/consume data across a wide variety of actors.
- Don’t re-invent the wheel
  - Existing data formats and data transfer protocols
  - Enable adding more technologies later



Digital twins and Ontology for Robot Assisted Decommissioning Operations

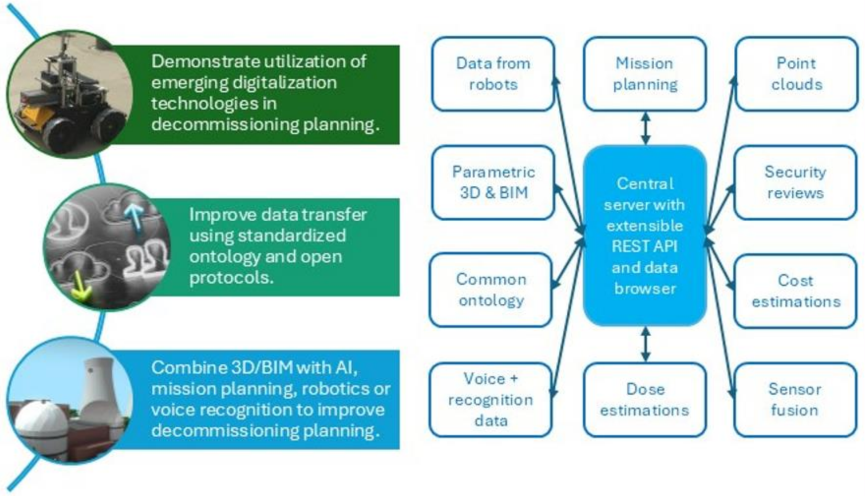
Key facts

36 months
12 partners
8 countries
5 work packages

Technologies

Robotics
Sensor fusion
Data management
Voice recognition
Ontology
BIM / 3D
Artificial intelligence
Dose estimation
Mission planning

Research goals



Work packages in brief

WP1
Prepare and manage project

WP2
Finetune research goals

WP3
Implement technologies

WP4
Demonstrate on real use cases

WP5
Train, exploit & standardize

Final expectations

1) Integrate emerging digital technologies into one coherent platform to support decommissioning planning.
2) Extend decommissioning ontology and data transfer protocols to cover new use cases.
3) Describe extensible API to provide standardized data exchange between tools used in decommissioning planning.

Technical requirements and data security

End-user's opinions

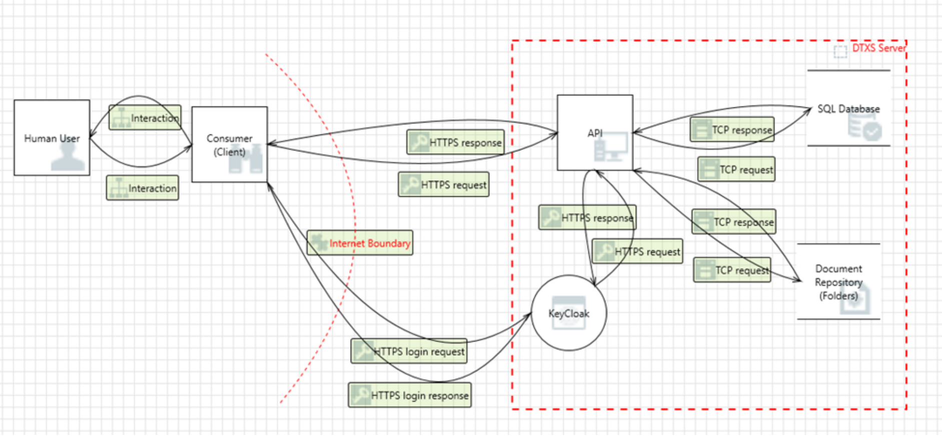
- Some of the responses highlighted the tendency to use the same methods used before to decommission similar plants;
- Some of the responses highlighted **the need to adopt the technologies needed to suit the needs of the nuclear industry (e.g., standardize how nuclear related data are represented in BIM**);
- **Data security** is one of the main concerns regarding the implementation of emerging digital technologies, which was reflected by the need for **local servers** in most responses;
- The need for **training or 3rd party operations** for new technologies is one of the main obstacles;
- Digital twin updates shall be frequent, but a real-time update is not necessary unless an immediate notification is needed for a hazard spotted or an anomaly detected;
- This was reflected by the interest in using the digital twin features for scenario planning, and visualization of contamination spread and migration while still having a strong need for real-time updates of sensor readings ;
- **Automatic pre-filling of reports and work permits** was one of the applications with high interest ;
- **Inefficient data management was one of the main issues reported**, especially for big projects where excel sheets or similar data logging methods have issues with scalability.

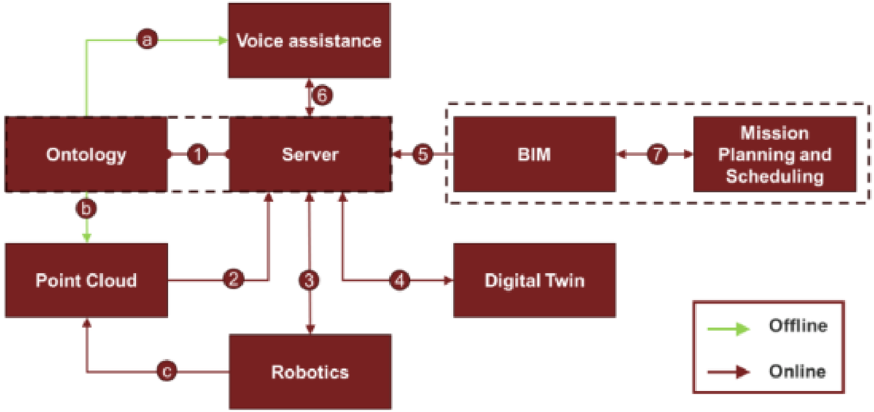
Technical design requirements

- Requirements from stakeholder's needs (e.g. historical data, visualization needs), technical implementation (automations, validation) and safety (validation, data security) and available hardware.
- E.g. comply with industry standards, enable manual validation and hybrid/offline mode, automation of most frequent steps, identifying the data formats.
- Handled separately for each technology during WP2 in 2024-2025 being implemented now in WP3.

Safety and data security

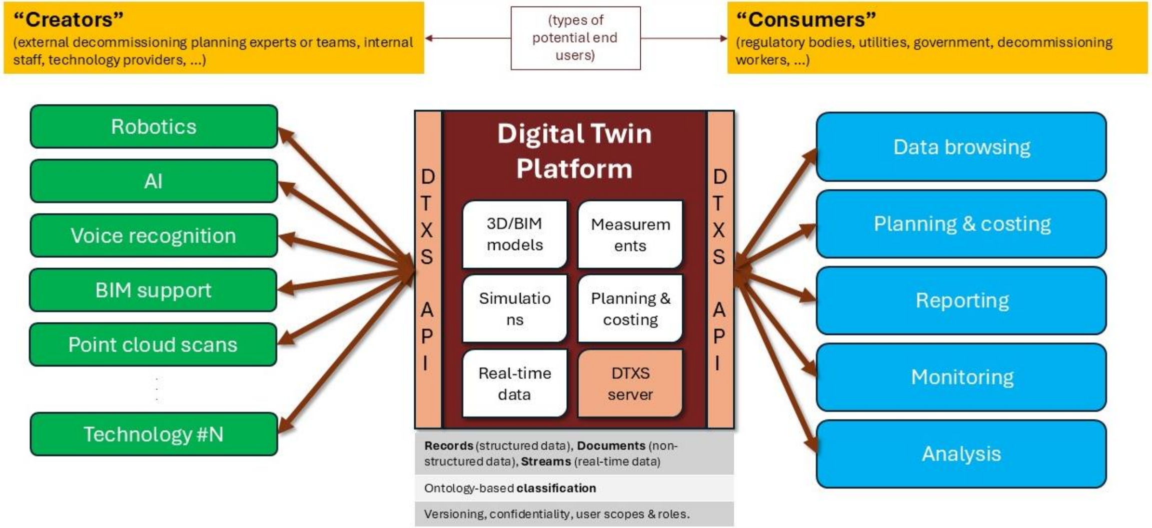
- Safe integration and operation of interconnected technologies by embedding risk management principles early in system design.
- Following ISO 27005 and ISO 27002 standards.
- Risks related to e.g. incomplete data, misaligned coordinates or robot malfunction.
- Enable hybrid online/offiline operation
- Threat modelling in the server operation.





Technological development, examples

Further development in DORADO
Data compatibility and ontology implementation

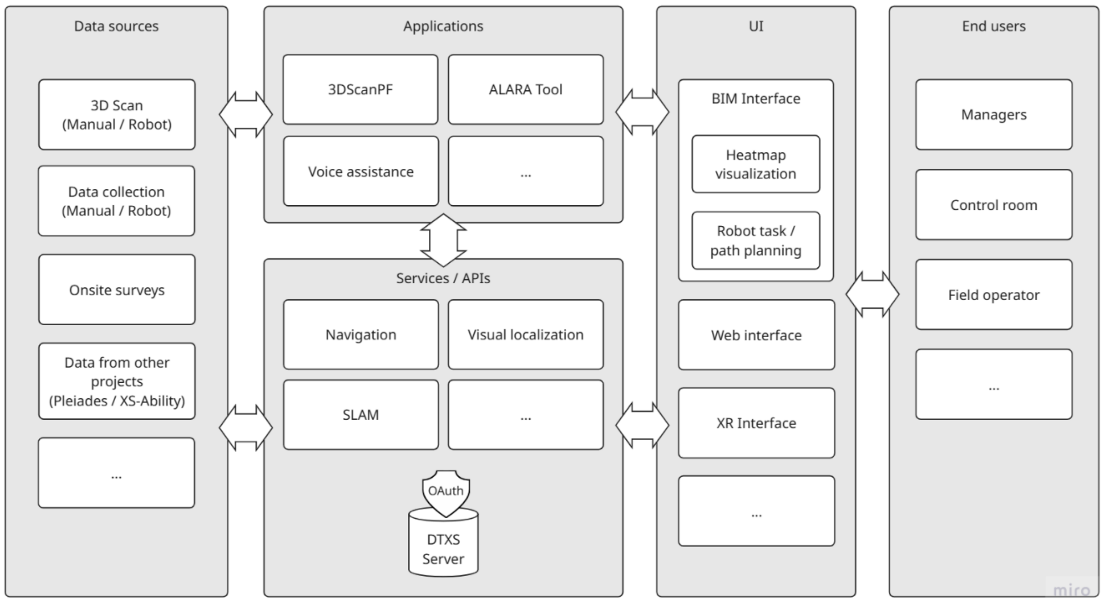


- DORADO aims to incorporate essential compatibilities, like:
  1) Sensor data mapping with temporal dimension;
  2) Environment data comparison against BIM;
  3) Point-cloud and 3D model change detection;
  4) Digital twins based ALARA dose estimation;
  5) Server-based integration with IFC file format and extended data queries;
  6) Mission control, robot route optimization;
  7) Human to System smart voice assistant interface;
  8) Standardization using the common ontology.

Technological applications in DORADO

System architecture

- Extensible, modular structure based on ontology, clearly specified interfaces and standardized conventions between modules;
- Designed to support various data types/sources, accommodate different applications and integrate various user interface types;
- Possibility to extend or even change individual implementations without disturbing the functionality of the whole system;
- It aims to ensure compatibility and flexibility.



[21] DORADO system architecture

Technical development work in DORADO
Ontology based approach

Ontology helps to find common definitions and wording;

Ontology defines basis for data structure development;

Shown DORADO ontology has common members with the DECOM CORE ontology from the PLEIADES project:

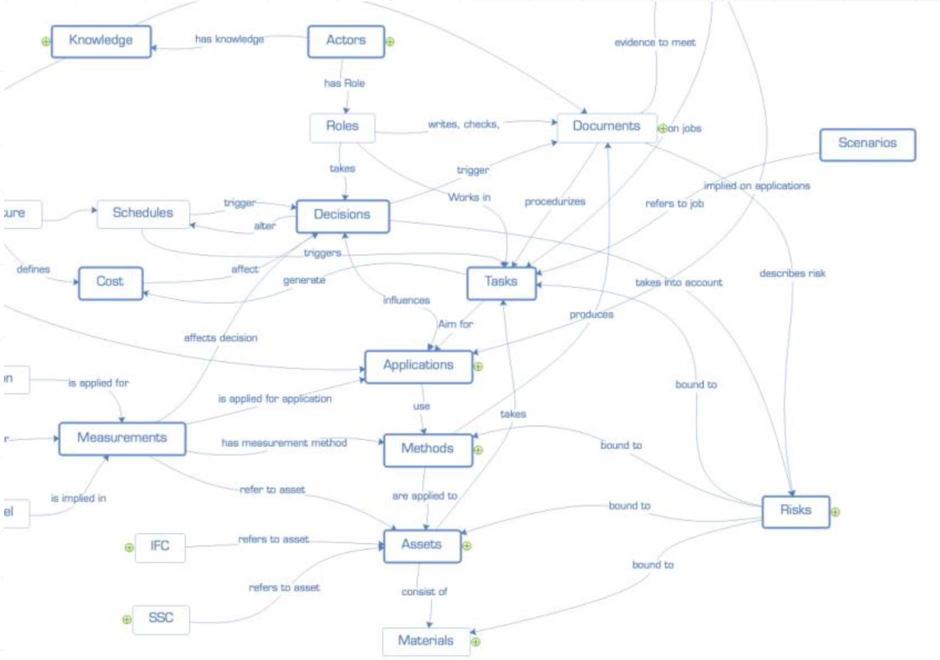
Actor

Room (as part of IFC)

Risk

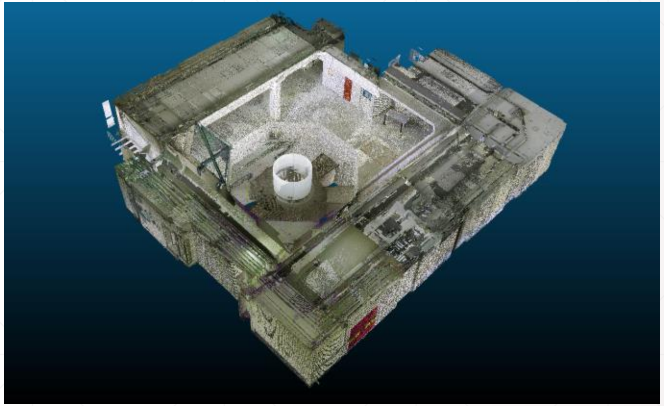
While the DECOM CORE ontology is focusing on the project, DORADO is adding the mission planning and feedback part.

Compatible with IAEA IDN Wiki, NEA and EU-JRC ontology research



Visual Positioning using laser-scanned point clouds

- Estimate the camera pose (position and orientation) relative to a visual representation of a known scene (dense laser-scanned point cloud).
- Visual Place Recognition (VPR) combined with ML-based dense feature matching and fast raytracing using NanoVDB (NVIDIA's library for sparse volumetric grids)
- Supports multiple concurrent spaces (input point clouds)
- Use cases:
  - 6DoF cm-level indoor positioning for any given camera
  - Project image pixels to the 3D scene
  - Initialize relative tracking (e.g., VIO)
  - AR headset and robot tracked in the joint coordinate frame -> human-robot interaction in 3D



The only input for the visual positioning is the laser-scanned point cloud of the environment

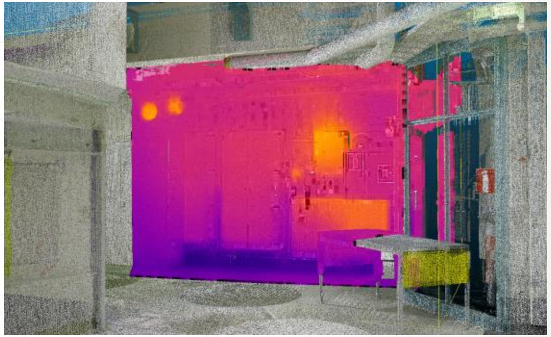
FiR1 scan: Test image versus image rendered from point-cloud using the estimated pose

Development work in DORADO
Sensor data fusion

- Current State-of-the-Art of environmental mapping relies on sensors which operate independently;
- In DORADO, new methods for sensor data mapping are developed to automatically integrate data from multiple sensor types into a unified reference frame;
- The method uses SLAM (Simultaneous Localization And Mapping) based locations tracking and automatic pose detection by comparing photos and LiDAR (Light Detection And Ranging) point clouds.

- Use of FLIR One Edge Pro thermal camera mounted on Android phone
  - No real radioactive sources in this case, but data processing procedure from e.g. a gamma camera would be the same.
- Steps:
  - Estimate the 6 DoF pose of visible light image using visual positioning
  - Use 2D-2D correspondences between visible light and Multi-Spectral Dynamic Imaging (MSX) image together with dense depth (rendered from the laser-scanned point cloud) to estimate the pose of MSX image
  - Project MSX pixels to 3D
- Work in progress

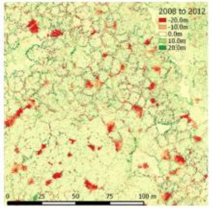
View to laser-scanned point cloud

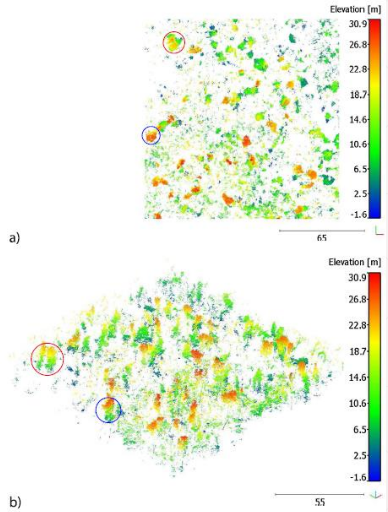


View after projecting colors from MSX image to 3D

Change Detection: State-of-the-Art (I)

- Used in a variety of areas:
  - Traffic monitoring;
  - Documentation of urban development;
  - Damage assessment (e.g. following natural disasters);
  - Etc.
- Change detection depend on spatial dimension [13]
  - Vertical changes
    - Referred to as a one-dimensional (1D) method
  - Changes in all possible directions
    - Referred to as a three-dimensional (3D) method



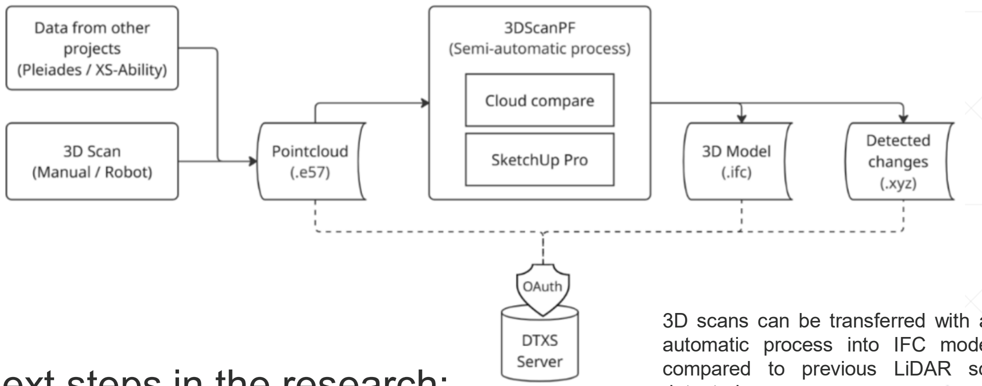


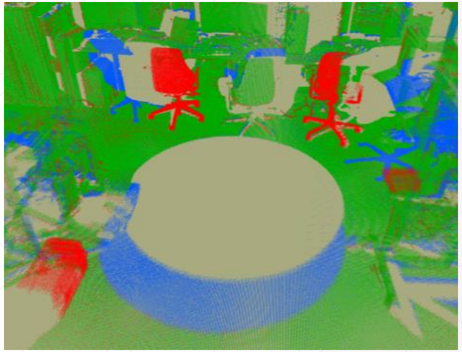
[13] Lindenbergh, R., & Pietrzyk, P. (2015)

Technological applications in DORADO

Change detection

- System design and implementation workflow





3D scans can be transferred with a well-defined semi-automatic process into IFC models. Here, changes compared to previous LiDAR scans can also be detected.

- Next steps in the research:
  - Automated segmentation of complex objects / geometries in a Point Cloud;
  - Automated modelling of complex objects from (segmented) Point Clouds;
  - Detection of materials in point clouds;
  - Dealing with gaps / holes / hidden areas in a Point Cloud;
  - Dealing with loss of accuracy due to voxel information.

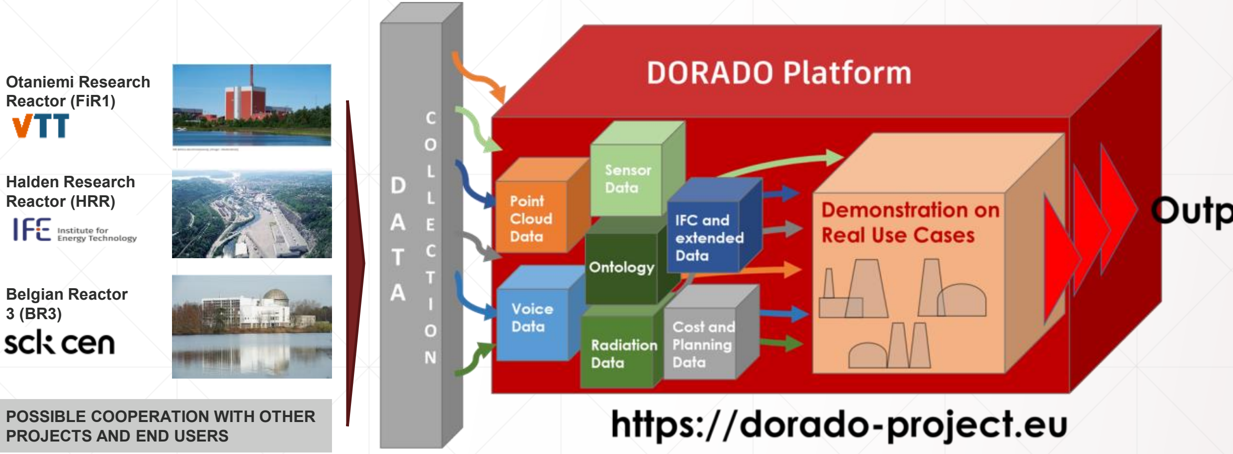
Mission Control and Route Optimization

- BIM-based navigation and SLAM integration.
- Semantic mapping with scene graphs.
- Multi-robot task allocation and planning.
- Use of AI for dynamic route optimization.

Technical use cases

Implementation in DORADO

- DORADO will use data based on information from real facilities, like:
  - Point clouds;
  - Historical photogrammetry;
  - Dose rate survey;
  - 3D models;
  - Robot data (LiDAR and RGBD);
  - LiDAR SLAM and Visual SLAM;
  - Inventory data;



- Further data is being collected or completed, like:
  - Dose rate mapping and spectrometry;
  - Etc.

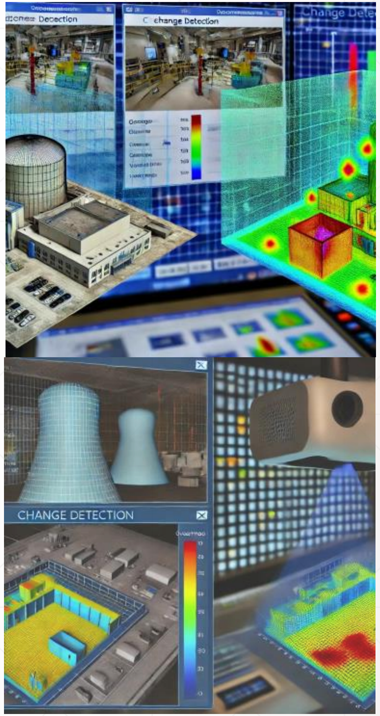
Use Case 1: Intelligent Mission Planning and BIM Integration

- **Scenario: A decommissioning team receives a high-level mission plan for surveying a specific area within a legacy facility.**
- High-level mission plans translated into robotic/manual tasks
- Integration with BIM for spatial visualization and planning
- Robots perform LiDAR scans and generate point clouds
- Radiation heatmaps created using simulation engines
- Voice-assisted reporting enriches BIM with semantic data

(AI generated image for illustration purposes only)

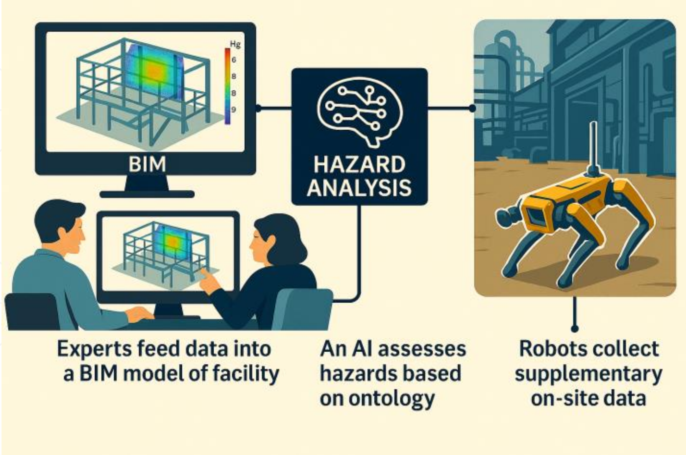
Use Case 2: Precise Localization and Change Detection

- **Scenario: Over time, multiple scans of the same area within the legacy facility are conducted using robots or handheld devices from various viewpoints. Accurate localization of these scans (within a global coordinate system) and the ability to identify changes over time are crucial for monitoring the decommissioning progress and identifying potential issues.**
- Multi-view scan registration for accurate localization
- Comparison of historical and new scans to detect changes
- Ontology categorizes and evaluates detected differences
- Supports long-term monitoring and safety assurance



Use Case 3: Ontology-Driven Reporting and AI-Enhanced Hazard Assessment

- **Scenario: Decommissioning personnel need to generate comprehensive reports about the state of the legacy/decommissioning site. In this process, there is a need for proactive hazard identification based on the available data.**
- Voice-assisted reporting generates structured documentation
- Automatic comparison with BIM to identify discrepancies
- AI assesses hazards based on ontology and data
- Robots collect missing data for comprehensive analysis



Use Case 4: Autonomous Waste Drum Monitoring

- **Scenario: Numerous waste drums are stored within a designated area (e.g. interim storage) of the legacy facility. The condition of the waste needs to be regularly monitored, including radiation levels and the structural integrity of the drums.**
- Robots navigate to scan points for radiation monitoring
- Real-time readings compared with expected values
- Alerts triggered by significant deviations
- Reduces manual inspections in hazardous areas

(AI generated image for illustration purposes only)

Next steps and conclusions

Conclusions

- DORADO continues the previous PLEAIDES project by integrating more technologies to the server and extending the ontology for new applications.
- Eight new technologies are handled. Emphasis on utilizing BIM and AI.
- Holistic approach and data compatibility is the key!
  - Don’t re-invent the wheel and leave room for future applications
  - The development work can benefit from experiences in other fields of industry (and vice versa)
- After the first year we have completed the techinical requirements and business value analysis
- Technical development work is on-going in 2025-2027.
- Looking forward for end-users’ comments for demonstration of use cases.
- Interested? Join our events and newsletter for more info.

Thank you for your attention!

Funded by the European Union