Cáceres 2025
24-26 de septiembre
51 REUNIÓN ANUAL
SOCIEDAD NUCLEAR ESPAÑOLA

SNE NUCLEAR
IMPRESCINDIBLES CONTRA EL CAMBIO CLIMÁTICO

Digital twins and Ontology for Robot Assisted Decommissioning Operations
DORADO

Digital Technologies in European Nuclear Decommissioning Projects

51st Annual Meeting of the Spanish Nuclear Society (SNE)
September 24th- 26th, 2025. Cáceres, Spain

Antti Räty, José A. Ridao, Omar Zahra, Petri Honkamaa , Dusan Daniska, Sascha Gentes – on behalf of the DORADO consortium

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

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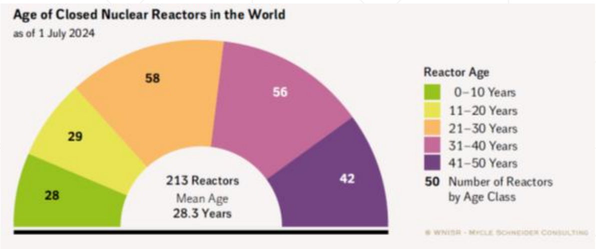
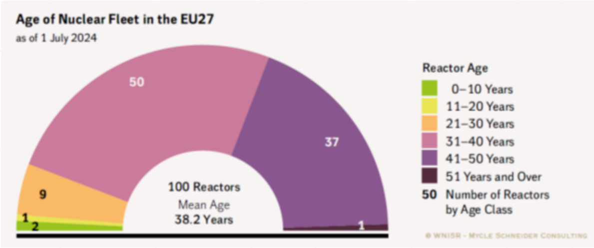
Content

1. Introduction

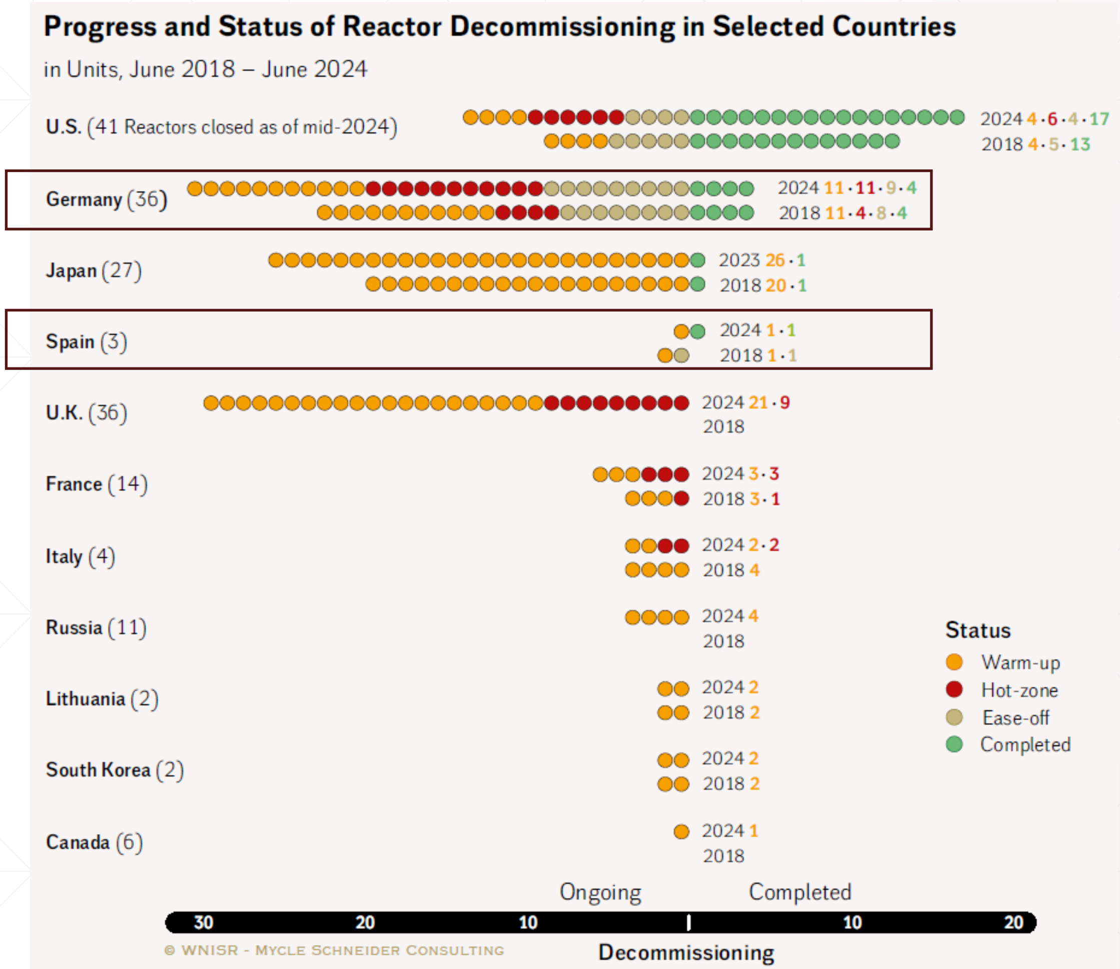
- In 2024, only 23 of 213 closed power reactors in the World have been fully decommissioned;
  - In the European Union (EU27), only Germany and Spain have carried out complete dismantling of Nuclear Reactors;
- By 2040, the number of Nuclear Decommissioning Projects (NDPs) in the World will increase from 50 today to over 400 [26];
  - The average closure age of Nuclear Reactors between 2019 and 2023 was 42.8 years;
  - Taking into account the mean age of the European fleet, 38.2 years, decommissioning is a growing market in the EU;
  - Collaborations between European countries is necessary.



Age of closed nuclear reactors in the World [25] (Fig. 19)



Age of closed nuclear reactors in the EU27 [25] (Fig. 19)



Progress and Status of Reactor Decommissioning [25] (Fig.52)

2. The European Project DORADO:
Digital twins and Ontology for Robot Assisted Decommissioning Operations

DORADO Partners

VTT
IFE
KIT Karlsruher Institut für Technologie
WAI
ASNR
iUS
AMPHOS 21 Scientific and Strategic Environmental Consulting
SPIX INDUSTRY
Université de Strasbourg
sck cen
Catenda
EPRI

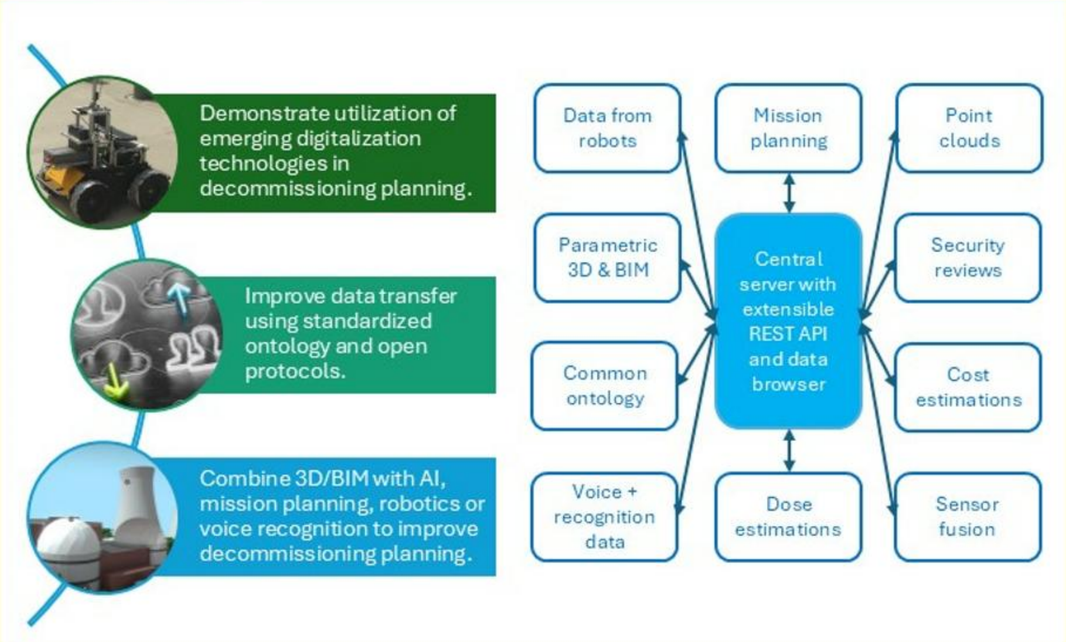
Key facts

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.

[1] www.dorado-project.eu [2] Antti Räty & DORADO consortium. Euratom project DORADO. Digidecom2024 conference, November 2024. Halden, Norway

2. The European Project DORADO

2.1. Objectives

The problem to solve

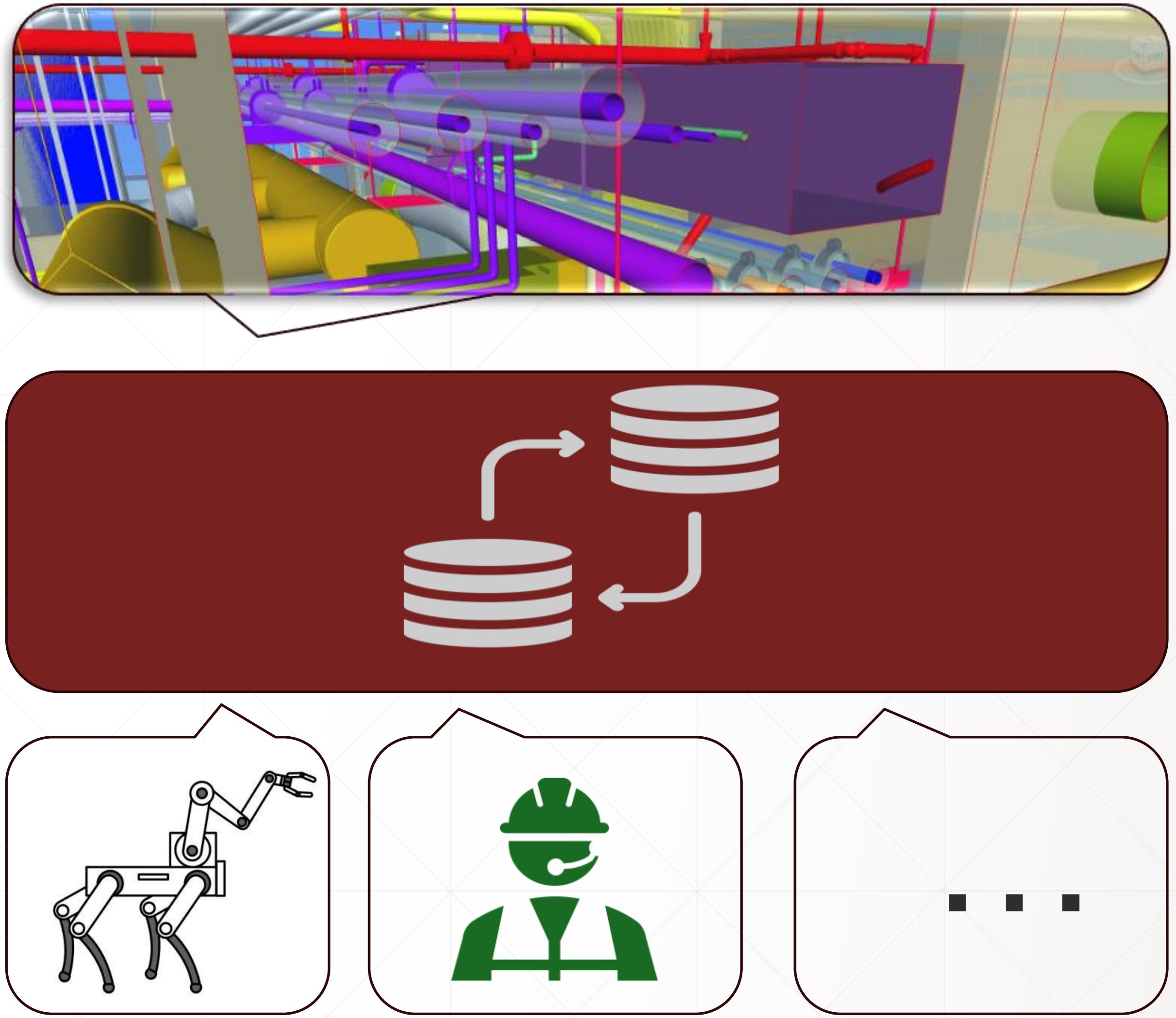
- BIM and Digital Twins are used at all steps of large projects;
- Such data needs to be up-to-date and accessible by many actors;
- Common language and protocols are needed to insure the coherence of the data.

Sample technologies / situations

- Data for *robot planning;*
- *Field operators*' data generation.

The proposal from DORADO

- A platform to share/consume data across a wide variety of actors.



[3] A. Räty, M. Becker, F. Borrmann, J. Ridao & DORADO consortium. Digital technologies in DORADO project. 3rd webinar, April 8, 2025

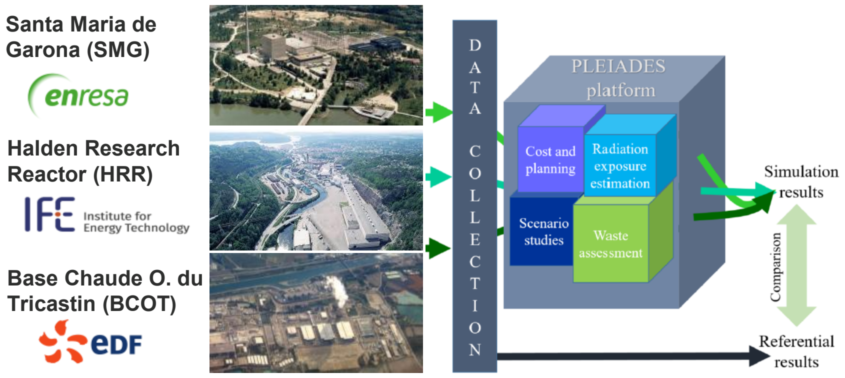
3. Previous steps in PLEIADES:

PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES

PLEIADES
Smarter Plant Decommissioning

[4] PLEIADES partners

[5]



[6] Implementation of PLEIADES on real use cases (Fig. 2)

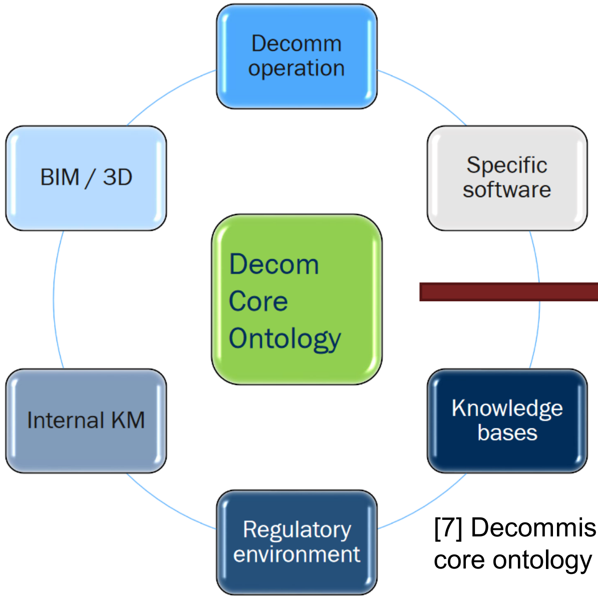
- **Call**: H2020 NFRP-2019-09 "Fostering innovation in decommissioning of nuclear facilities”
- **Duration:** 3 years (1/10/2020 - 30/09/2023)
- **Consortium:** 14 partners
  - Countries: FR (6), DE (2), NO (2), ES (1), FI(1), BE (1), SK (1)
  - 4 academic/research organisations, 1 TSO, 4 industrial companies, 5 SMEs
- **Objectives:**
  - Demonstrate a modular software ecosystem based on interconnection of front-line support tools through a decommissioning specific ontology building upon open BIM (Building Information Modeling);
  - Propose an ontology for an international standard of decommissioning with specific terminology/ vocabulary definition for a common understanding and common knowledge modeling;
  - Validation of the platform in the 6 user stories from 3 case studies in different European countries

3. Previous steps in PLEIADES:
3.1. Achievements

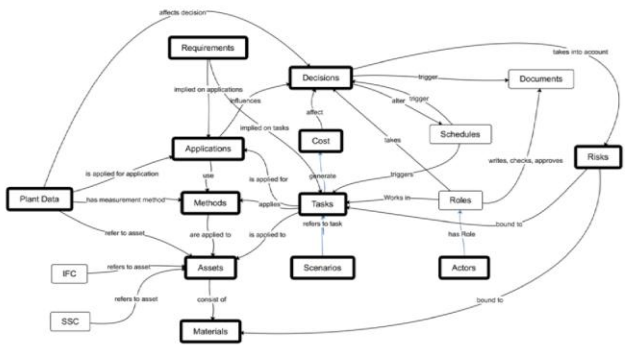
PLEIADES
Smarter Plant Decommissioning

[4] PLEIADES partners

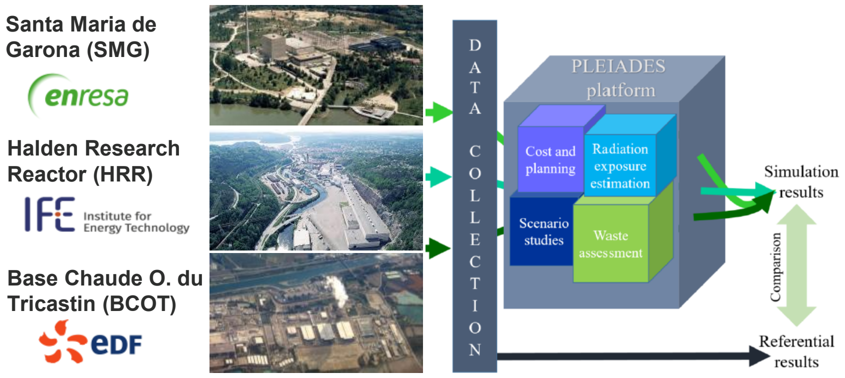
[5]



[7] Decommissioning core ontology



[8] Decommissioning core ontology



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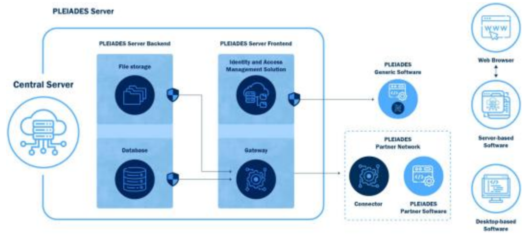
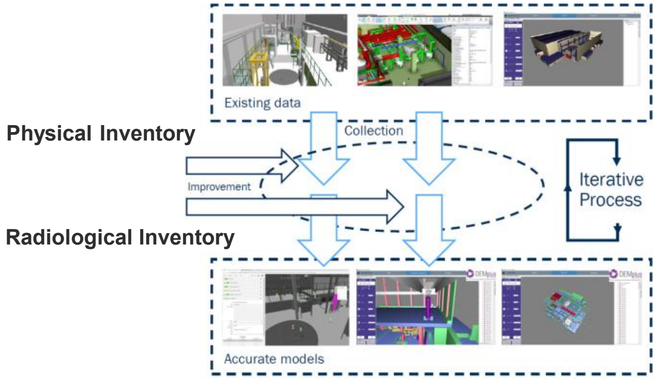


[6] Server architecture in PLEIADES (Fig. 4)



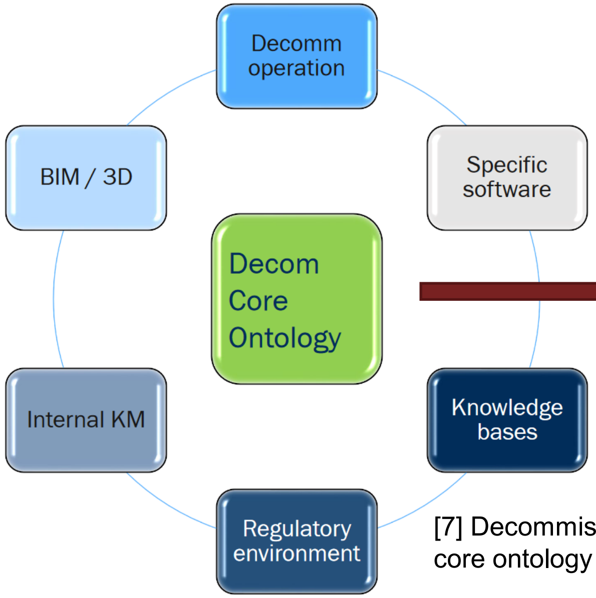
[6] Use cases 3D models and data in PLEIADES (Fig. 3)

4. Further development in DORADO

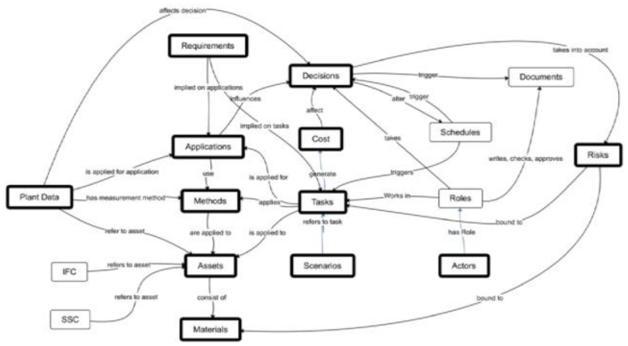
Digital twins and Ontology for Robot Assisted Decommissioning Operations
DORADO

PLEIADES
Smarter Plant Decommissioning

- In PLEIADES, a platform was developed, but software integration just started. Recommended next steps:
  - Extension of the coverage of the supported ontology and supported decommissioning planning activities;
  - Continuation in the development of the ontology and the API (Application Programming Interface);
  - Integration of further technologies such Artificial Intelligence (AI), Robotics and sensor networks;
  - Promotion of the concept for wider use.



[7] Decommissioning core ontology



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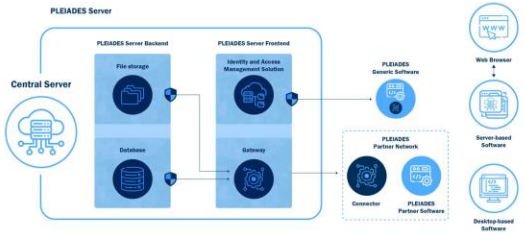

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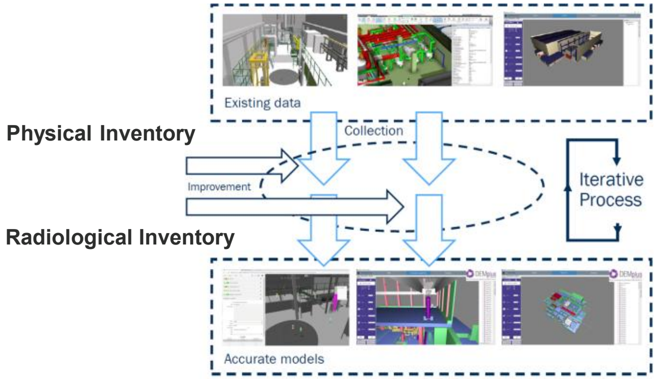
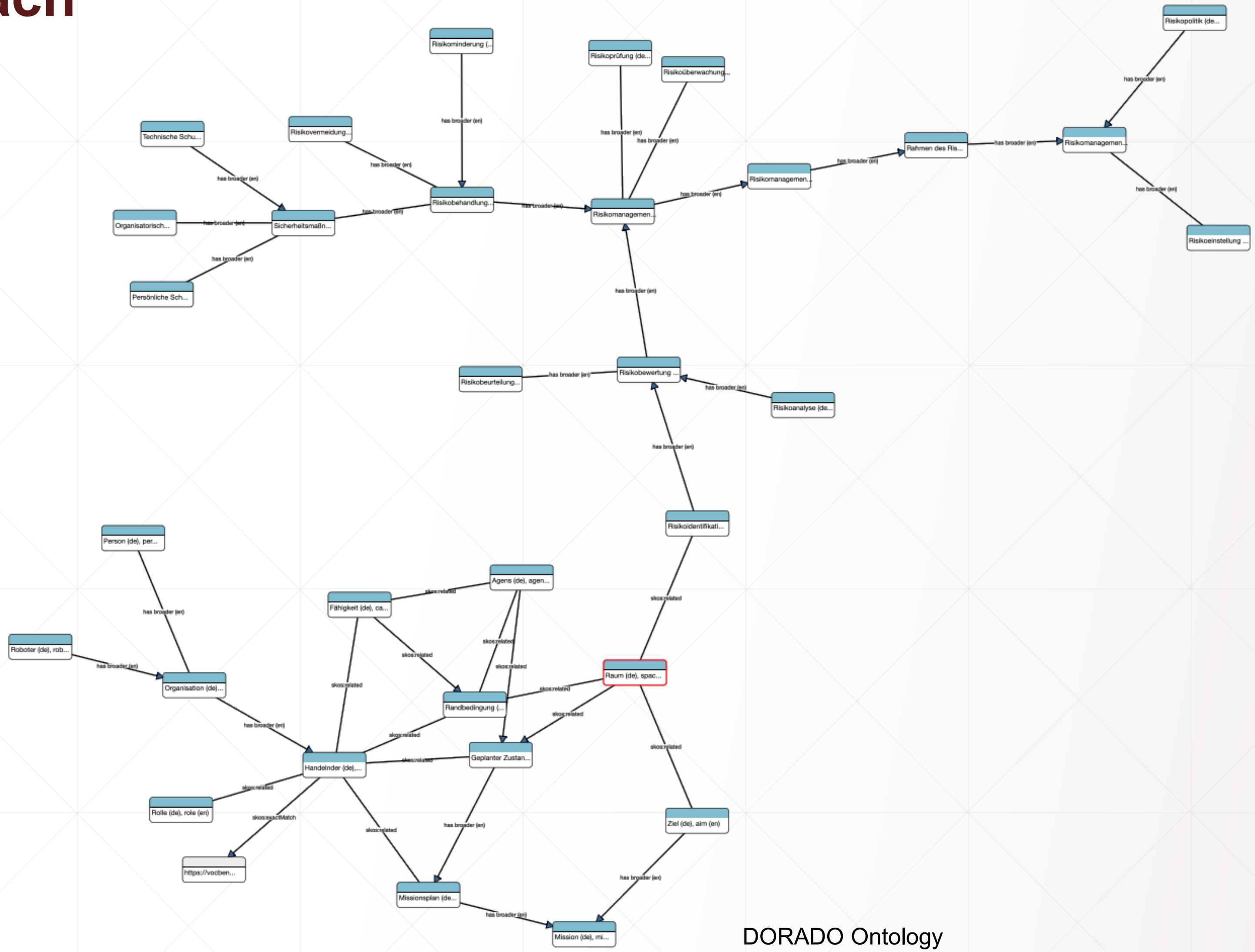


[6] Use cases 3D models and data in PLEIADES (Fig. 3)

4. Further development in DORADO

4.1. Ontology based approach

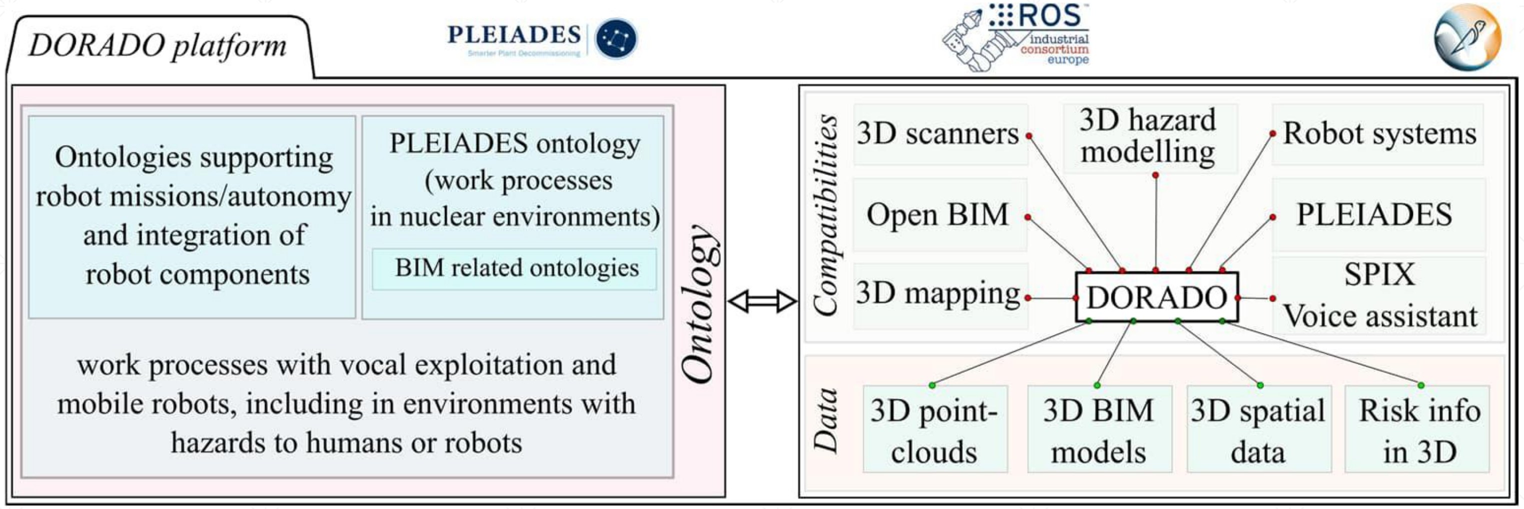
- Ontology helps to find common definitions and wording;
- Ontology defines basis for data structure development;
- Shown DORADO ontology has common members with the DECOM CORE ontology from the PLEIADES project:
  - **Actor**
  - **Room** (as part of IFC)
  - **Risk**
- While the DECOM CORE ontology is focusing on the project, DORADO is adding the mission planning and feedback part.



DORADO Ontology

4. Further development in DORADO

4.2. Data compatibility and ontology implementation

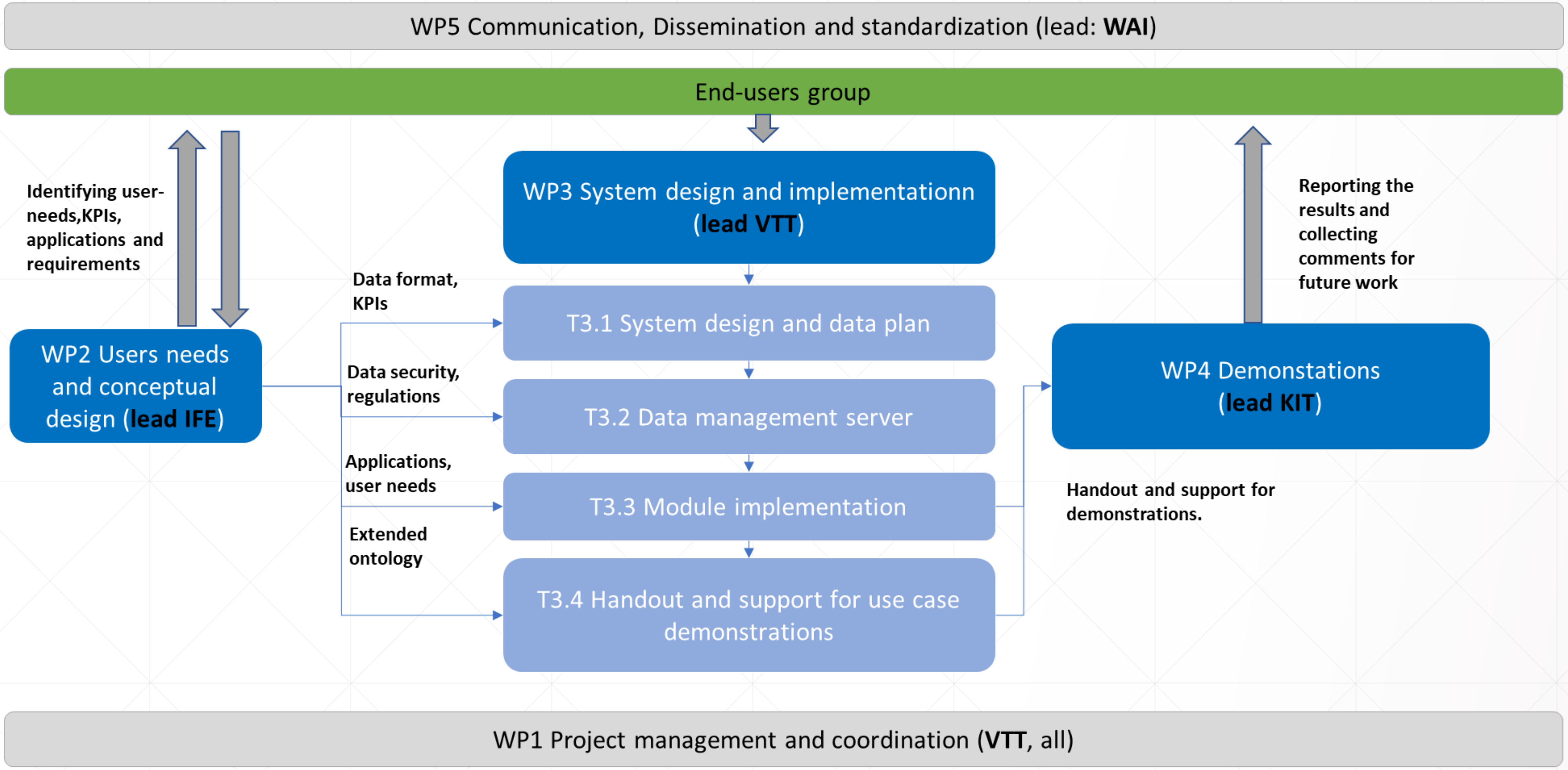


[9] Existing taxonomies and ontologies related to the project

- In a NDP, the interconnected and overlapping roles of active agents (workers, software entities, robots, etc.) are crucial for safety and productivity;
- Necessity to maintain a common knowledge representation and standardised data storage and exchange among agents;

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

5. DORADO project organization



[10] DORADO project flow

6. Demonstrations on real use cases

6.1. Linking technologies to demonstrations

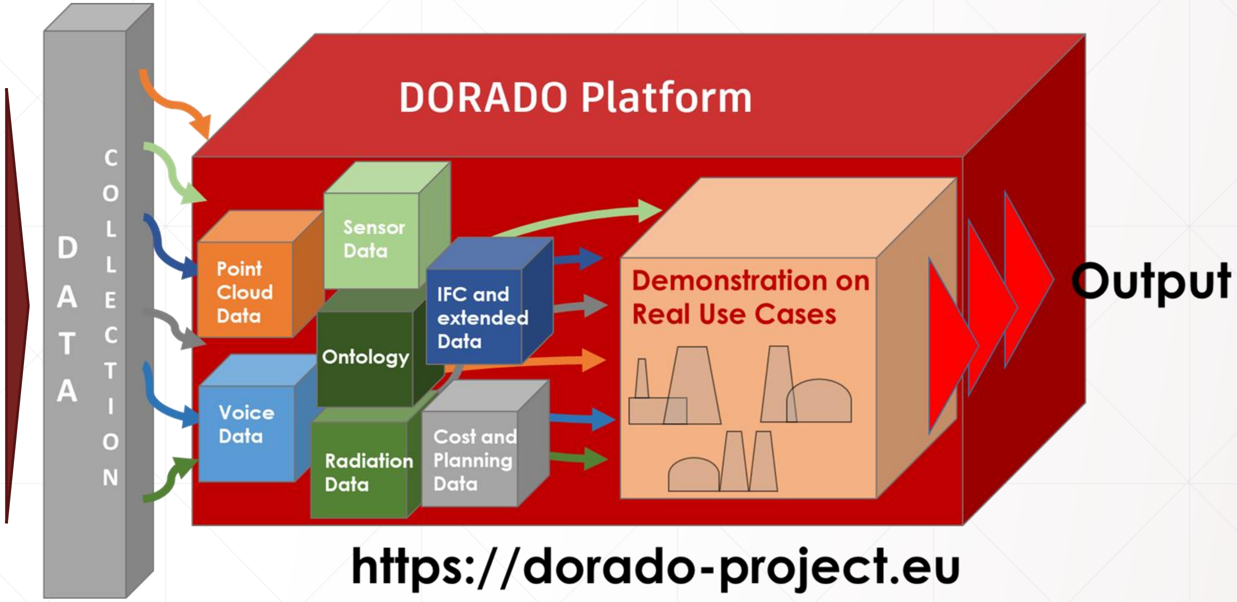
- DORADO will use data based on information from real facilities, like:
  - Point clouds;
  - Historical photogrammetry;
  - Dose rate survey;
  - 3D models;
  - Robot data (LiDAR and RGBD);
  - LiDAR SLAM and Visual SLAM;
  - Inventory data;
  - Etc.

Otaniemi Research Reactor (FiR1)

Halden Research Reactor (HRR)

Belgian Reactor 3 (BR3)

POSSIBLE COOPERATION WITH OTHER PROJECTS AND END USERS

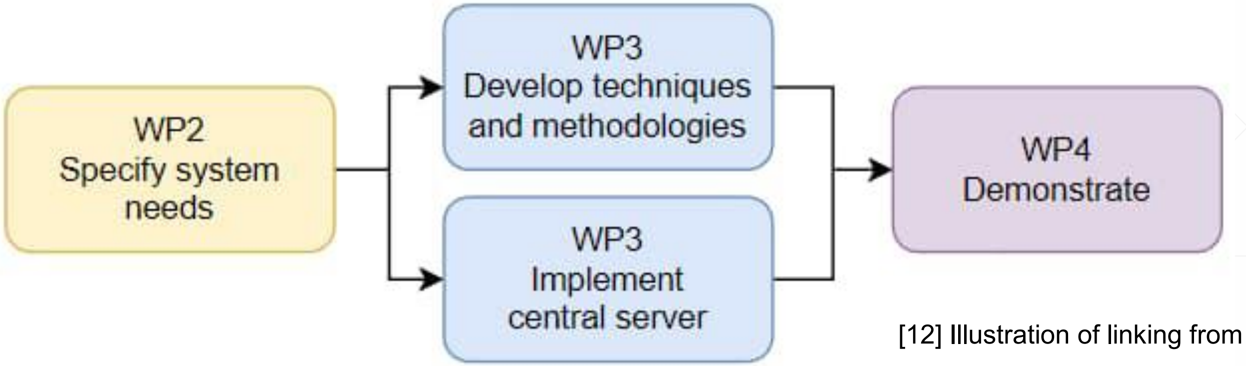


[11] Demonstrations on real use cases

- Further data is being collected or completed, like:
  - Dose rate mapping and spectrometry, in particular from the **XS-Ability project** [24], aiming at extending robotics and radiological sensors integration;
  - Etc.

6. Demonstrations on real use cases
6.2. Implementation

- **Main objective**: to demonstrate that the implementation of DORADO is possible in real use cases:

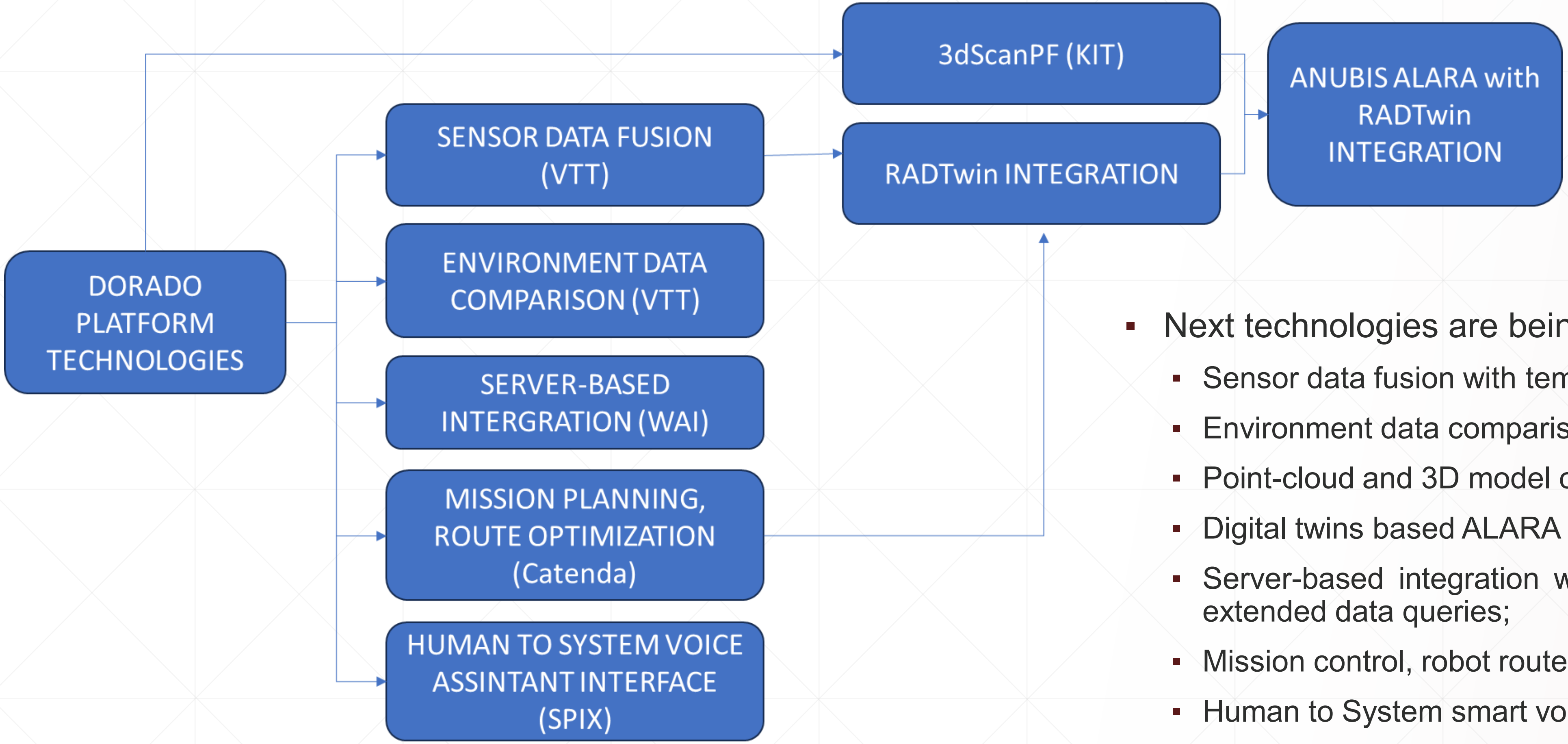


[12] Illustration of linking from techniques to demonstrations

- Data from different facilities will be used;
- The different demonstrations are defined separately and independently;
- However, they can partially benefit from the data from other demonstration cases.

1) Creation of a parametric 3D model;
2) Detecting the changes in the 3D models over time;
3) Comparison of plans vs. reality;
4) Decommissioning safety and risk/hazards assessment.

7. Technological applications in DORADO



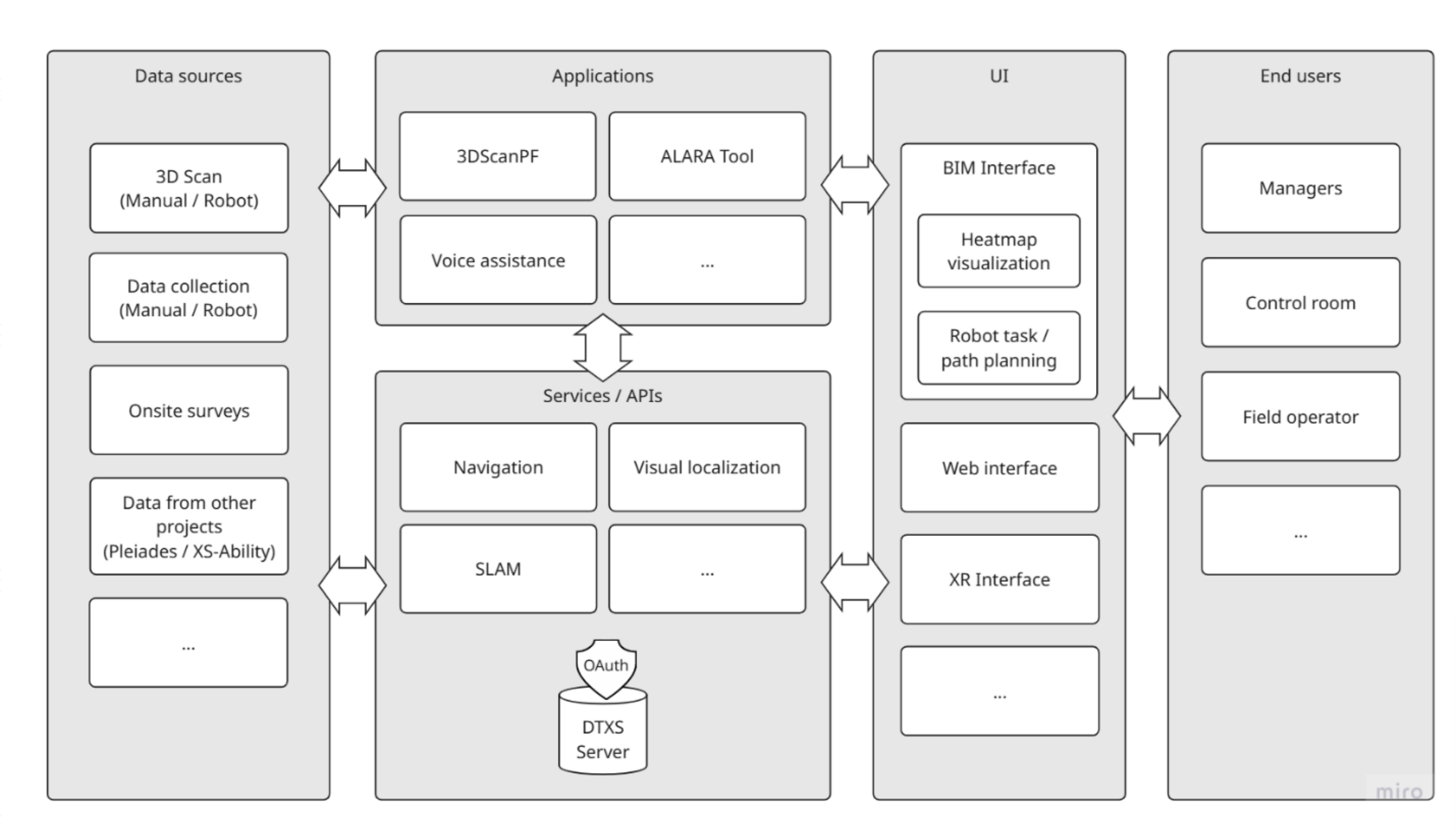
- Next technologies are being incorporated:
  - Sensor data fusion with temporal dimension;
  - Environment data comparison against BIM;
  - Point-cloud and 3D model change detection;
  - Digital twins based ALARA dose estimation;
  - Server-based integration with IFC file format and extended data queries;
  - Mission control, robot route optimization;
  - Human to System smart voice assistant interface;
  - Standardization using the common ontology.

[24] Technological applications under development.
Antti Räty et al., DORADO-projekti tuottaa digitaalisia malleja käytöstäpoistoon, ATS Ydintekniikka, 4|2024 Vol. 53

7. 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.

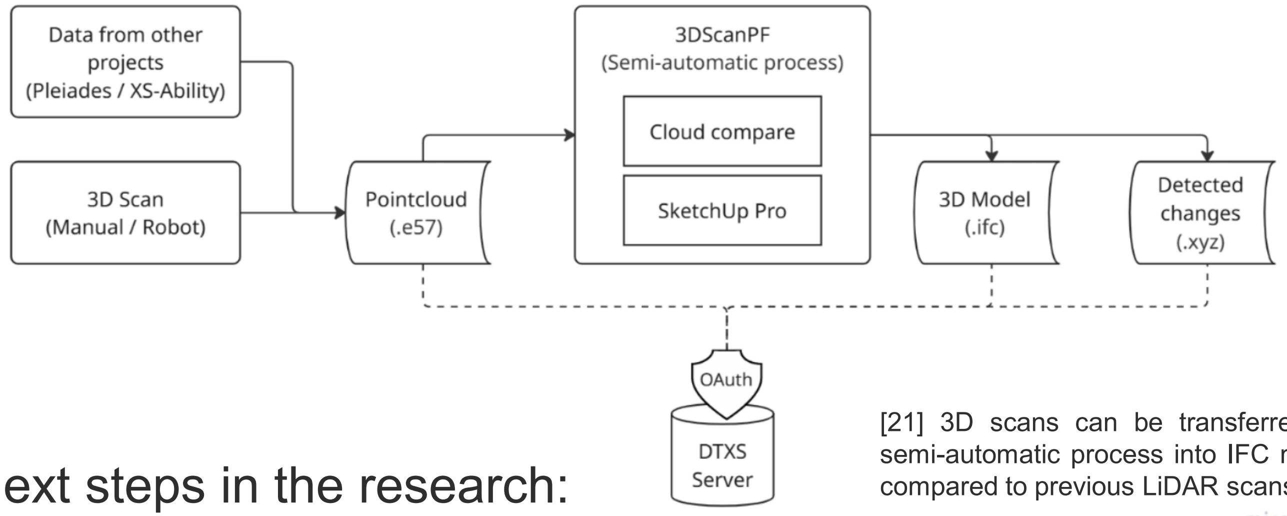


[21] DORADO system architecture

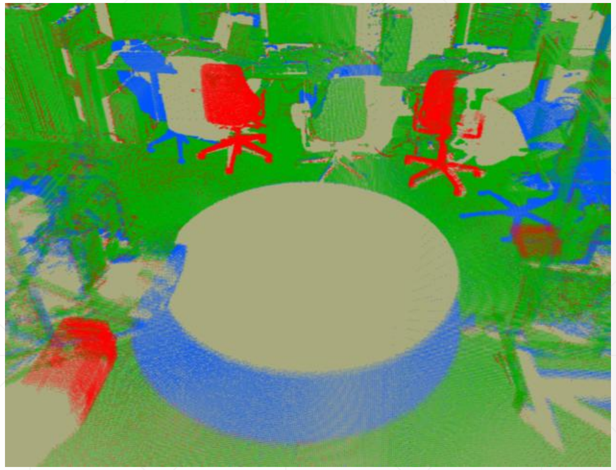
7. Technological applications in DORADO

Change detection

- System design and implementation workflow



[21] 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.



[15] A. Räty & DORADO consortium (2024)

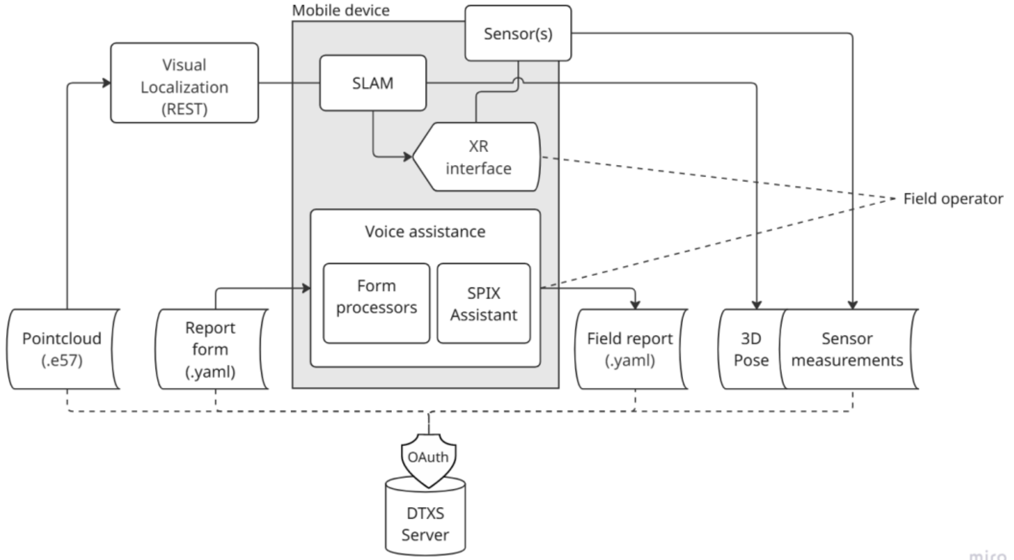
- Next steps in the research:
  - Automated segmentation of complex objects / geometries in a Point Cloud;
  - Automated modelling of complex objects from (segmented) Point Clouds;
  - Detection of materials in point clouds;
  - Dealing with gaps / holes / hidden areas in a Point Cloud;
  - Dealing with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

[14] KIT-TMB-RKKB

7. Technological applications in DORADO

Sensor data mapping

- Creation of a comprehensive view of the environment, linking data to specific time points:



[21] Illustration of data flow between the field operation and the DORADO server

- 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.

8. Summary and Results

- **DORADO continues the work of PLEAIDES by integrating more technologies and extending the ontology for new applications;**
- **Eight new technologies are handled, emphasizing the use of BIM (Building Information Modeling) and AI (Artificial Intelligence);**
- **Developed technologies will be demonstrated with data from real facilities. Holistic approach and data compatibility is the key!**
- **Next results of the project are available:**
  - Deliverable D2.1: State-of-the Art and Business Value Analysis Report
  - Deliverable D3.1: System Design and Data Plan
- **Next publications are available:**
  - Marie-Bénédicte Jacques, Antti Räty, Joseph A. Ridao Cabrerizo, Dusan Daniska. European Collaborations for Safe and Efficient Dismantling: Digital twins, Ontology and Data Exchange, EPJ Nuclear Sci. Technol. **11**, 19 (2025). https://doi.org/10.1051/epjn/2025022
  - Abdenour Benkrid, Omar Zahra, stván Szőke. Digital Twin-Enabled Multi-Robot Systems for Safe and Efficient Nuclear Decommissioning. NAIS 2025: Symposium of the Norwegian AI Society, June 17–18, 2025, Tromsø, Norway. https://ceur-ws.org/Vol-3975/paper6.pdf
  - A. Räty, D. Daniska, J. A. Ridao Cabrerizo, M. Brandauer, O. Zahra, M. Becker. Digital twins and Ontology for Robot Assisted Decommissioning Operations. Poster on WM-Symposia 2025 conference. https://www.dorado-project.eu/assets/img/wm-symposia-2025/WM-Symposia-poster-v4.1.jpg
  - Antti Räty et al., DORADO-projekti tuottaa digitaalisia malleja käytöstäpoistoon, ATS Ydintekniikka, 4|2024 Vol. 53 https://bin.yhdistysavain.fi/1608821/Hk8OJiHcEk5Ouc8t9VUO0bO3jz/ATS%20Ydintekniikka_4-2024.pdf
  - Antti Räty & DORADO consortium. Euratom project DORADO. Digidecom2024 conference, November 2024. Halden, Norway. https://www.dorado-project.eu/downloads/DigiDecom-2024-DORADO-presentation.pdf
  - Joseph Ridao, Antti Räty, Dusan Daniska, Franz Borrmann, Omar Zahra, Petri Honkamaa (2025). Ontology-based BIM data exchange for decommissioning in the DORADO project. Technical Meeting on Innovations in Data Analysis and Retrieval for Nuclear Decommissioning of the IAEA (EVT2404267)
- **3 webinars presenting digital technologies have been organized. Presentations and results are available here:**
  - https://www.dorado-project.eu/events

9. End-users group interaction

End-users are invited to follow our project via webinars, newsletters and other publications.

- Technological experts and DORADO tools users
- Business management (how tools connect to business value chain and enable new services)

What will be the value for end-users to participate?

The end-user's value in following the project is built on the opportunity to increase their understanding of each technology, strengthen their own understanding of the benefits of using each technology and hence, gain a better understanding of how the technologies can be utilized in their own business. We aim to focus on following questions:

- **What is the technology and how is it used?**
- **What are the benefits of using the technology? Examples presented.**
- **How can the technology be applied? Examples presented.**
- **How does the technology support nuclear decommissioning and dismantling projects?**

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

References

[1] [11] [12] www.dorado-project.eu

[2 [9] [10] [15] Antti Räty & DORADO consortium. Euratom project DORADO. Digidecom2024 conference, November 2024. Halden, Norway

[3] A. Räty, M. Becker, F. Borrmann, J. Ridao & DORADO consortium. Digital technologies in DORADO project. 3rd webinar, April 8, 2025

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[23] P. Ingwer et Al. (2015). Practical usefulness of structure from motion (SfM) point clouds obtained from different consumer cameras, Proceedings of SPIE - The International Society for Optical Engineering · March 2015 https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9411/1/Practical-usefulness-of-structure-from-motion-SfM-point-clouds-obtained/10.1117/12.2074892.full

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DORADO

Thank you for your attention!

Any questions?

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

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