Digital twins and Ontology for Robot Assisted Decommissioning Operations

DORADO

Digital technologies in DORADO project

Ontology for nuclear decommissioning planning (iUS)
Change detection in point clouds (KIT)

Maarten Becker, Franz Borrmann, Joseph Ridao

April 8, 2025

DORADO Webinar

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

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Digital twins and Ontology for Robot Assisted Decommissioning Operations

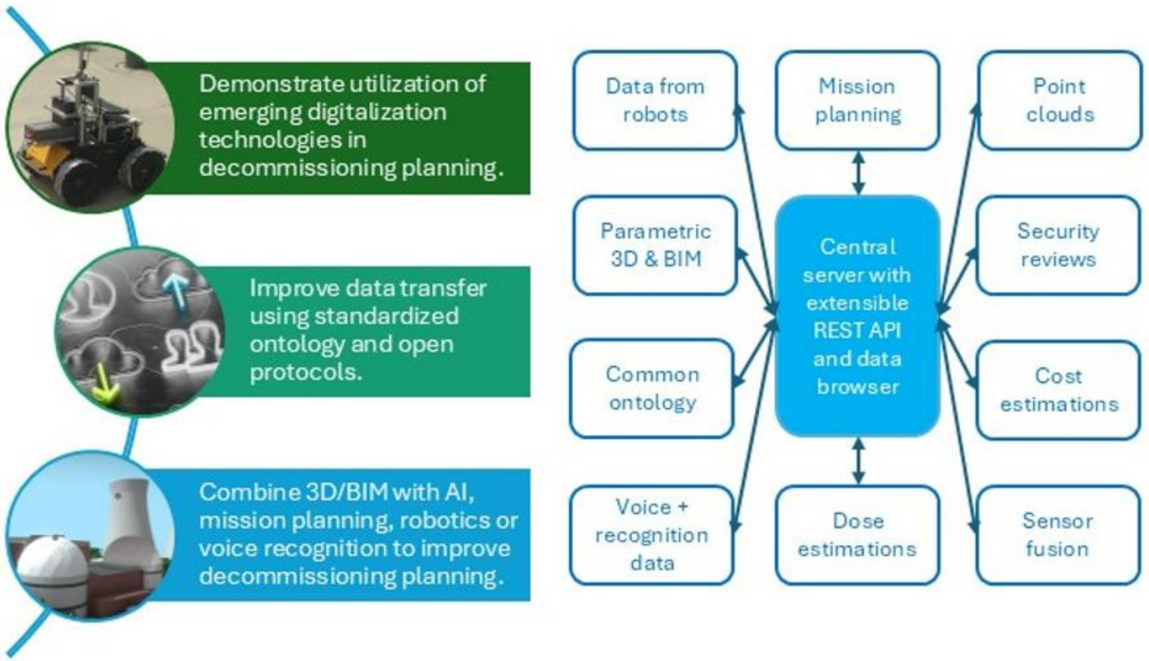
Key facts

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.

The objective of DORADO

The problem to solve

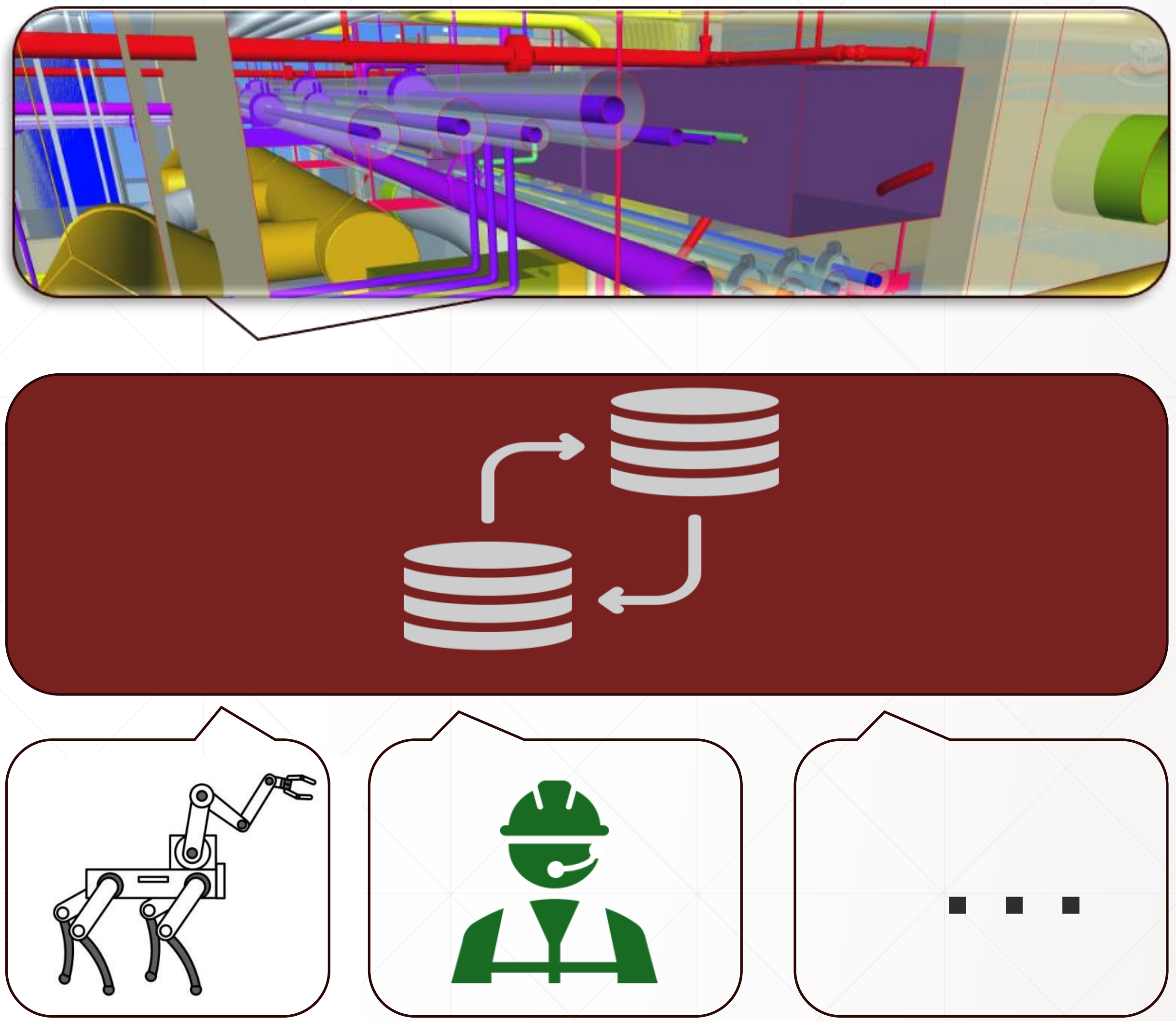
- BIM and Digital Twins are used at all steps of large projects.
- Such data needs to be up-to-date and accessible by many actors.
- Common language and protocols are needed to insure the coherence of the data.

Sample technologies / situations

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

The proposal from DORADO

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



Agenda and purpose of the webinar

- Strengthen the understanding of each technology and utilization in nuclear decommissioning.
- Provide feedback and ideas for the technology developers.

Introduction	
Introduction	5 min
End-user's perspective (Duriem Calderim, IAEA)	5 min
Technology developers' pitches	
Ontology for nuclear decommissioning planning, by iUS	10 min
Change detection in point clouds, by KIT	10 min
Discussion	
Questions and discussion	30 min

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Ontology for mission planning in nuclear decommissioning

Maarten Becker (iUS), Franz Borrmann (iUS)
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Why an ontology for DORADO?

- The task is to achieve a common platform for existing software for 3D, BIM and robotics in mission planning
- Each software has its own history, terms and concepts, i.e. an implicit ontology
- Direct interfaces would be very difficult to generate and maintain
- A common understanding of the mission planning process is necessary
  - Between subject matter experts from different organizations
  - Between subject matter experts and data scientists

Summary of ontological terms

Ontology

Ontologies describe a model of a section of the real world

Categories or classes describe concepts, processes or things

Inheritance: make instances of classes

Properties connect classes and instances

Example:
KKE is a Siemens Konvoi Reactor
Siemens Konvoi Reactor is subclass of power reactor

Inference: KKE is a power reactor

Information Triple:
Subject – Predicate - Object

Taxonomy

Taxonomies describe the content of classes or categories

Classes or categories are collections of similar things

Taxonomies built a strictly hierarchical order, i.e. every item can have exactly one parent item

Example:
RPV is part of Primary Circuit
Primary Circuit is part of NPP
NPP is part of Site

Taxonomies can be graphically shown as tree graphs

Thesaurus/SKOS

(Simple Knowledge Organisation System)

Allows to organize metadata

Describes nearby terms, synonyms, antonyms

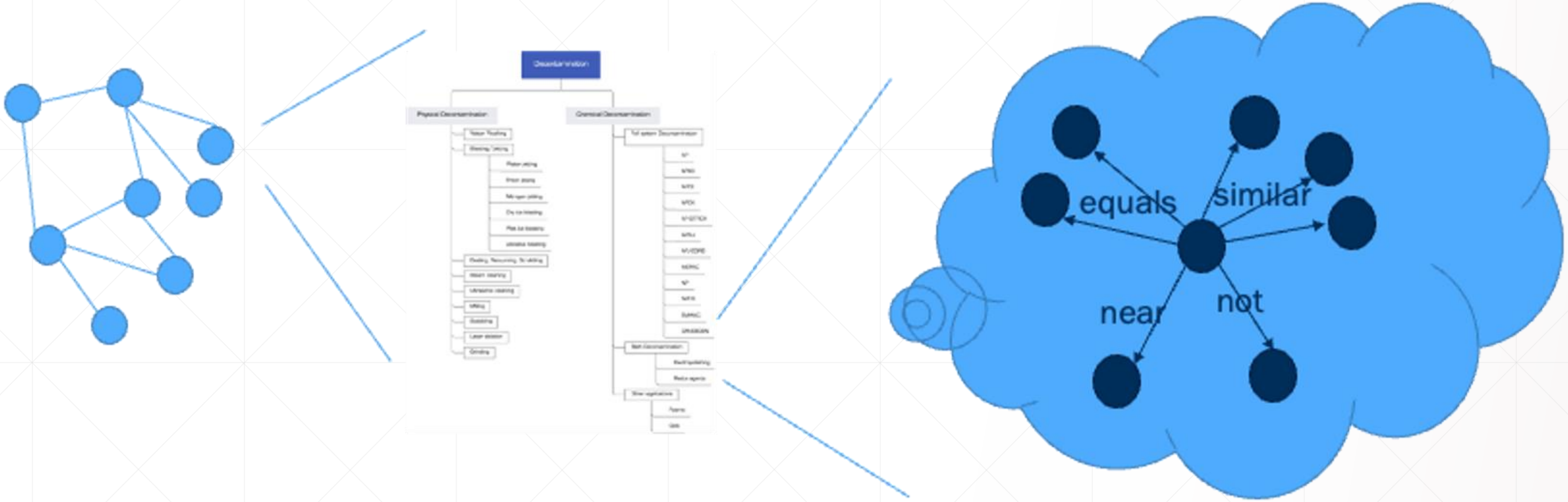
Used to describe the concepts

Example:

A BWR is not the same as a PWR

A PWR FA has some similarities with a BWR FA

Ontologies, Taxonomies, Thesauri

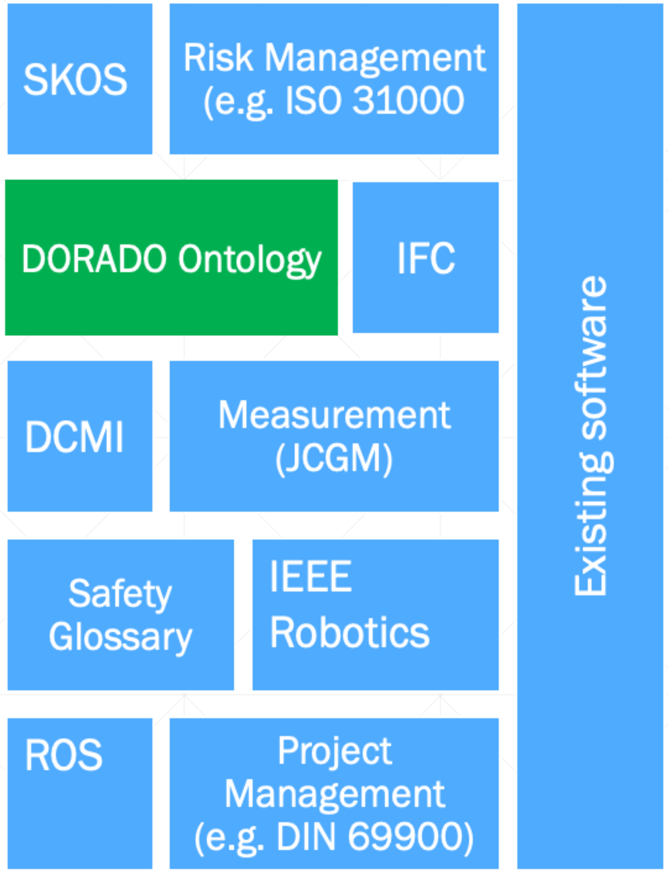


Ontology
linking
concepts

Taxonomy
sorting terms inside
concepts

Thesaurus/SKOS
describing terms and their
environment

The development approach



- No intention to reinvent the wheel, use what is available, established and suitable
- Simultaneous top-down and bottom-up approach
- DORADO ontology covers specific parts and defines interfaces

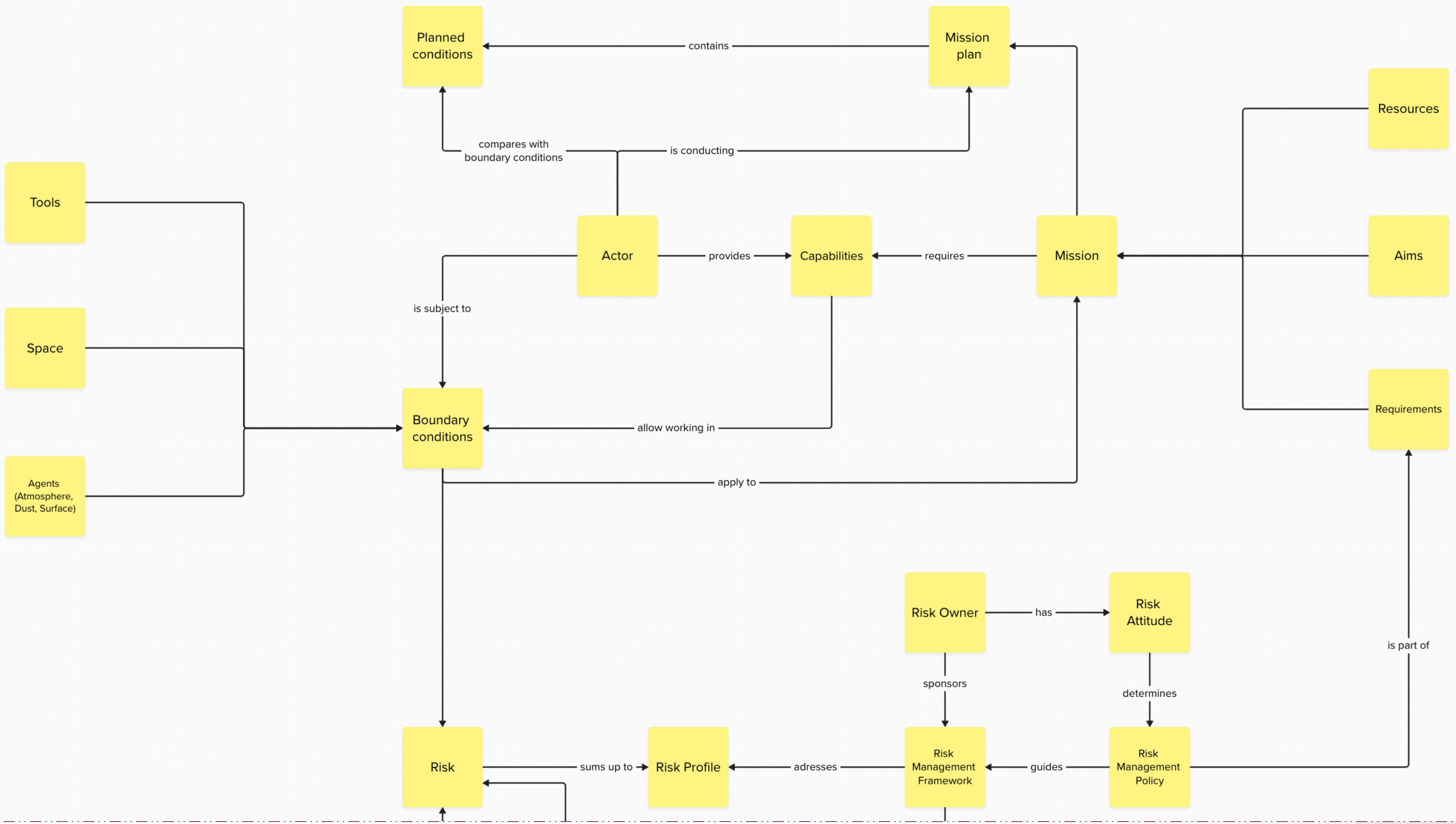
Development steps

- Definition of boundaries
- Informal capture of concepts from subject matter experts
  - Series of discussions captured on mindmaps
  - Final review workshop with external participants (planned)
- Connection of concepts by core properties
- Reality check – can we describe a real project?
- Formalization (SKOS, definitions, translations, OWL-format)

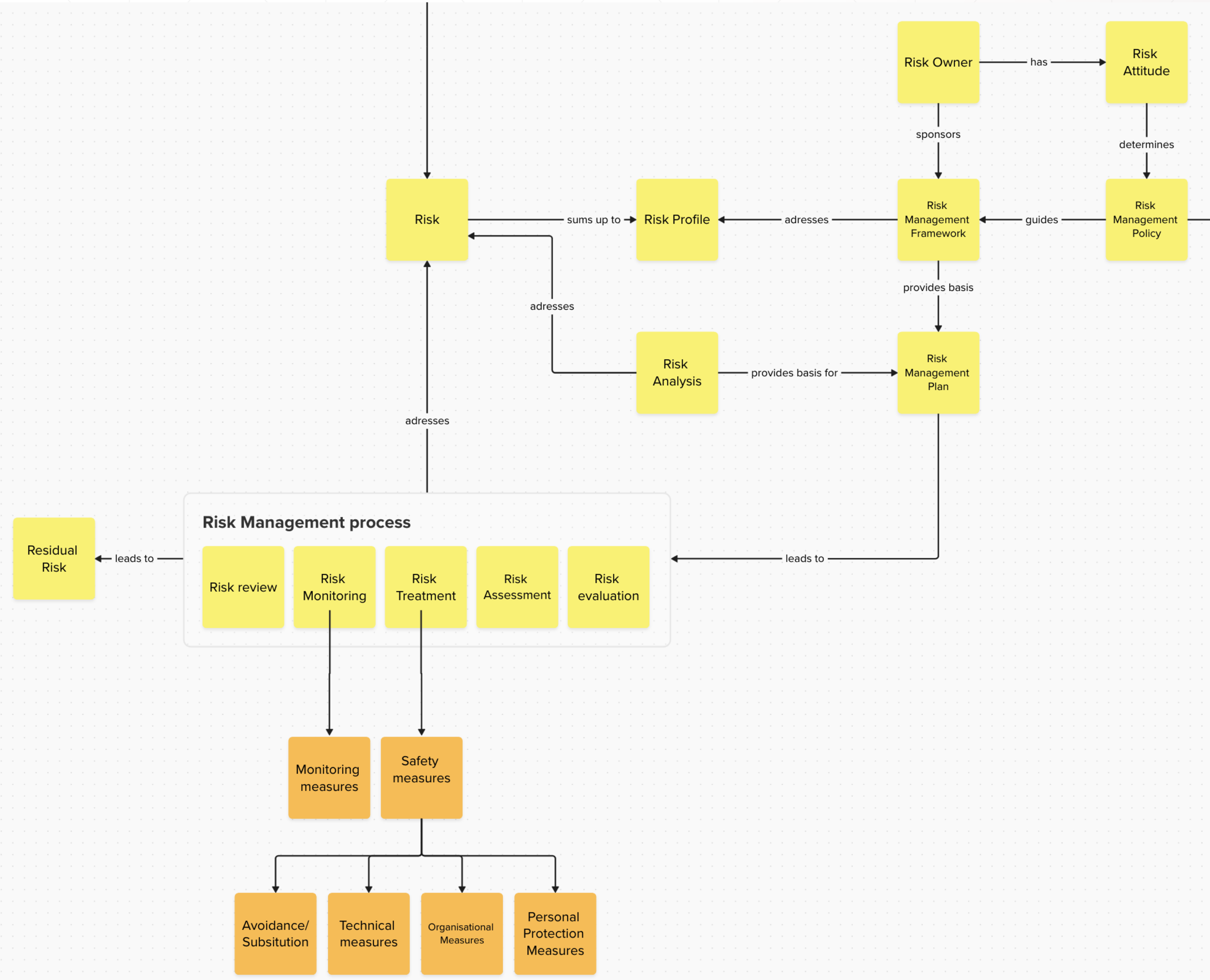
Topics to be covered

- BIM (IFC)
- Risk Management
- Robotics
- Voice input
- Mission planning
- Boundary conditions
- Connections

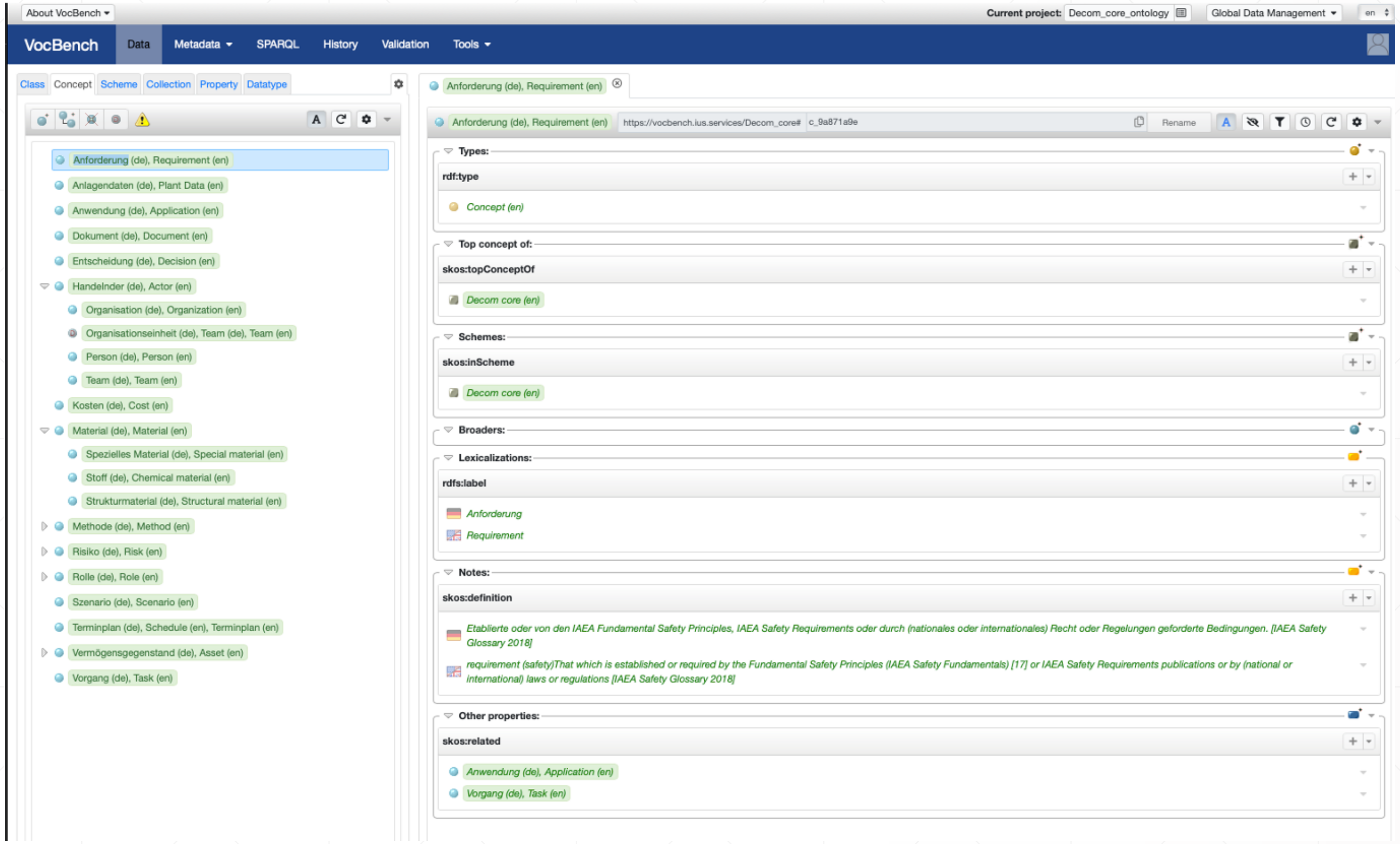
Mission


Planned conditions
contains
Mission plan
Resources
compares with boundary conditions
is conducting
Tools
Actor
provides
Capabilities
requires
Mission
Aims
is subject to
Space
Boundary conditions
allow working in
Requirements
Agents (Atmosphere, Dust, Surface)
apply to
Risk Owner
has
Risk Attitude
is part of
sponsors
determines
Risk
sums up to
Risk Profile
adresses
Risk Management Framework
guides
Risk Management Policy

Risk management according to DIN ISO 31000



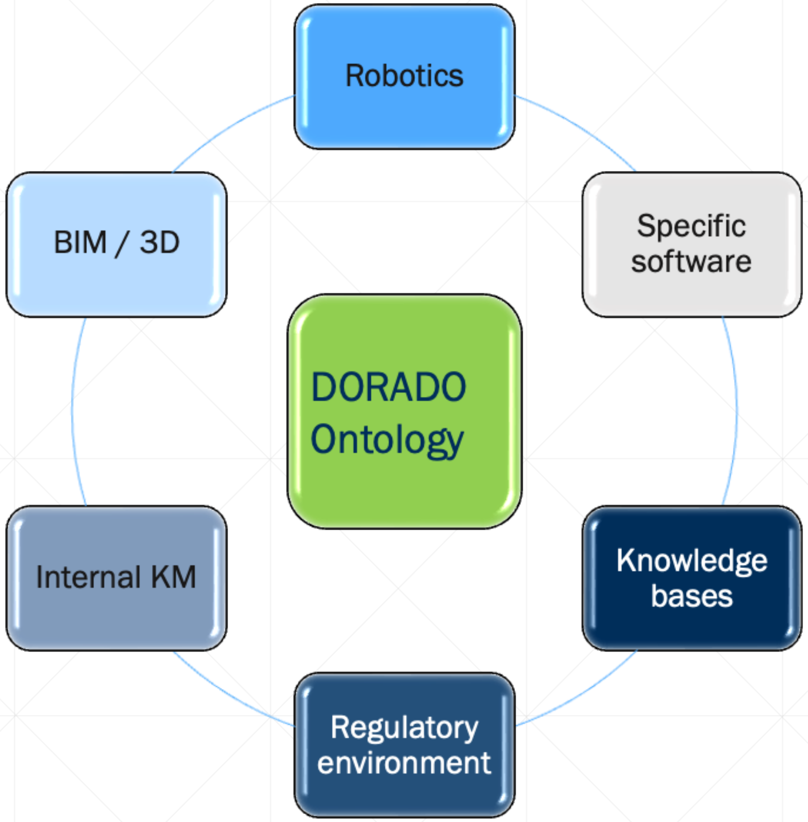
Formalization - VocBench



Conclusion

- The DORADO Mission Planning Ontology is the basis of the tools integration in the project
- Provision of an interface will only work if all participants have a common understanding of the content
- Development follows
  - A top-down approach ensuring compatibility i.a. to IAEA approach for the top layer
  - A bottom-up approach from the participant's existing solutions to ensure a common understanding
- Alignment of approaches highly recommended and beneficial for all sides
- Ontology is a living document (with some constraints), feedback from project flows into the update

Ontologies foster interoperability



- Through the DORADO ontology, it will be much easier to connect different applications and knowledge bases
- Terms are often used differently, the connection by concepts offers a broader reliability of connections.
- The usage of AI approaches will require an ontology to get useful and reliable answers
- This will also allow to reuse the vast decommissioning knowledge

Beyond DORADO

- In parallel, a Working Group of IAEA and EU-JRC is working out the AI driven application of semantic technologies for managing the knowledge on decommissioning
- Different scope, DORADO aims for managing mission planning in decommissioning projects
- The interaction between the Working Group and DORADO allow both sides to come to an aligned approach
- The DORADO ontology will also be helpful in the context of work preparation procedures esp. with regard to AI applications

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Change detection in point clouds

Joseph Ridao (KIT)
April 8, 2025

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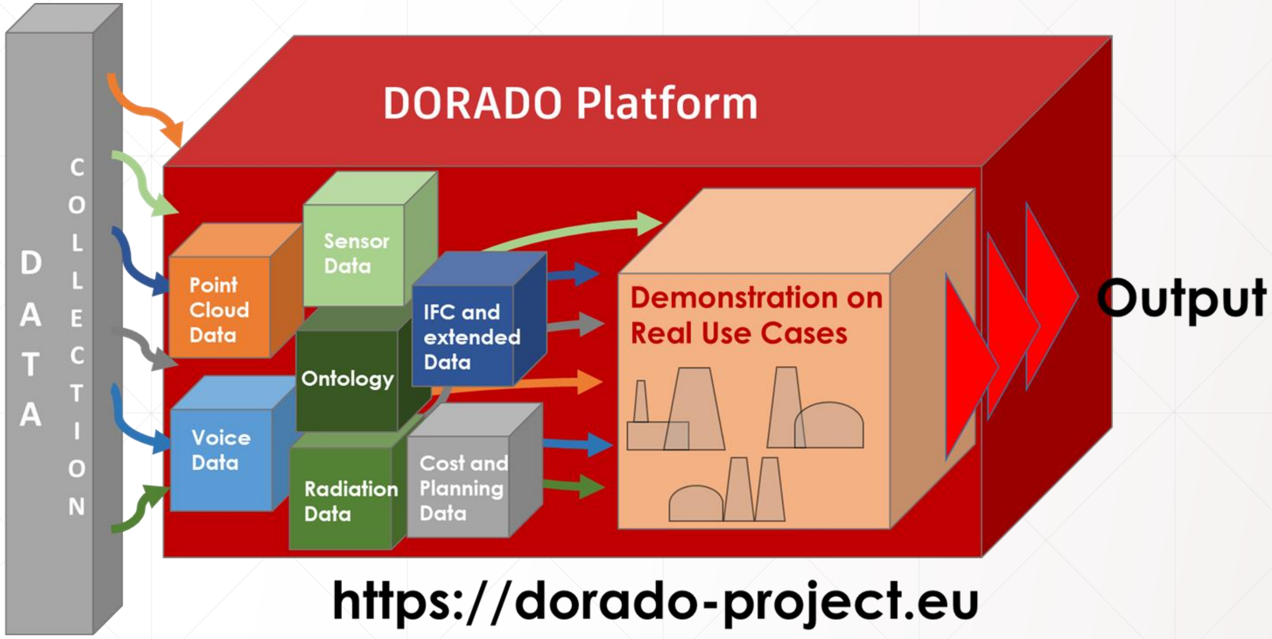
Contents

WP4: Demonstration on Real Use Cases

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

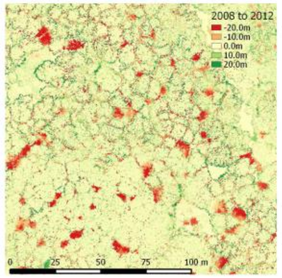
  - Data from different facilities will be used;
  - The different demonstrations are defined separately and independently;
  - However, they can partially benefit from the data from other demonstration cases.

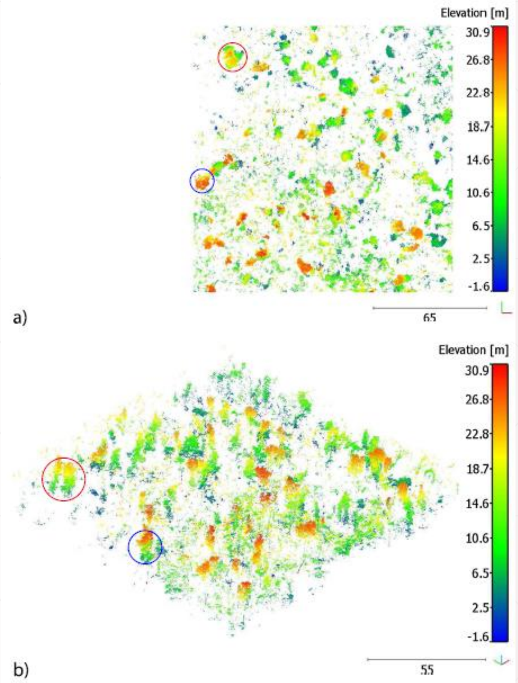
1) Creation of a parametric 3D model;
2) Detecting the changes in the 3D models over time;
3) Comparison of plans vs. reality;
4) Decommissioning safety and risk/hazards assessment.



Change Detection: Overview (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 [1]
  - Vertical changes
    - Referred to as a one-dimensional (1D) method
  - Changes in all possible directions
    - Referred to as a three-dimensional (3D) method





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

Change Detection: Overview (II)

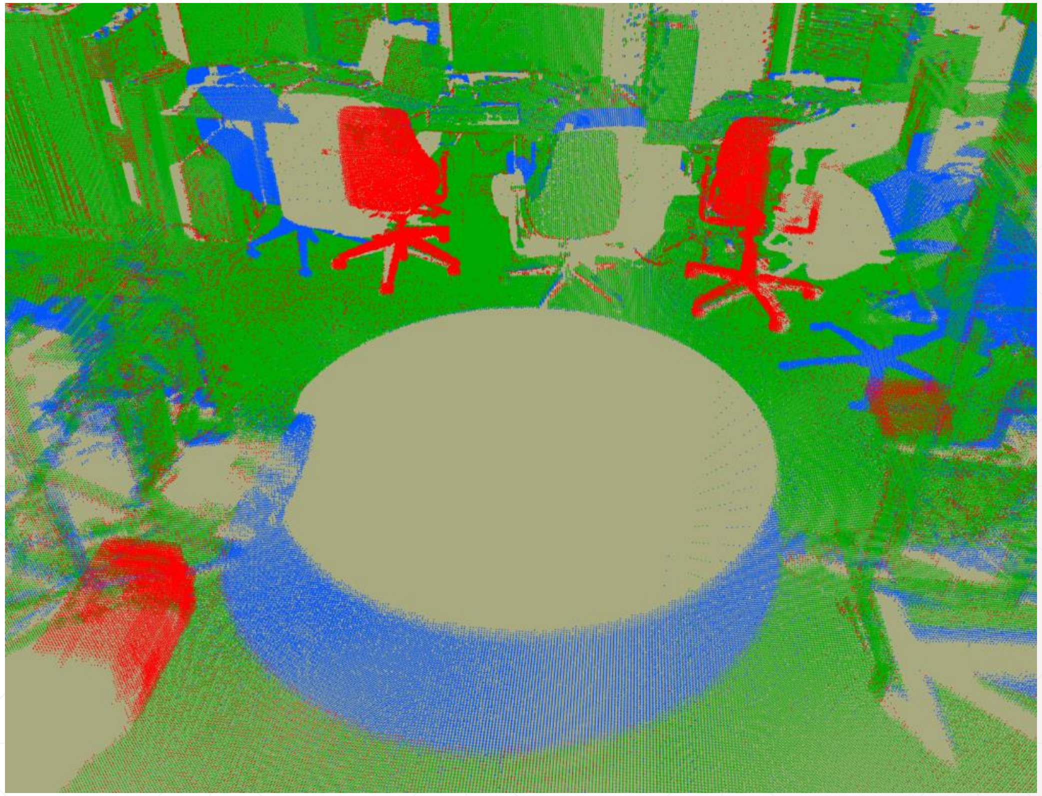
- In the AEC (Architecture, Engineering and Construction) field:
  - Significant role in documenting construction progress
    - Not used as much in demolition and dismantling tasks
  - Traditionally performed manually (visual inspections and measurements)
    - Improvement of measuring devices and creation of digital information
- Checking the geometry with the help of point cloud data
  - Generation of point cloud data using scanners
    - Laser scanners (e.g. Terrestrial Laser Scanner, TLS)
  - Generation of point cloud data using photogrammetry
    - Reconstruction (e.g. Structure from Motion, SfM)

The process is becoming increasingly automated

[7] KIT-TMB-RKKB

Point Clouds: Generation and Processing

- Use of two or more point clouds from a same environment in two different periods of time
- Aspects to be taken into account [2]
  - Geometry and surface properties
    - Dimensions
    - Position in global coordinate system
  - Point Cloud Generation
    - Noise behavior
    - Point cloud density
    - Shadow effects
- Processing of the Information
  - Data Cleaning
  - Efficient handling and presentation of Data
  - Segmentation of Point Clouds



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

Point Clouds: Segmentation

- Different methods for the segmentation of point clouds [3]

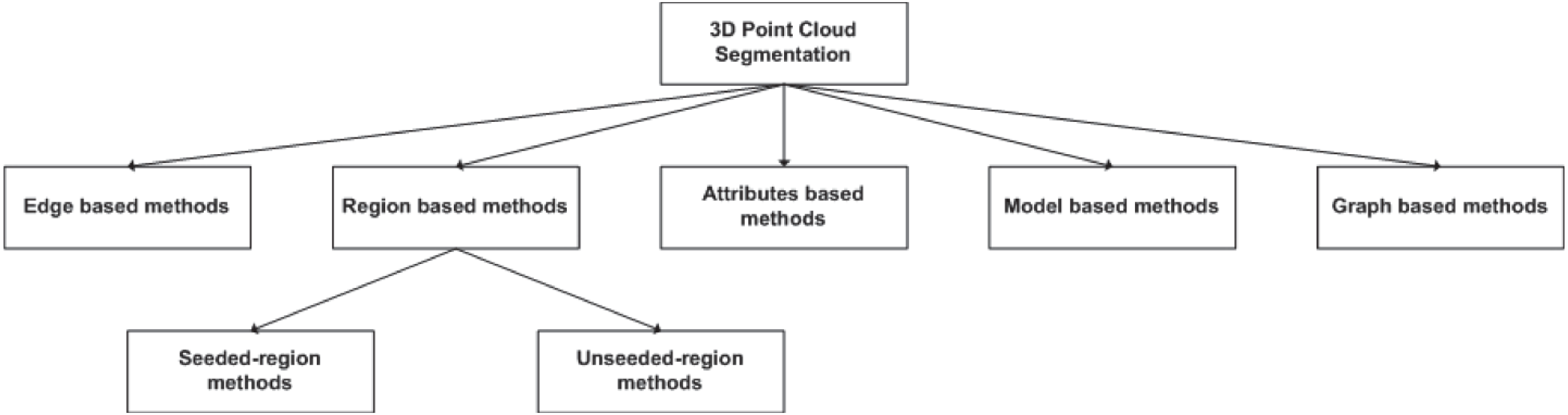


Fig. 2. Taxonomy of 3D point cloud segmentation methods.

[3] Nguyen, A., & Le, B. (2013). 3D point cloud segmentation: A survey. 2013 6th IEEE Conference on Robotics, Automation and Mechatronics (RAM), 225–230. https://doi.org/10.1109/RAM.2013.6758588

Automation of Change Detection with Point Clouds

- Different methods
  - Voxel-based analysis [2] [8]
  - Point-based approach [9]
  - Change detection using Machine Learning (ML) [10]

Still Missing in DORADO

- 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

Sources

[1] Lindenbergh, R., & Pietrzyk, P. (2015). Change detection and deformation analysis using static and mobile laser scanning. Applied Geomatics, 7(2), 65–74. https://doi.org/10.1007/s12518-014-0151-y

[2] Gehrung, J., Hebel, M., Arens, M., & Stilla, U. (2019). A FAST VOXEL-BASED INDICATOR FOR CHANGE DETECTION USING LOW RESOLUTION OCTREES. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, IV-2/W5, 357–364. https://doi.org/10.5194/isprs-annals-IV-2-W5-357-2019

[3] Nguyen, A., & Le, B. (2013). 3D point cloud segmentation: A survey. 2013 6th IEEE Conference on Robotics, Automation and Mechatronics (RAM), 225–230. https://doi.org/10.1109/RAM.2013.6758588

[4] J. Ko and Y. S. Ho, “3D Point Cloud Generation Using Structure from Motion with Multiple View Images,” The Korean Institute of Smart Media Fall Conference, pp. 91-92, Oct. 2016. http://icserv.gist.ac.kr/mis/publications/data/2016/3D%20Point%20Cloud%20Generation%20Using%20Structure%20from%20Mot.pdf

[5] 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

[6] Antti Räty & DORADO consortium. Euratom project DORADO. Digidecom2024 conference, November 2024. Halden, Norway

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[8] Meyer, T., Brunn, A., & Stilla, U. (2022). Genauigkeitsbetrachtung voxelbasierter Änderungsdetektion im Gebäudeinnenbereich zur automatisierten Baufortschrittsüberwachung.

[9] Girardeau-Montaut, D., Roux, M., Marc, R., & Thibault, G. (2005). Change detection on points cloud data acquired with a ground laser scanner. ISPRS Workshop. https://www.researchgate.net/publication/228684497_Change_detection_on_point_cloud_data_acquired_with_a_ground_laser_scanner#fullTextFileContent

[10] Tran, T., Ressl, C., & Pfeifer, N. (2018). Integrated Change Detection and Classification in Urban Areas Based on Airborne Laser Scanning Point Clouds. Sensors, 18(2), 448. https://doi.org/10.3390/s18020448

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Discussion

Brief Overview

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Ontologies

- Ontologies describe a model of a section of the real world (*„a formal, explicit specification of a shared conceptualization“*)
- Categories or classes are used to describe concepts, processes or things
- Inheritance allows to make instances of classes for example KKE as an instance of the class power reactors
- Properties connect classes and instances – network structure
- Example: KKE is a Siemens Konvoi Reactor
  Siemens Konvoi Reactor is subclass of power reactor
- Inference: KKE is a power reactor
- Information Triple: Subject – predicate - object

Taxonomies

- Taxonomies describe the content of classes or categories
- Classes or categories are collections of similar things
- Taxonomies built a strictly hierarchical order, i.e. every item can have exactly one parent item
- Example: pine tree is part of needle tree
  needle tree is part of tree
  tree is part of terrestric flora
- Taxonomies can be graphically shown as tree graphs

SKOS

- Simple Knowledge Organisation System
  - Allows to organise metadata
  - Describes nearby terms, synonyms, antonyms
  - Used to describe the concepts
- Example:

A pine tree is not the same as a birch tree

A pine tree has some similarities with a fir tree

A pine tree is somehow related to scents