



Applying Digital Twins and Ontology for Robot Assisted Decommissioning Operations - Euratom Project DORADO

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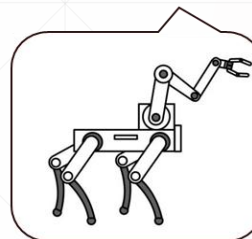
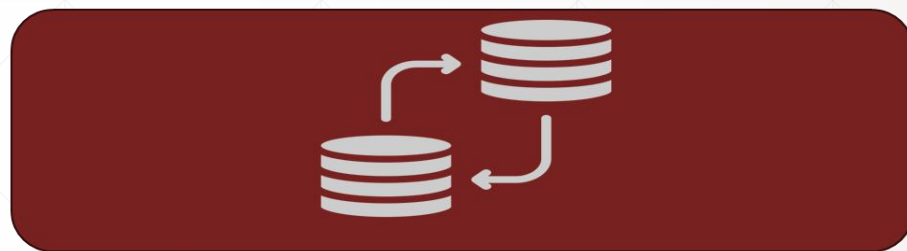
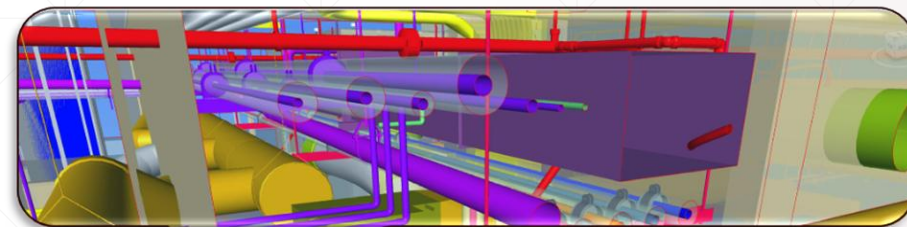
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Introduction and project background

The objectives of DORADO

- Legacy nuclear sites suffer from missing data, unknown radiological conditions, hazardous access, and poor spatial information;
- BIM and Digital Twins are already applied technologies in other fields of industry:
 - They are not just simulations, they help e.g. planning, remote operations, training, and AI validation;
 - require better data and integration.
- Key challenges include fragmented data, low digital maturity, integration issues:
 - the need for trustworthy AI;
 - and sandbox testing.
- Proposal by DORADO: a shared data platform using existing formats and protocols, designed to be extensible for future technologies.



Digital twins and Ontology for Robot Assisted Decommissioning Operations

DORADO Partners



Key facts	Research goals	Work packages in brief
36 months 12 partners 8 countries 5 work packages		WP1 Prepare and manage project WP2 Finetune research goals WP3 Implement technologies WP4 Demonstrate on real use cases WP5 Train, exploit & standardize
Technologies		
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.	

Business value analysis and technical requirements

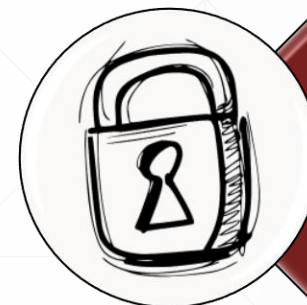
User needs and conceptual design

Establishing design requirements: determine the requirements for the DORADO platform's design to align with project expectations;

Developing Prototype Specifications: Create specifications for the system prototype and testing/demonstrations in accordance with established requirements;

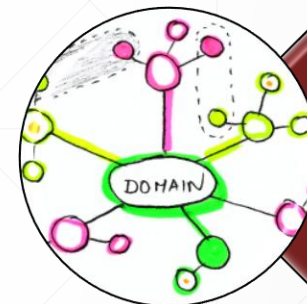
Defining Key Performance Indicators (KPIs): Identify/Update KPIs to assess the DORADO platform's impact relative to user needs;

Understanding the impact mechanisms of the *platform changes* and *KPIs* into **business value (KBIs)**. How the changes are linked to different business processes and how to evaluate the impact.



Data governance

- Safety and security
- Data management framework

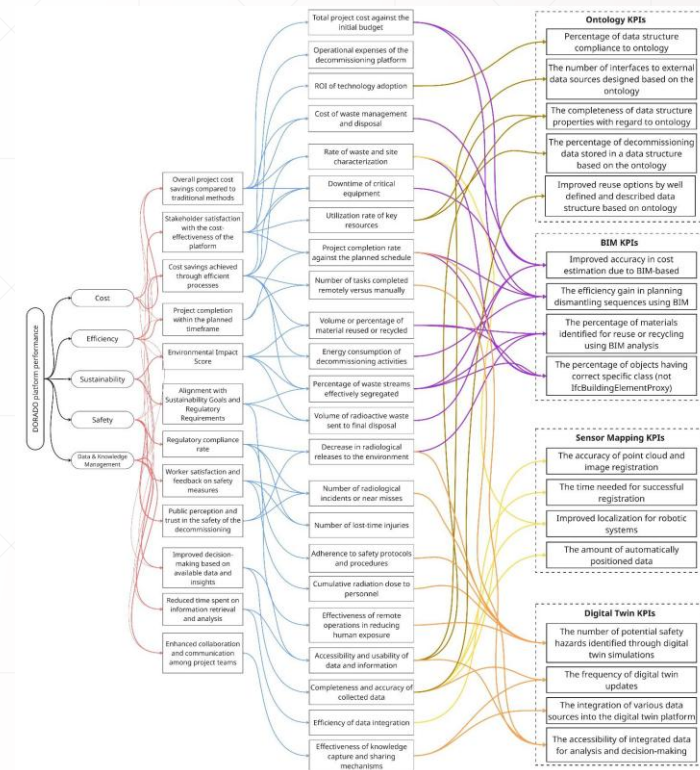
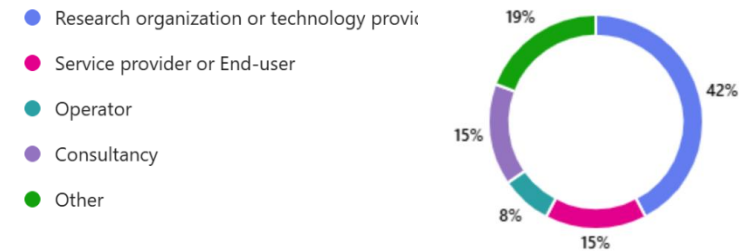


DORADO Ontology

- Ontology for the decommissioning
- Accommodate target technologies

Business Value Analysis

- Better understanding of the state-of-the-art for each technology and the synergy between these technologies;
- Better understanding of user needs and how technologies can contribute to fulfill these needs;
- Defining the main use cases and blocks needed to complete the system architecture;
- Mapping of the system KPIs (S-KPIs), technology specific KPIs (T-KPIs), and the KBIs to ensure better tracking of the platform development to fulfill the needs of the stakeholders.



Identified technical user requirements

Stakeholder-Driven Requirements

- Offline capability for limited-connectivity facilities.
- Intuitive interfaces for workers in high-risk environments.
- Frequent digital twin updates and integration of radiological + geometric data.
- Automated reporting to reduce manual workloads.

Data Security Considerations

- OAuth2.0-based authentication, secure DTXS REST API.
- STRIDE-based threat modelling identifying spoofing, tampering, DoS, SQLi.
- Mitigations: TLS enforcement, logging/auditing, mutual authentication, input validation.

Use Case–Driven System Design

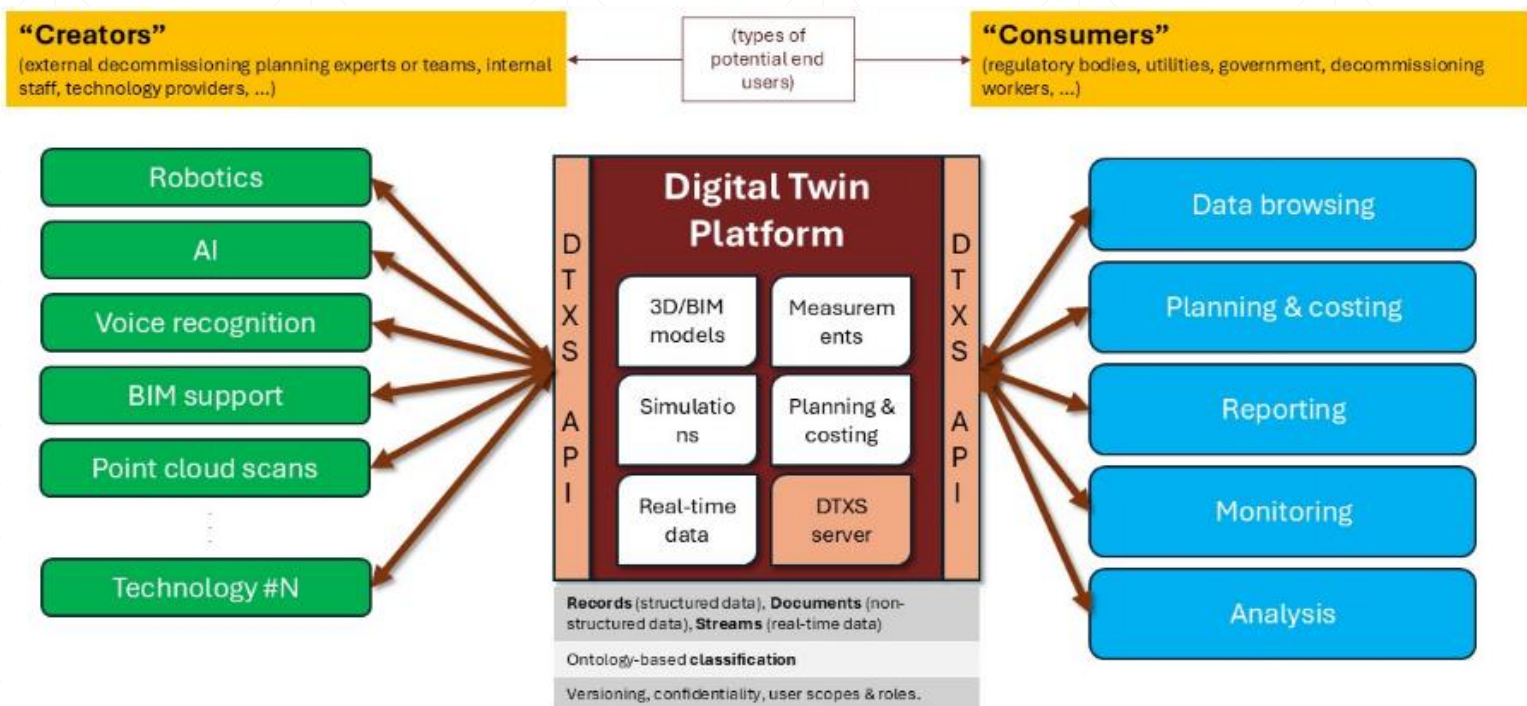
- Mission planning & BIM integration.
- Change detection via multi-scan comparison.
- Ontology-driven reporting and hazard assessment.
- Autonomous waste drum monitoring.

Hardware & Architecture

- Robots: quadruped (Spot), wheeled (Jackal), advanced sensors (LiDAR, RGB-D, thermal, gamma detectors).
- Central secure server for IFC/BIM, point clouds, sensor data with high-speed retrieval and interoperability.

Technical development work: Examples

Technological implementation

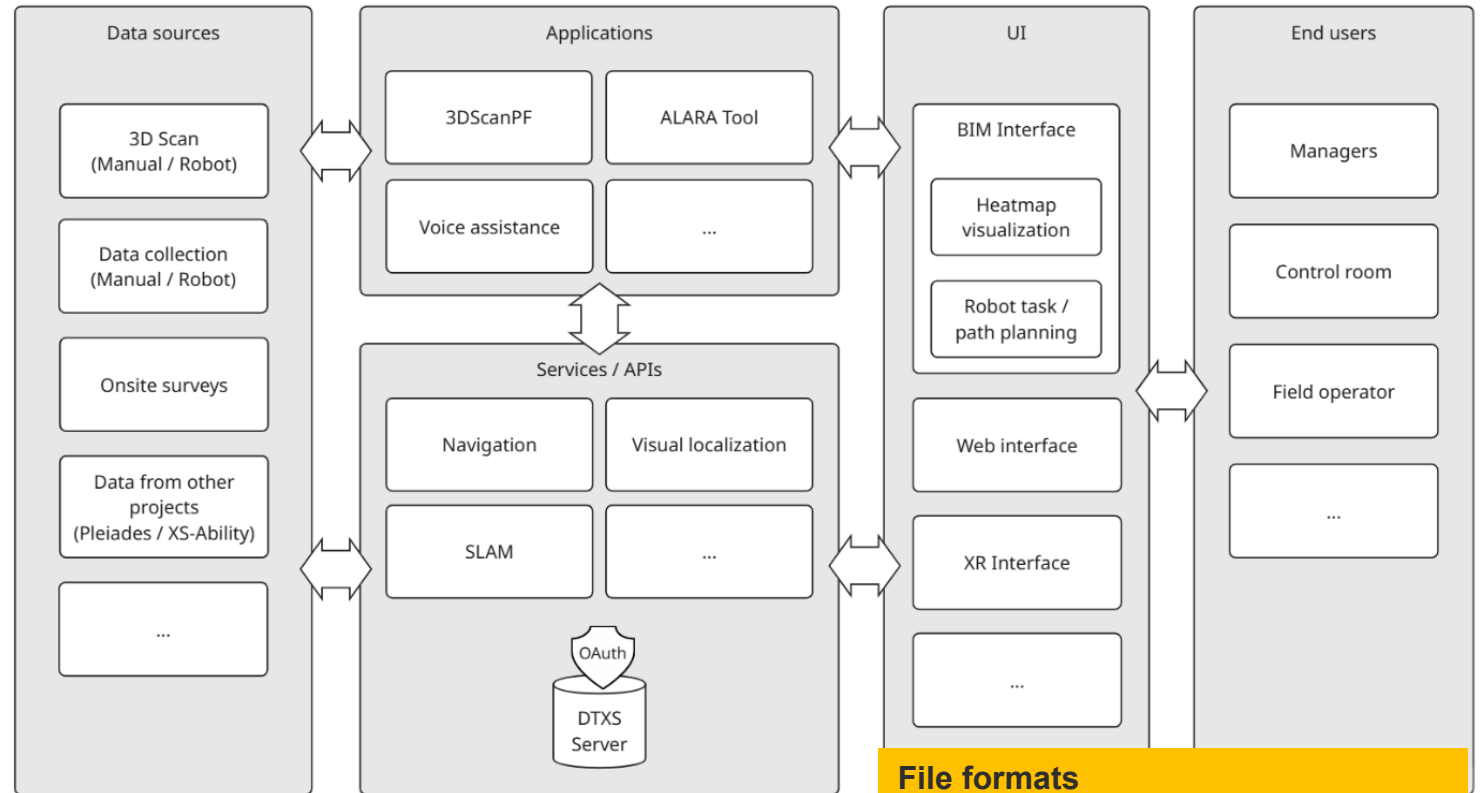


DORADO aims to incorporate essential compatibilities, like:

- 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.

System architecture

- Extensible, modular structure based on ontology, clearly specified interfaces and standardized conventions between modules;
- RESTfull API available to upload/download data:
 - Opensource Python client available on Github.
- 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.



File formats

- .ifc - 3D models
- .e57 - point clouds
- .xyz - spatial dose-rate maps
- .czt, .spe - spectrometry data
- .json - custom metadata
- .rviz - robotic visualization config

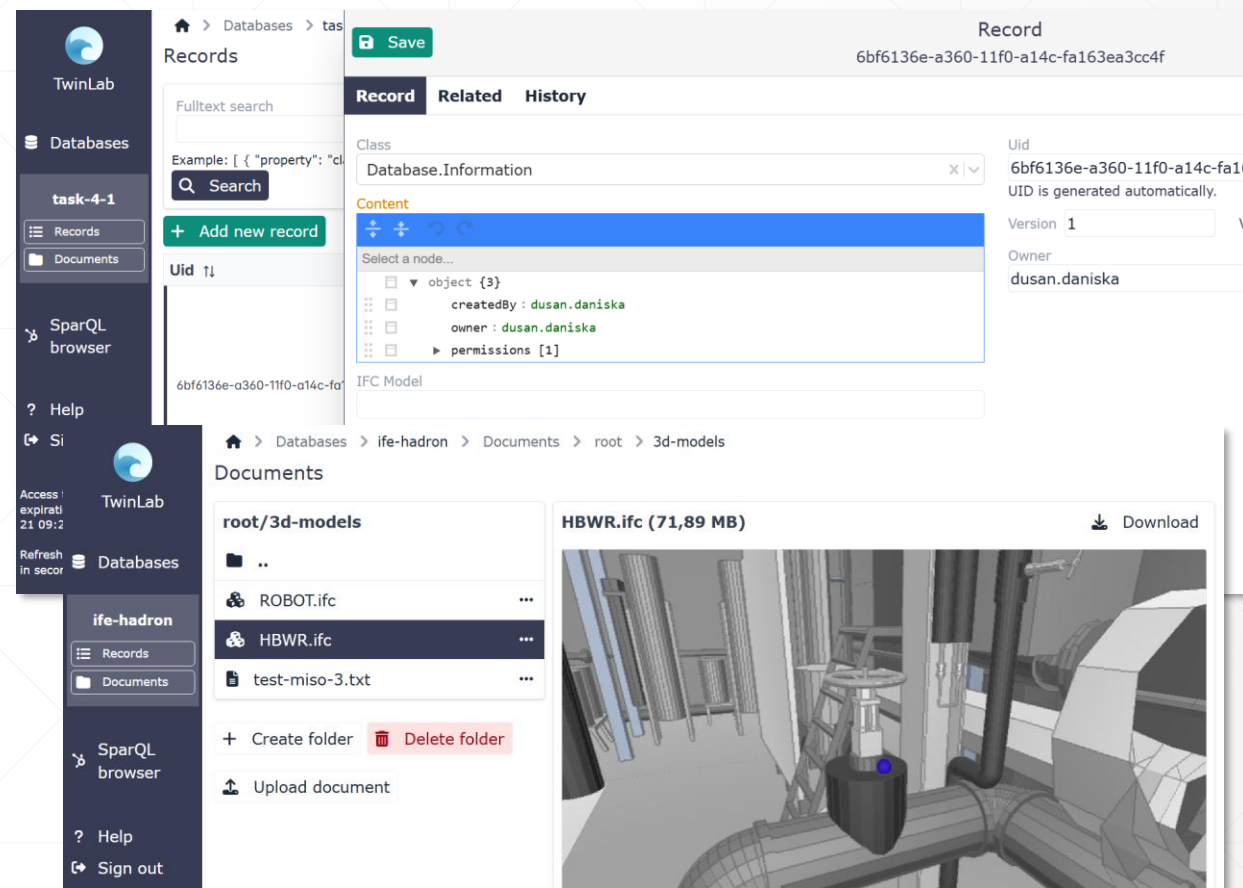


System architecture: Web based data visualization

- Specialized tool developed to visualize data;
- Files & folders;
- Structured records for further machine processing (JSON-formatted data);
- Integrated 3D visualisation;
- Secured with Keycloak OAuth IAM;

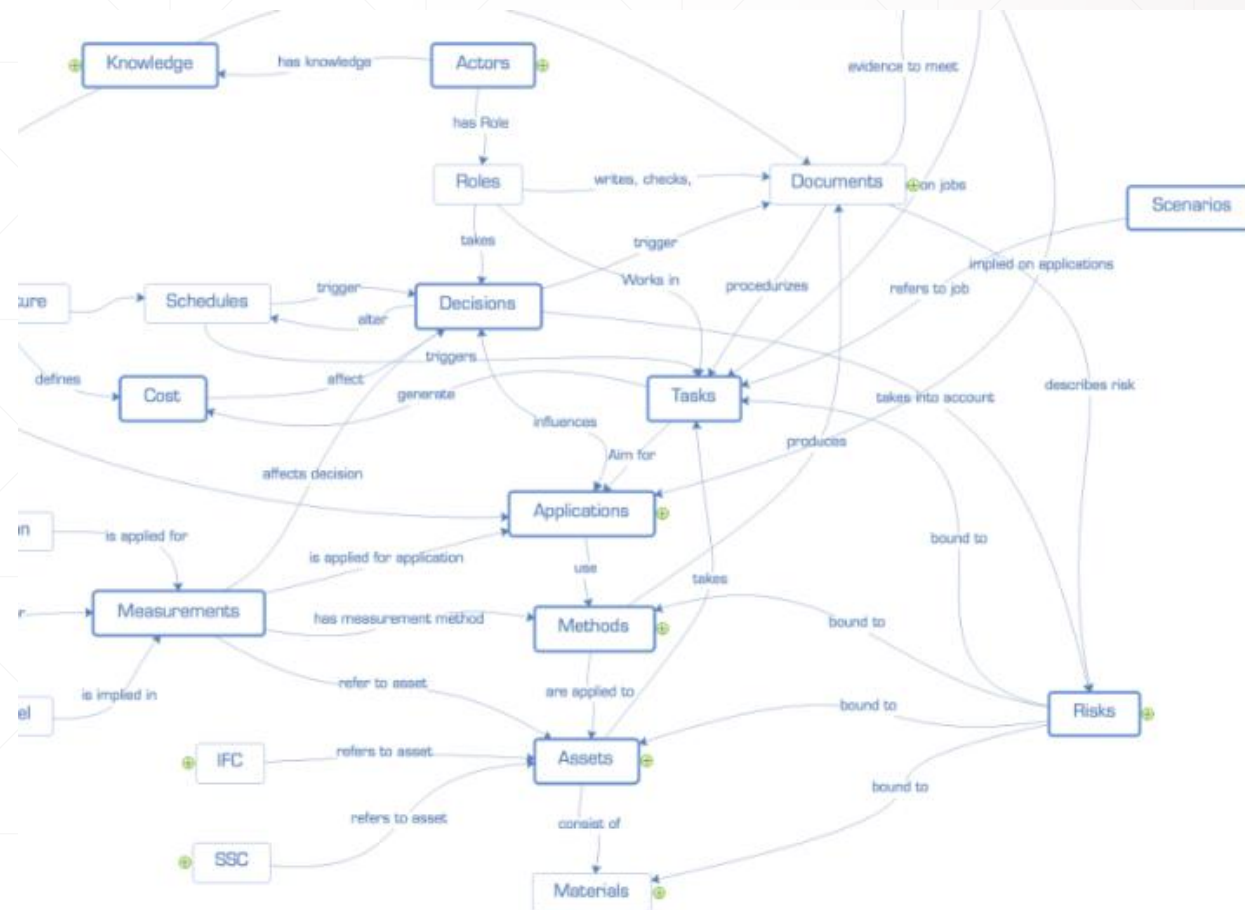
On-going work:

- Add multi-layer feature to 3D visualisation - show static 3D model layered with metadata (measurements, risks, robots, ...);
- Optionally implement real-time visualisation engine.



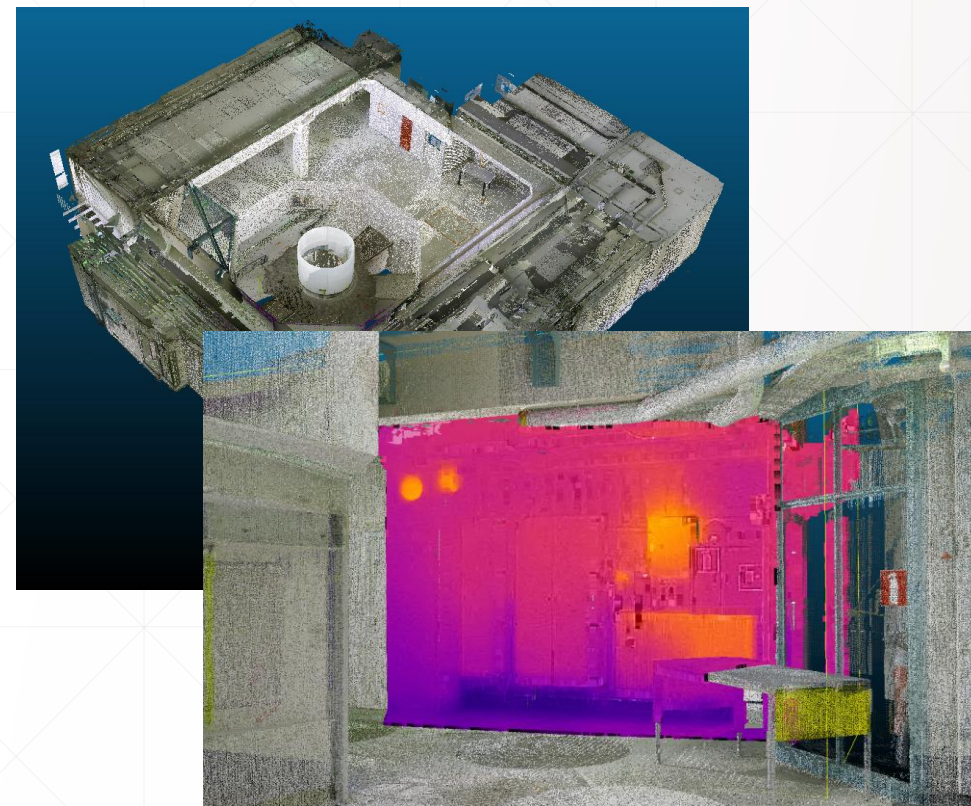
Ontology based approach

- 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;
- Co-operation with IAEA IDN Wiki, NEA and EU-JRC related ontology research.



Sensor data fusion with visual localization

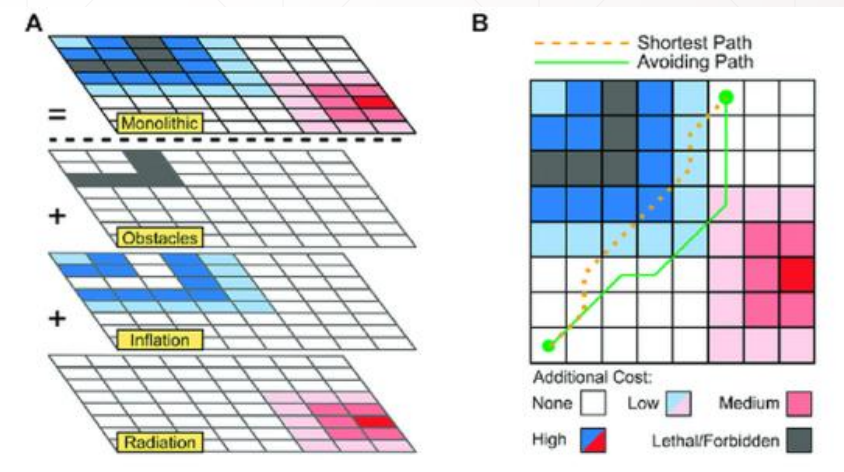
- Nuclear facilities require unified coordinate systems for consistent environmental and radiological data.
- Data fusion integrates multiple sensor types with support for temporal (time-series) analysis.
- Approach builds on aligned LiDAR point clouds and automatic alignment of previously mapped areas.
- Camera pose is estimated from images relative to a known 3D scene to localize different sensor measurements.
- The first demonstration included allocating thermal image data to the to the BIM model at the FiR1 research reactor in Finland
- Visual localization enhances robot and device tracking, supporting AR interfaces and manual data input.
- Current performance (~3 s query time) already enables real-time alignment of local and global coordinate frames.



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

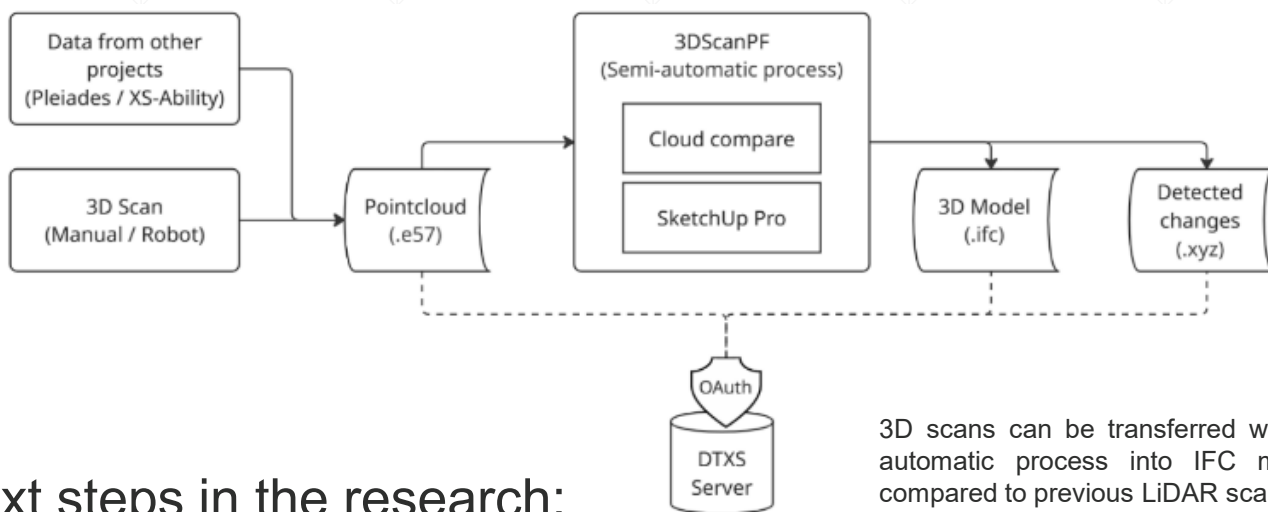
Robot mission control and route optimization

- **SOTA:** Existing mission control and robot route optimization methods lack ontology-based planning;
- **Ontological Planning:** introduce semantic modeling of spatial interdependencies, enabling context-aware mission planning;
- **Heterogeneous Robot Fleet:** The system dynamically assigns tasks to a diverse set of robotic agents with varying mobility, sensors, and payloads;
- **Integrated Safety Monitoring:** Real-time worker safety and risk assessment are supported through sensory data, semantic mapping, and AI-driven hazard detection;
- **Visual BIM-Based Planning:** High-level mission planning in a BIM interface allows intuitive waypoint and scanpoint definition, which feeds into detailed technical planning.



Change detection

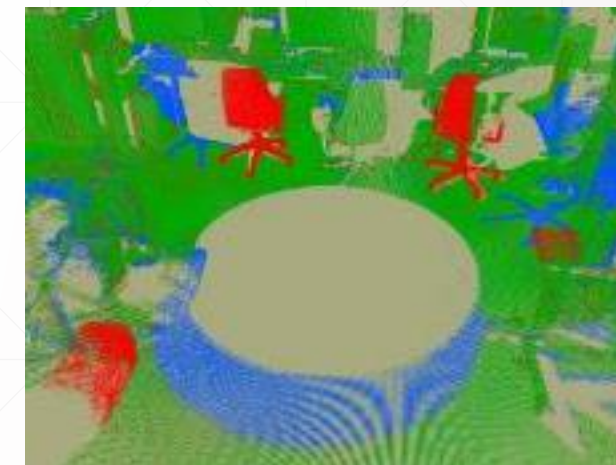
System design and implementation workflow



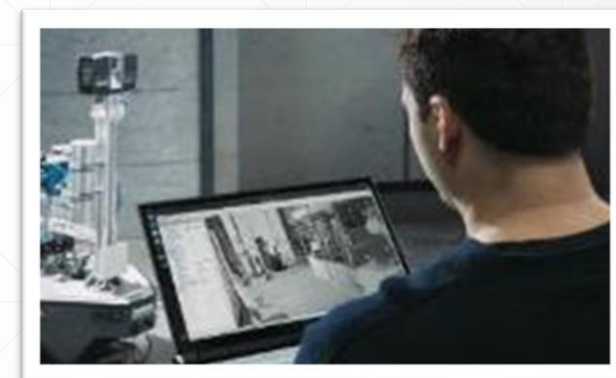
3D scans can be transferred with a well-defined semi-automatic process into IFC models. Here, changes compared to previous LiDAR scans can also be detected.

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.



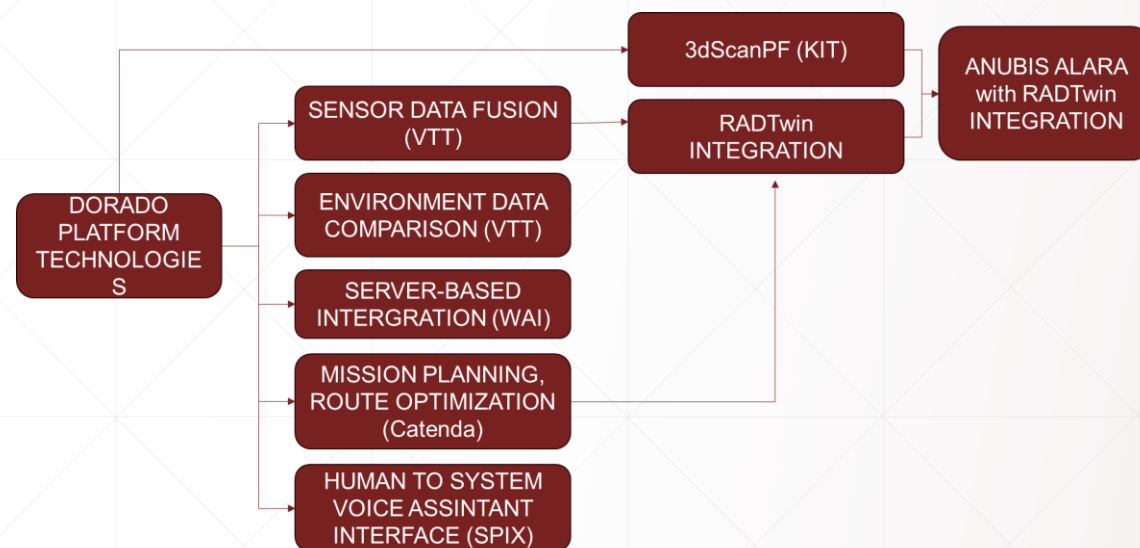
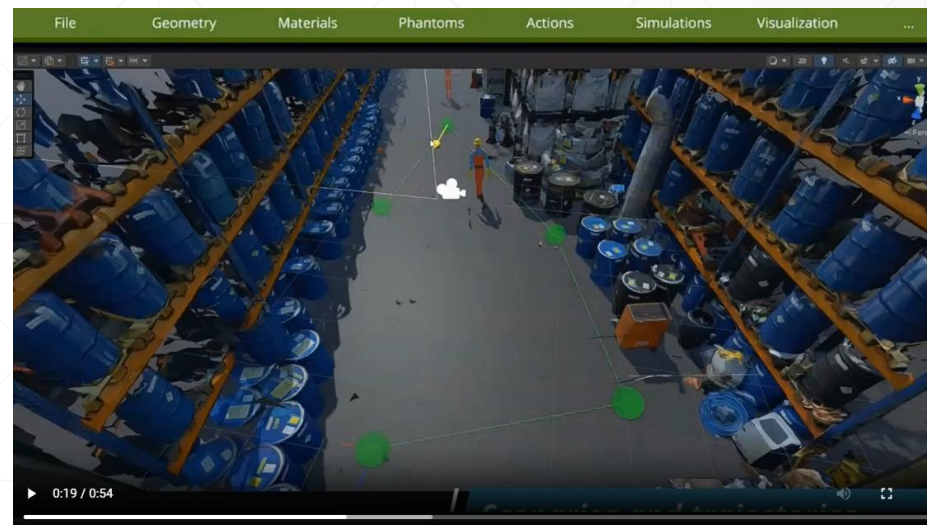
Change detection example with highlighted in blue and red colors, DORADO – Deliverable D2.1



KIT-TMB-RKKB- <https://www.tmb.kit.edu/RKKB.php>

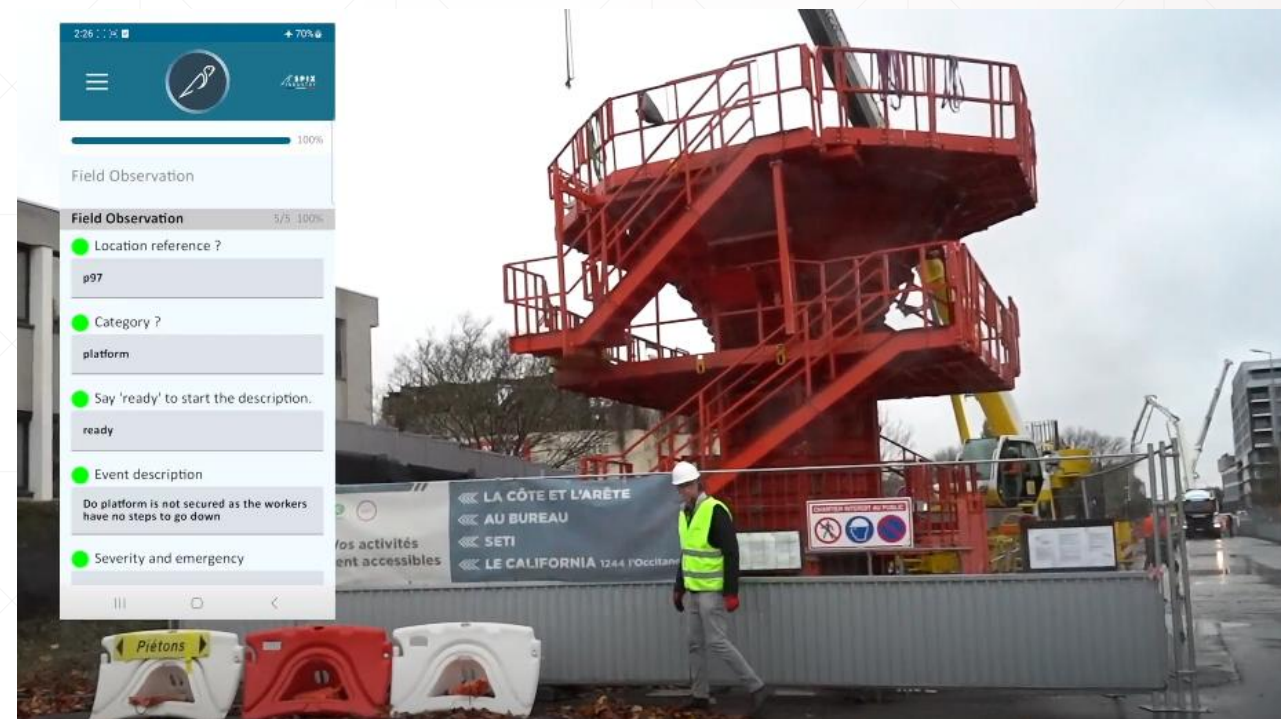
ALARA dose estimation

- SOTA: **Static model only** → **extend to dynamic.**
Enable uploading sensor data from the BIM model.
- New RADTwin dose assessment tool will dynamically adapt to changes in radioactive source terms during decommissioning
- Streamlines radiation protection by adjusting plans based on ongoing structural changes, minimizing the radiation characterization effort and exposure risk while supporting efficient dose management.
- Digital twins simulate radiation exposure.
- Sensor fusion updates geometry and radiation fields.
- Supports regulatory compliance and safety planning.



Voice assistant interfaces

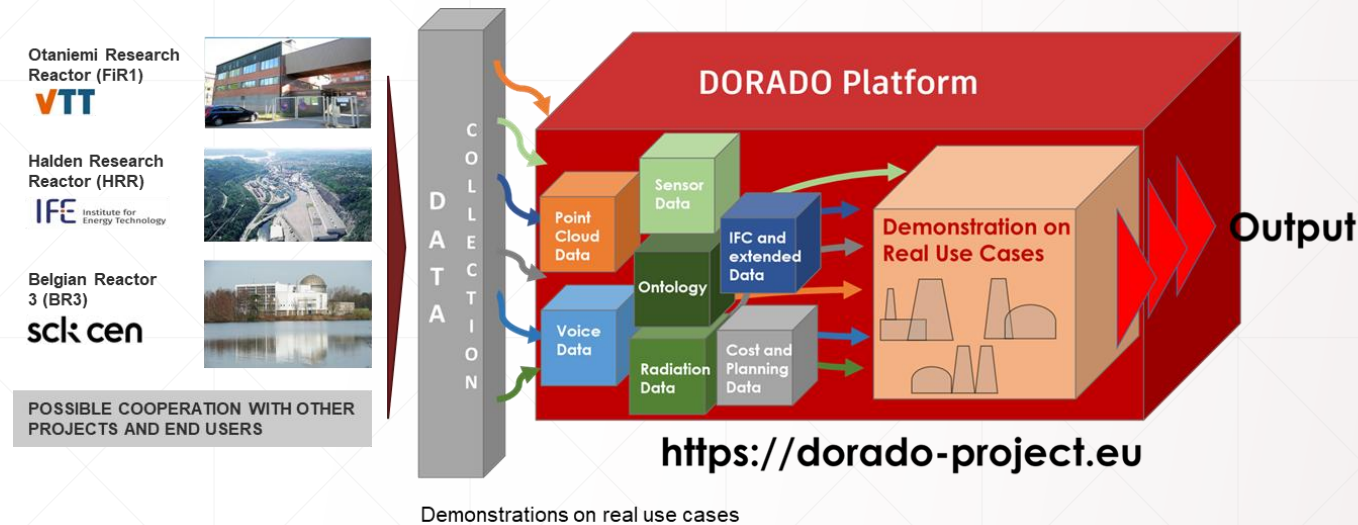
- SPIX voice assistance enables hands-free reporting;
- Supports offline operation in hazardous areas;
- Voice linked to BIM and ontology;
- Improves safety and data accuracy;
- In DORADO, voice assistance will be integrated in AI and ontology creating a dynamic knowledge representation system.



Technology demonstrations on use cases

Expected activities in demonstration use cases

- DORADO will use data based on information from real facilities: FiR1 TRIGA (Finland), BR3 reactor (Belgium), Halden research reactor (Norway);
- Five demonstration cases combine data from:
 - Use LiDAR + RGBD scanning and convert environments to IFC models;
 - Detect changes in point clouds using (semi-)automated methods;
 - Plan missions and tasks to collect field data with robots and manual tools;
 - Collect and process radiological and other environmental measurements into spatial information,
 - Visualize results (web-based 3D, AR/VR) and use them for risk and safety assessment.

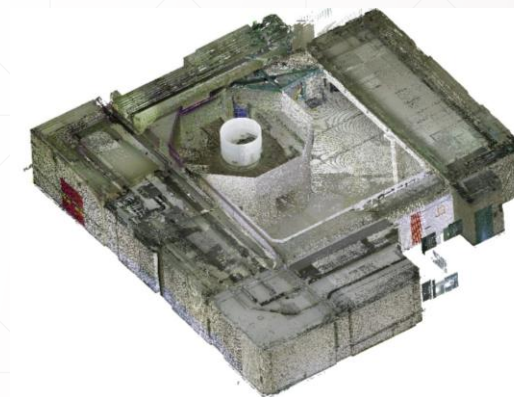


Use case 1: LiDAR+RGBD scan of the room and conversion to ifc

- Scenario: IFC 3D models are created from specific rooms, based on previous point cloud measurements;
- Radiation measurements are also to be provided;
- Several robots with sensors (LiDAR, RGBD camera, dose rate sensor) are used;
- The DTXS server is used to exchange data and visualize the IFC model, aiming to include dose rate measurements / hotspots.



Example of point cloud:
FiR 1 reactor



Scan-to-BIM



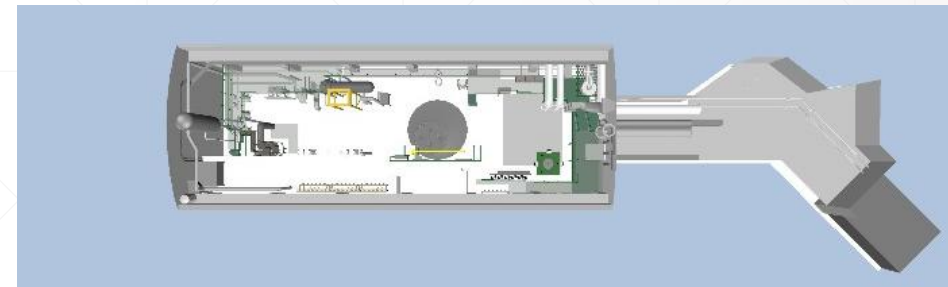
Example of IFC:
3D model of a room in the Halden Reactor (HRR) PLEIADES, Deliverable 1.2.



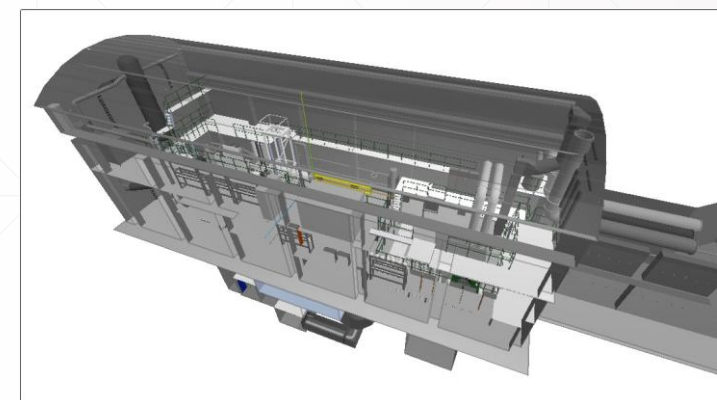
Model to be integrated in BIM

Use case 2: Task planning, risk assessment, inspection and output analysis

- Scenario: A decommissioning team prepares a sample task plan, identifies and assesses risks, and visualizes the task outputs;
- The team specifies simple decommissioning tasks and uploads the specifications to the DTXS server.
- Sample set of files, documents and records specifying the task may be produced and stored.
- The main goal is to demonstrate the capabilities of the platform for risk identification and assessment;



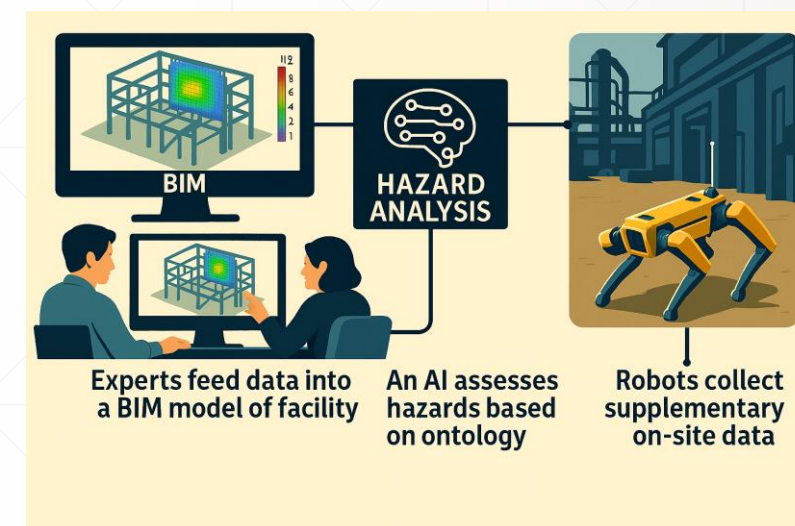
Plan of the Halden Reactor (HRR).



IFC model of the Halden Reactor (HRR)

Use case 3: Ontology-driven, robust and comprehensive reporting

- 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;
- Broken connection is being simulated, and risk mitigation procedures are being specified.



Use case 4: 3D mapping from sensor measurements for autonomous waste drum monitoring

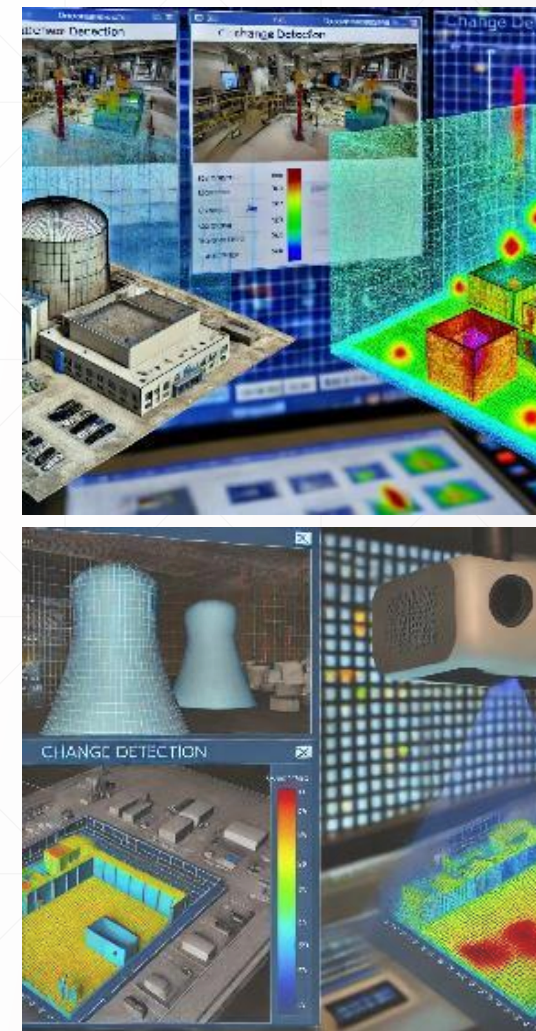
- Scenario: Numerous waste drums are stored within a designated area (e.g. interim storage) of the legacy facility. The condition of the waste needs to be regularly monitored, including radiation levels and the structural integrity of the drums;
- Robots navigate to scan points for radiation monitoring;
- 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)

Use 5: Precise location 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.



Conclusions

Conclusions

- DORADO continues the previous Euratom project PLEAIDES 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 half of the project we have completed the technical requirements and are currently progressing with the technical implementation;
- Next steps include finishing the technical implementation and demonstrations;
- Interested? Join our events and newsletter for more info.



<https://www.dorado-project.eu/join-us>

Thank you for your attention!



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