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Report D5.6 “Final validation, demonstrators of industrial cases and agreement with wider stakeholders”

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Report D5.6
"Final validation, demonstrators of industrial cases and agreement with wider stakeholders"

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Task	T5.5 | Final validation, demonstration of use cases and agreement with wider stakeholders
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Glossary of terms

Item	Description
DO	Domain Ontology
EP	Early Prototype
FAIR	Findability, Accessibility, Interoperability, and Reusability
FP	Full Prototype
KPI	Key Performance Indicator
TLO	Top Level Ontology
TRL	Technology Readiness Level

Keywords

Ontology; Data; Standardisation, Community Demonstrators, final Validation, FAIR, TRL

Disclaimer

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Executive Summary

This deliverable represents the final report of Workpackage 5 of the European project OntoCommons. Within the OntoCommons project, an ecosystem of reference top, middle and domain ontologies and their alignments as well as best practices, guidelines and tools for ontology development and use is being built. For this purpose, 22 industrial and industry-related demonstrators are involved in the project, which support the incorporation of industrial requirements for ontologies and tools. In addition to 11 demonstrators (initial use cases), which are involved in the project from the beginning, 11 further demonstrators (new use cases) were selected in the second year of the project, which are to support and consolidate an industry-oriented implementation of the OntoCommons goals.

Building on the previous deliverables D5.1 to D5.5 of Workpackage 5, which described the requirements of the individual use cases of the demonstrators at the beginning and the progress of the use cases during the project in the sense of monitoring as well as the selection procedure of the new demonstrators, this deliverable 5.6 demonstrates the final validation of all demonstrators and their use cases.

The work for this deliverable was carried out within Task 5.5 "Final validation, demonstrators of industrial cases and agreement with wider stakeholders". In order to collect the required information from the demonstrators, a survey based on the monitoring surveys conducted during the project was set up and distributed to the demonstrators in May 2023. With this survey, the final information about the ontology and tool development, their final implementation, the final evaluation of the KPIs, the TRLs and the FAIR principles of the use cases were collected. The implementation of the FAIR principles was further considered in detail by the demonstrators through the completion of another questionnaire. Additionally, the final lessons learned, and the further benefits of the use cases were collected. All information was examined in more detail, validated, summarized, and completed with an outlook in this report.

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1. Introduction

1.1 Purpose

The OntoCommons project includes eleven cases selected in the proposal phase (so called Initial Cases - Demonstrators) ranging through the NMBP work programme domains. In the second phase of the project, these eleven initial demonstrators were completed by further eleven community proposed demonstrators (so called Community or new Demonstrators) and were active in the specification and implementation of the planned activities on the selection, development, enhancement, and use of ontologies in different industrial sectors. The aim of the demonstrators-cases is to provide recommendations about the tools and domain ontologies to be included in the OCES, and the need for new domain ontology development. The complete set of use cases cover different domains (Manufacturing, Materials Development, Biotechnology, Life Cycle Assessment, Materials Processing, Material Characterisation, Materials Modelling etc.), have diversity in the technology requirements, and are geographically distributed (countries include Sweden, Germany, Brazil, China, France, Italy, Luxembourg, United Kingdom). The demonstrators play an important role for the OntoCommons project as they provide information on ontologies, tools and frameworks used within the demonstrators as well as gaps for the development of suitable ontologies, tools and frameworks for use cases in industrial applications.

The purpose of this deliverable D5.6 **Final validation, demonstrators of industrial cases and agreement with wider stakeholders** is the analysis of the final feedback from the 22 use cases and their presentation on the form of brief use cases. Of those 22 use cases, 18 gave feedback in the form of a finale evaluation. These are represented by 11 out of 11 of the initial use cases and 7 out of 11 of the new use cases. Some of the demonstrators already finished their work at an earlier stage of the OntoCommons project and gave their finale reporting in previous deliverables. The results will be used as input for the project roadmap (WP1). The deliverable is part of the task T5.5 and continues to build on the previous deliverables D5.1-D5.5 where further information on all demonstrators can be found.

1.2 Approach applied

The approach of this deliverable follows the previous deliverables D5.1-D5.5 and follows their methodology. Based on those, a survey was created and sent out to all use cases. This survey included a detailed description of each use case, particularly focusing on detailed main scenarios, FAIRness assessment, an assessment of the used or developed ontologies and tools and KPIs to measure the success of the demonstrator with regards to the results of OntoCommons project. The template of the survey can be found in

Annex I survey template.

The results and final status of the development of the use cases are analysed to extract common conclusions and provide the feedback to the other WPs and to the OntoCommons Roadmap (see D1.16 and D1.17).

1.3 Structure of the deliverable

The deliverable is structured as follows. Section 2 includes the descriptions of the final evaluation of each of the 18 demonstrators. Each section has the same structure according to the defined template (see

Annex I survey template):

- A brief description of the use case and in some cases a visual representation.
- Description of the used or developed ontologies and tools used for the use case as well as information on the publication of self-developed ontologies and tool, if provided
- Implementation steps describing the steps planned and the expected status of their executions at the end of OntoCommons
- KPIs Assessment addressing the assessment of the KPIs identified by the owners of the use cases
- FAIR Assessment – providing an assessment of the improvement in fulfilling FAIR criteria, i.e., aiming to identify any changes in comparison to the time the demonstrator joined the project
- TRL Assessment – offering assessments of the TRL evolvement
- Assessment of further benefits of the uses case besides the KPIs
- Assessment of planed future developments
- Lessons learned
- Other comments

The overall analysis of cases, common conclusions and lessons learned, as well as a brief outline of our future work, is provided in section 3.

2. Demonstrators

The following chapters provide information on the demonstrators, give a short introduction and focus on the progress of the demonstrators regarding the use and development of ontologies and tools, the improvement of the TRL and the FAIRness as well as other KPIs for each of the demonstrators.

Some demonstrators have different schedules than the overall OntoCommons project, and, therefore, the reports on their status partly differ from the descriptions of the other cases and do not cover some aspects (e.g., FAIR) addressed in the finale evaluation.

2.1 Demonstrator 1: IRIS – IndustRIal co-design Support (AIRBUS)

2.1.1 Brief description and visual representation

The primary goal of the use case is to increase the interoperability and improve the communication between aircraft assembly and the industrial system design. Airbus aims to use ontologies to support trade-off decision making, represent domain and process knowledge explicitly and improve traceability of the decisions made during the design and assembly processes. The use case aims to demonstrate:

- decreased development time via automatized decision making and improved re-usability,
- improved reliability via traceability,
- improved communication between assembly and design experts via data integration and increased domain knowledge interoperability.

This will be demonstrated with an illustrative case of product aircraft design and its orbital joint process design. This use case will be based on the output of a relevant project (QU4LITY) pilot. An application ontology corresponding to this scenario is under development. The main knowledge sources for that ontology are documented historical system specifications and experts' feedback.

In OntoCommons the application ontology will be further improved by collecting information and knowledge from more stakeholders and taking references from other application or domain ontologies in the OntoCommons ecosystem if available. Another objective is to improve the interoperability by aligning the application ontology to the TLO or top reference ontology which are expected output of OntoCommons. An overview of the use case is shown in Figure 1.

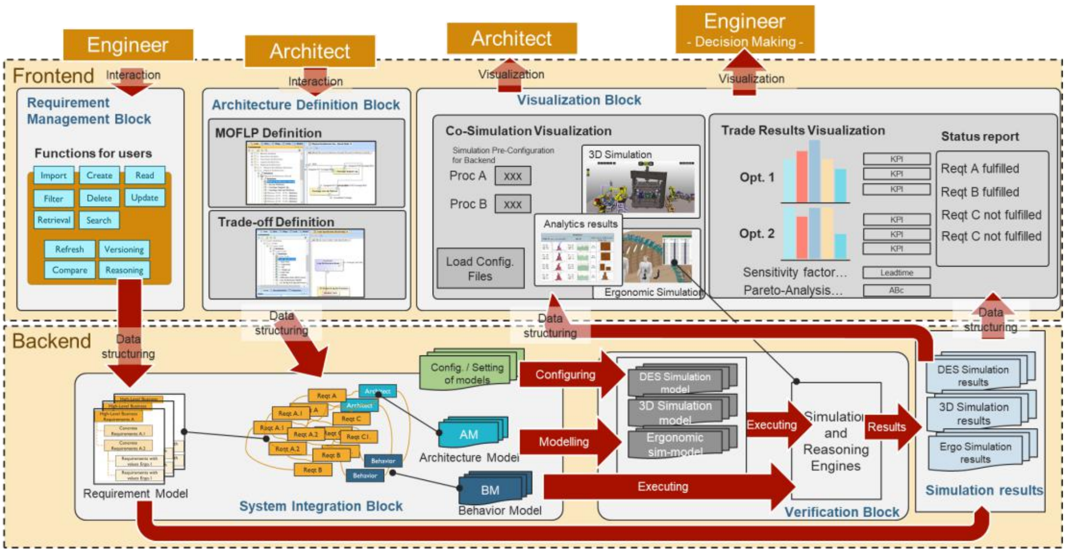


Figure 1: An overview of UC1

2.1.2 Ontology level and development during the project Ontologies developed/reused

The following table shows details of the demonstrators used or developed ontologies and tools.

Table 1: Ontologies and tools of UC1

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Knowledge capturing by Knowledge scientists	BFO		IOF-Core		QU4LITY Domain Ontology (under development)		Protégé	
2	Process design by System engineering expert and Assembly process engineer	---		---		---		---	
3	Architecture models by systems engineering expert and Assembly process engineer	BFO		IOF-Core		IOF-MBSE ontology		MetaGraph 2.0	
4	Simulations models development supported by	---		---		---		Neo4j	

	ontology by System engineering expert and Knowledge scientists								
5	Simulation and visualization by Simulation engineer	---		---		---		---	
6	Optimize Ontology according to application feedbacks	---		---		---		Protégé Neo4j	
7	Update and maintain Ontology according to new versions of MLO	BFO		IOF-Core		---		Protégé	

2.1.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 2: demonstrator development steps of UC1

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Analyse documented knowledge about existing assembly systems to extract top terms, thus creating classes and individuals for the application ontology development.	A draft version of the ontology is finished	None	Complete
2	Interview with internal domain experts and collect their feedback about the application ontology.	First-round of interview finished.	None	Complete
3	Collect and refine user stories and stakeholders'	A draft of the classes is defined.	None	Complete

	requirements for the target assembly system to complete the classes about the requirements in the application ontology.			
4	Develop an ontology to represent the knowledge of system architecture models following the MBSE methodology.	A draft version of the ontology finished.	None	Complete
5	Integrate the application ontology about domain knowledge, the requirement ontology and the MBSE ontology based on the IOF-Core and BFO structure.	A draft version of the ontology finished.	Currently using the old version of IOF-Core, adjustment is needed when new version is released.	Complete
6	Apply the developed ontology for automatically generating new assembly system design solutions to support trade-off according to predefined performance indicators.	The overall workflow has been verified based on a simplified example, currently under improvement.	None	Complete

2.1.4 KPIs Assessment

In use case 1, improvements were achieved in the KPIs FAIR and TRL. Improvements were also targeted in the areas of "Avoidance of physical testing", "CO2 emission - improved architecture", "Automation level", "Lead time in e.g., production, ontology modelling" and "Optimised performance". However, these could not be quantified in the last period of the project.

2.1.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 3: Shall requirements of UC1

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC1_RQ_U_01	Support industrial design process	Support the design of assembly process of aircrafts	**Shall**	---	Partly
UC1_RQ_U_04	Reasoning and decision making	Apply ontologies for reasoning and decision making	**Shall**	---	Partly

2.1.6 TRL Assessment

In the overall view, the TRL has increased from 2 for the initial assessment to 5 at the end of OntoCommons.

In July 2022, the use case has reached the targeted TRL 5. They have taken various steps along the way to achieve this. The ontology is integrated with requirement management, architecture design, simulation and visualization functional blocks.

During the year 2021, this use case has evolved from internally defined MVP2 (Simple trade-off scenario simulation) to MVP4 (Global semantic integration). From the Ontology perspective, the application ontology has been adapted to comply with the MLO IOF-Core ontology which adopts BFO itself. Since December 2021, this case has been evolved to MVP5. A complete application ontology has been developed based on the dummy dataset and applied for supporting new process design.

2.1.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: All the principles in the Findable dimension have been implemented. Rich metadata is provided to allow discovery is already in the implementation phase. The principles regarding persistent identifiers for metadata and data are also in the planning phase. The application ontology classes and individuals based on an exemplary pseudo-dataset have been stored in a cloud server making it findable by authorized users.

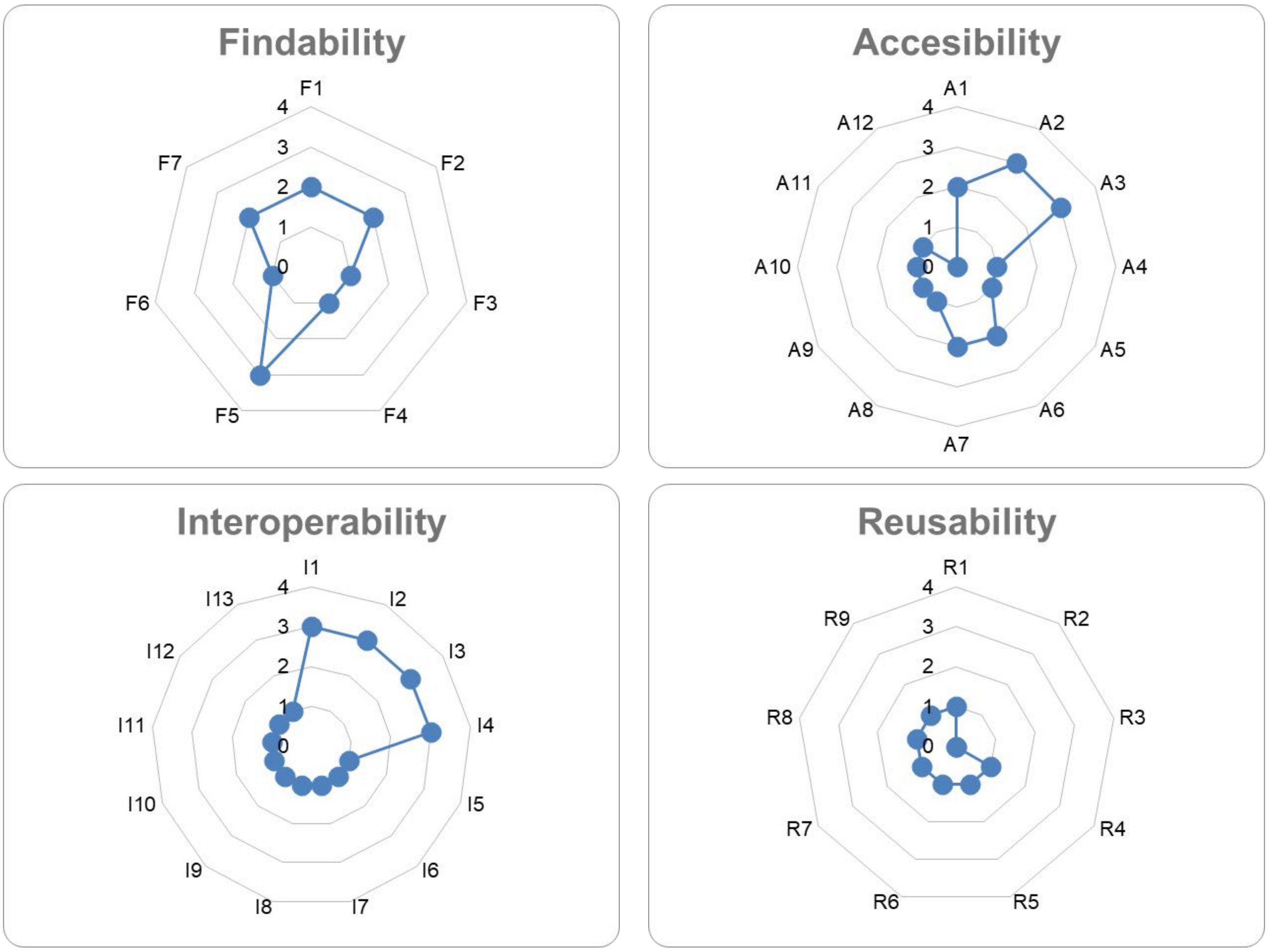
Accessible: 11 of the 12 principles in the Accessible dimension have been implemented. There are already principles regarding manual access to the data and metadata being implemented. Publication of data and metadata over a standardized protocol is in the planning phase.

Interoperable: All the principles in the Interoperable dimension have been implemented. Interoperability is arguably the strongest dimension in this use case with four principles already in the implementation phase. This situation indicates that both metadata and data are represented with standardized and machine-understandable metadata formats.

Reusable: 8 of the 19 principles in the Reusable dimension have been implemented. At the Reusability front, the use case is still at an early stage as none of the principles have not even been considered yet.

Due to the regulations of the owner of use case, a major part of the data related to the detailed application scenario cannot be shared publicly. However, some common knowledge including the ontology and the system framework will be published through workshop/conference papers, which will be available in the following months. Currently, a conference paper and a journal paper have been submitted, which are expected to be published in the near future. It will increase the scores of some dimensions of the FAIR evaluation.

Table 4: Final FAIR results of UC1 in blue



2.1.8 Lessons learned

1) The adoption of upper ontologies, such as BFO top-level ontology and IOF-Core domain ontology, could indeed accelerate the development process of application ontologies.

2) The information exchange between domain experts and ontology engineers is critical. Web-based tool such as WebProtégé could be a more efficient tool than the traditional desktop version. During the development of the application ontology, experts from different domains, such as requirement management and systems engineering, need to exchange information frequently. It usually results in modifications to the ontology. With a local desktop version Protégé, all the modifications are performed by one user to avoid different versions. With WebProtégé, all the partners can edit the ontology whenever necessary, which improves the efficiency. During this phase, most efforts are spent on discussions about vocabularies and relationships. The functions provided by WebProtégé are enough.

3) Cross-domain ontology integration is a challenging task, for example, the integration of the application ontology for assembly system domain knowledge and the MBSE ontology for system architecture model ontology. It is difficult to map and interlink classes from one to another. It currently is done manually. The adoption of middle-level ontology (IOF-Core) enables to embed these classes into the same structure at a high level. However, there also exist more detailed relationships between lower-level classes. For example, a certain “Manufacturing Resource” class in the domain knowledge ontology has relationship with a “Performance Requirement” class in the requirement ontology. Such relationships need to be specified manually when integrating the two ontologies.

4) For querying and reasoning, it turns out the Protégé is not as efficient as some graph database such as the Neo4j used in this case. They are faster and more flexible and provide various APIs for integration with existing software and information system.

2.2 Demonstrator 2: SeDIM Semantic Data Integration for Manufacturing (Bosch)

2.2.1 Brief description and visual representation

The main goal of this use case is to foster scalable development of Machine Learning (ML) pipelines for condition monitoring of industrial equipment. The use case aims to improve the reusability of existing ML pipelines for similar processes of tasks. The company aims to achieve the adaptation of ML pipelines with affordable, minimal modifications in the existing pipelines.
The core of the use case relies on the semantic technologies by representing domain knowledge both for manufacturing processes and ML pipelines explicitly with ontologies. A reasoner is then able to derive feature groups from the annotated data and selects the suitable ML algorithms. This knowledge-based approach also improves explainability.

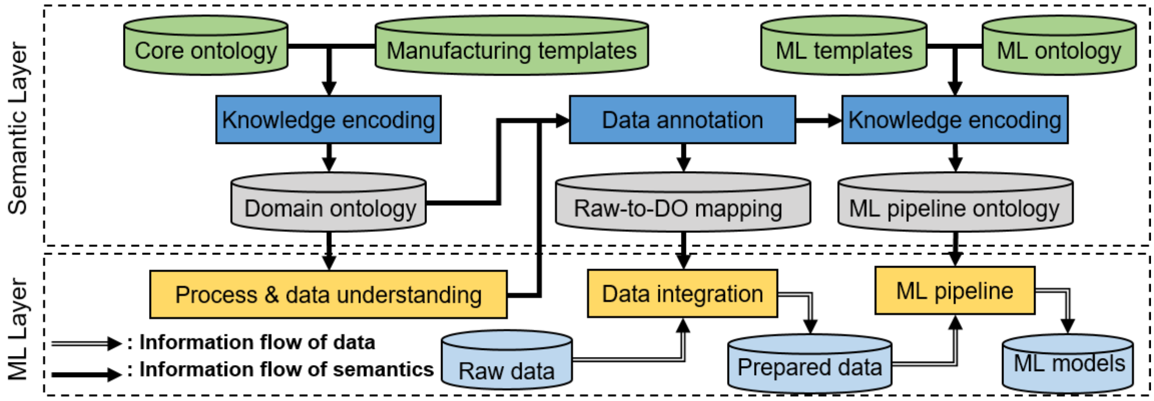


Figure 2: An overview of UC2

The use case focused on applying the above workflow on Bosch's welding data. To do so, Bosch produced the Resistance Spot Welding Ontology (RSWO), a domain ontology for spot-welding welding data, based on Bosch domain expert's knowledge and international standards; as well as Executable Knowledge Graphs (Ex-eKGs), a tool supported by an openly available library (ExeKGLib) to produce ML pipelines in a transparent and reusable way.

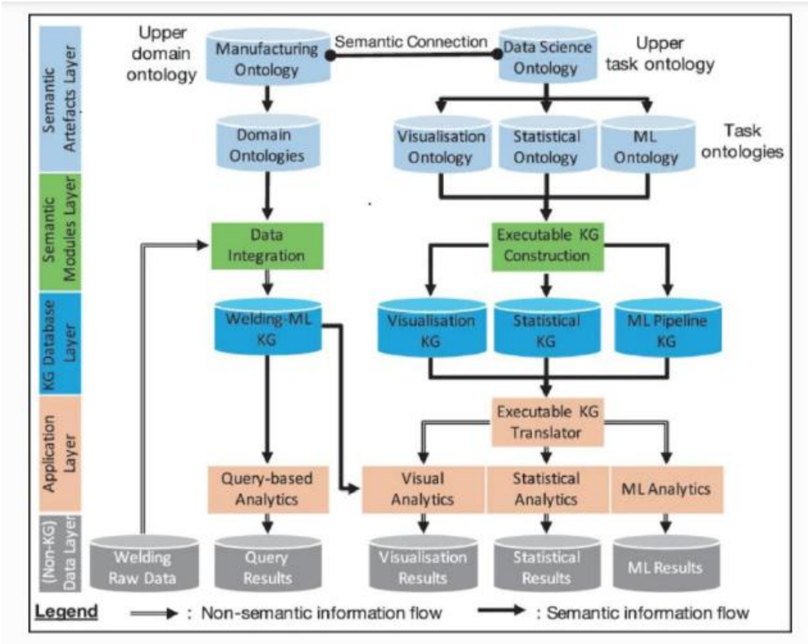


Figure 3: An expansion of the above overview focusing on how the ML pipeline is obtained (see https://link.springer.com/chapter/10.1007/978-3-031-19433-7_45#ref-CR2)

2.2.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 5: Ontologies and tools of UC2

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Data acquisition from three sources	---		---		---		---	
2	Task negotiation, to define feasible and economic tasks	---		---		---		---	
3	Data integration, to integrate data from different conditions and factories	---		QMM-Core Ontology	X	i) QMM-Domain Ontology ii) RSWO: Bosch's Resistance Spot Welding Ontology	x	an ontology-based software system: SemML	x

4	Data analysis, ML model development	---		QMM-ML Ontology	x	i) ML Pipeline Ontology ii) Data science ontology	x	i)an ontology-based software system: SemML ii) ExeKGLib, a library for executable KG constructions	x

Table 6: self-developed ontologies and tools of UC2

Ontology / tools (O/T)	name	description	Publishing link (if applicable)
O	QMM-Core	Ontology for quality monitoring in manufacturing. See https://link.springer.com/chapter/10.1007/978-3-030-62466-8_33 for a more in-depth description	-- -
O	QMM-ML	Ontology for machine learning. See https://link.springer.com/chapter/10.1007/978-3-030-62466-8_33 for a more in-depth description	---
O	Data science ontology	Upper task ontology, aligned with the QMM-core ontology, that formalise the general knowledge of data science activities. See https://link.springer.com/chapter/10.1007/978-3-031-19433-7_45#ref-CR2 for a more in-depth description.	---
O	Visualization ontology	Task ontology, aligned with the data science ontology, that describes the most common visual analytics methods. See https://link.springer.com/chapter/10.1007/978-3-031-19433-7_45#ref-CR2 for a more in-depth description.	---
O	Statistical ontology	Task ontology, aligned with the data science ontology that describes the most common statistical analytics methods. See https://link.springer.com/chapter/10.1007/978-3-031-19433-7_45#ref-CR2 for a more in-depth description.	---

O	Visualization ontology	Task ontology, aligned with the data science ontology, that describes the most common machine learning analytics methods. See https://link.springer.com/chapter/10.1007/978-3-031-19433-7_45#ref-CR2 for a more in-depth description.	---
O	Resistance Spot Welding Ontology	Domain ontology for resistance spot welding. See https://ieeexplore.ieee.org/document/10101786 for a more in-depth description	https://nsai-uio.github.io/RSWO/
T	ExeKGLib	Python for constructing and executing Machine Learning (ML) pipelines represented by Knowledge Graphs. See https://arxiv.org/pdf/2305.02966.pdf for a more in-depth description.	https://github.com/boschresearch/ExeKGLib#usage

2.2.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 7: demonstrator development steps of UC2

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	QMM-Core Ontology development in line with ISO standards and existing ontologies	First round development is finished and is being verified to be integrated into the legacy system	None	The QMM-Core Ontology was improved, and several other ontologies were produced. Further work on ontology evaluation is expected for the end of OntoCommons
2	Further data acquisition to cover more welding processes and datasets	First-round finished. Second round not started	None	---

3	Task negotiation, to define feasible and economic tasks	First-round finished. Second round not started	None	---
4	Data integration, to integrate data from different conditions and factories	First-round finished. Second round not started	None	---
5	Data analysis, ML model Development	First-round finished. Second round not started	None	Executable KGs library developed

2.2.4 KPIs Assessment

Use case 2 shows improvements in KPIs FAIR and TRL. Improvements were also targeted in the areas of " Cost reduction of the machine learning data pipeline process", "Cost reduction of maintenance" and "Quality control Improvement". However, these could not be quantified in the last period of the project, as the work continues.

2.2.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 8: Shall requirements of UC2

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC2_RQ_U_01	Coverage of domain terms	---	**Shall**	---	Complete
UC2_RQ_U_02	Computational efficiency	---	**Shall**	---	Partly
UC2_RQ_U_03	Good alignment with corresponding domains	---	**Shall**	---	Complete

UC2_RQ_U_04	Modularization	---	**Shall**	---	Partly
UC2_RQ_U_05	Conformance to domain standards (ISO, etc)	---	**Shall**	---	Complete
UC2_RQ_U_06	Conformance to W3C standards	---	**Shall**	---	Complete
UC2_RQ_U_07	Compatibility with a wider ecosystem	---	**Shall**	e.g., with OPC UA	Planned
UC2_RQ_U_08	High quality	---	**Shall**	Consistency, connectivity, other quality metrics	Planned
Development of ontologies					
UC2_RQ_D_01	Controllability to follow good practices and guarantee high quality of development	---	**Shall**	Via templates, etc	Complete
Maintaining/extension of ontologies					
UC2_RQ_M_01	Controllability to follow good practices and guarantee high quality of development	---	**Shall**	---	Planned
UC2_RQ_M_02	Provenance	---	**Shall**	To know who has done what	Complete
Tools for ontology					
UC2_RQ_T_01	Visualization	---	**Shall**	---	Complete
UC2_RQ_T_02	Debugging	---	**Shall**	---	Partly
UC2_RQ_T_03	Validation	---	**Shall**	---	Planned

UC2_RQ_T_04	Quality analytics	---	**Shall**	---	Planned
Standardisation					
UC2_RQ_S_01	W3C Standards	---	**Shall**	---	Complete
UC2_RQ_S_02	Industrial standards (ISO, etc)	---	**Shall**	---	Complete
UC2_RQ_S_03	Good practices of modelling	---	**Shall**	---	Partly

2.2.6 TRL Assessment

In the overall view, the TRL has increased from 5 for the initial assessment to 6 at the end of OntoCommons.

For UC2 we developed ontologies of 3 types: Core Ontology that captures middle level welding knowledge, Domain Ontology that focuses on particularities of RSW or other specific welding processes, and ML Ontology that captures ML aspects such as feature groups and ML algorithms.

1. **MLOs**: The Middle level ontologies used for the Use Case have been decided.

· QMM-ML Ontology

· QMM-Core Ontology

2. **for DOs employment**: The DOs that will be used for our Use Case have been determined:

· QMM-Domain Ontology

· ML Pipeline Ontology

3. **for tools deployment**: we developed a system, called SemML, that extends the conventional ML

workflow with four semantic components: Ontology extender, Domain knowledge annotator, Machine learning annotator, Ontology interpreter. These components rely on ontologies, ontology templates, and reasoning. Indeed, SemML exploits upper-level and concrete domain ontologies and the ML-ontology that captures machine learning tasks.

The solutions described in the previous paragraphs (see e.g., Figure 2 and Figure 3) have been developed up to TLR 5 (Technology validated in relevant environment) to 6 (Technology demonstrated in relevant environment)

2.2.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: Data are findable to authorized users at Bosch but not to others due to corporate restrictions

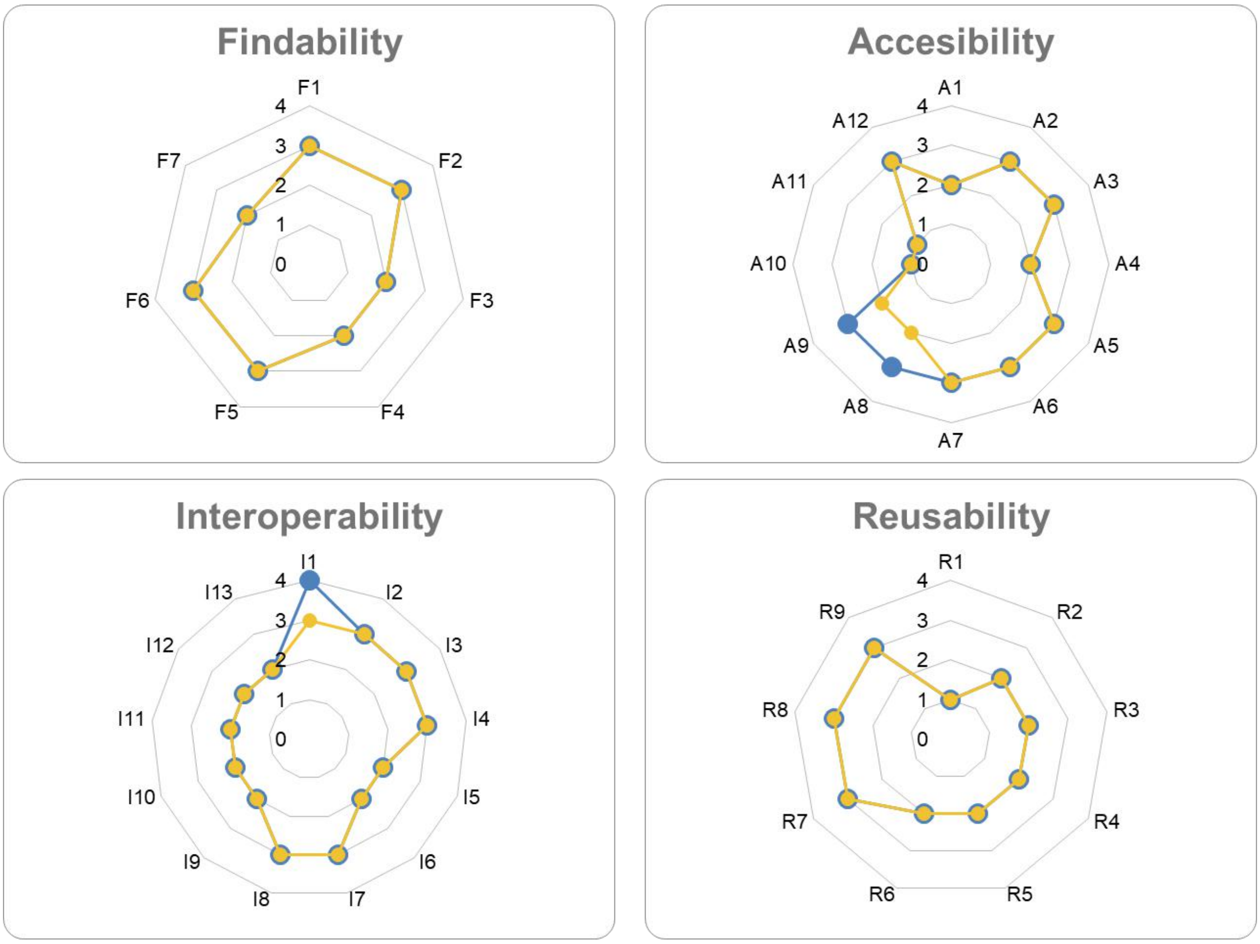
Accessible: Data are findable to authorized users at Bosch but not to others due to corporate restrictions.

Interoperable: Ontologies integration has started to enhance data interoperability. Terms (e.g., spot diameter, adhesive type, etc.) used for knowledge graph schema selected.

Reusable: Ontologies integration has started, in order to enhance data and machine learning model data pipeline reusability.

The demonstrator needs to improve the FAIRness of the data and metadata, so information about the data can be discovered. The data of the use case are not to be shared with third-party, so actions taken should regard the improvement of Findability, Accessibility, Interoperability, and Reusability among in the organization level.

Table 9: FAIR results of the initial survey of UC2 in yellow, final results in blue



2.2.8 Planned further developments

The development of semantic technology in Bosch is expected to continue along different research lines. In particular, work focusing on ontology evaluation is planned, as well as the development of an ontology for plastic simulation.

2.2.9 Lessons learned

1) Discussion with domain experts is difficult, although it is vitally important, since domain experts have their knowledge in life, and more practical experience that is substantially richer than the mere text or diagrams from the documentation or standards.

2) The domain experts are normally from engineering or mechanical background. Their language and vocabulary are highly specialized in their domain, and it is difficult in the beginning for knowledge engineers to understand them. A "lingua franca" that bridges the communication is needed.

3) The other difficulty is the vast amount of detail and knowledge fragments that far exceed the time capacity allowed by the discussion framework of workshops, while the available time of domain experts is on the other side extremely limited. Some more efficient way of communication should help in relieve this constraint.

4) The reading of welding standards is much more challenging than expected. The standards are typically written or formed following conventional ways, often with insufficient consideration on systematic nomenclature, taxonomy, and consistency. There exists often various duplication among the standards and some of them also contradict to each other.

2.3 Demonstrator 3: EngDemostrator (AIBEL)

2.3.1 Brief description and visual representation

The main goal of the use case is to describe data from various sources within the Aibel organization, semantically, in order to

- improve the reusability of data and processes,
- find inconsistencies via reasoning in terms of specific requirements,
- improve interoperability between departments/organizations, and
- improve interoperability between applications.

The use case will be built on top of the existing ontologies used in the company. The ontologies will be extended in the scope of the use case. The ontologies will be used for semantic modelling of material properties and chemical composition. Existing standards will be converted into ontologies via OTTR templates. Figure 4 gives an overview of the use case.

Industry standard material grades with content information is required in many work processes performed by multiple parts of departments in organisations such as Aibel. Such content is also embedded in applications. Industry standard material grades as ontologies should therefore be made available across the organisation.

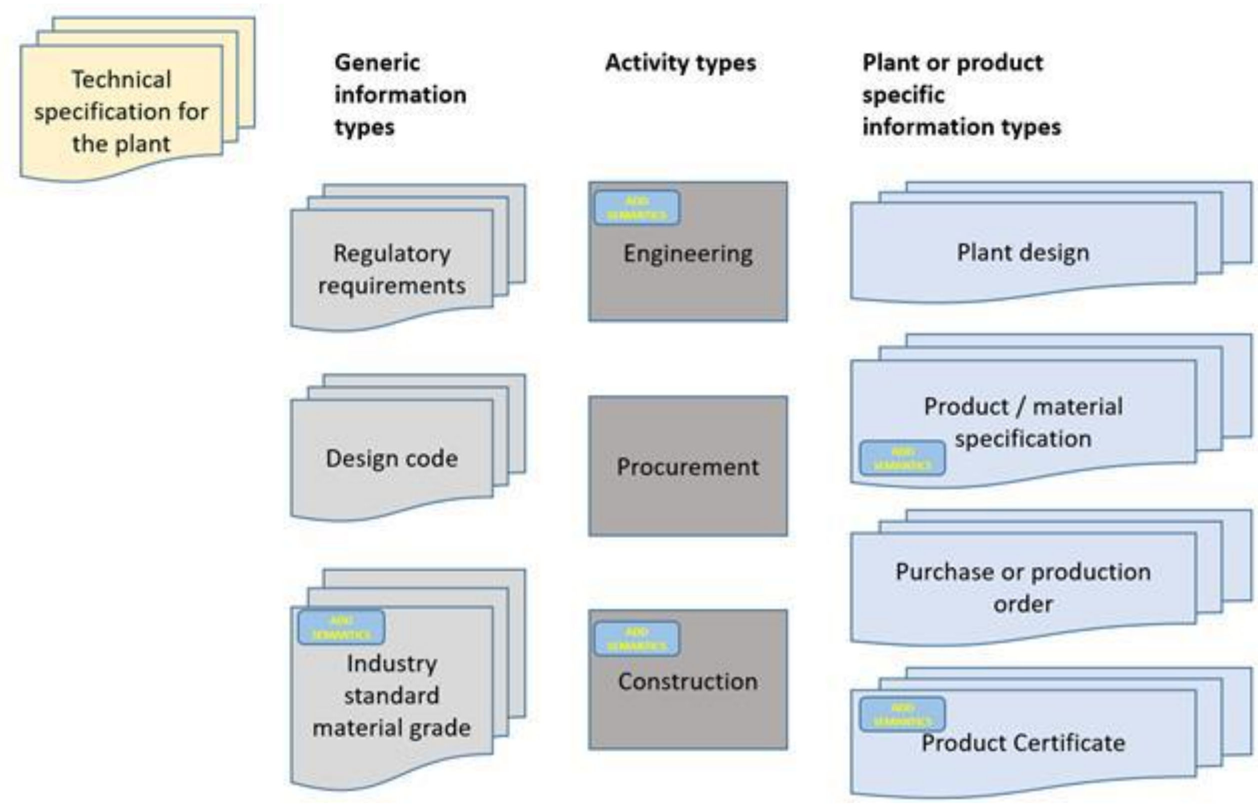


Figure 4: An overview of UC3

2.3.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 10: Ontologies and tools of UC3

No	**Description**	**TLO (mark if self-developed)**		**MLO (mark if self-developed)**		**DO (mark if self-developed)**		**Tools (mark if self-developed)**	
1	ISO 15926-14 will be used as the top ontology	ISO 15926-14 https://rds.posccaesar.org/ontology/lis14/ont/core/1.0/		---		---		---	
2	Mid-level ontology Units of measure and physical quantities Elements with CHebi reference	---		ISO 15926-14 https://rds.posccaesar.org/ontology/plm/		---		---	
3	---	---		---		Material-Core (In-house development) – domain ontology - reuse and extend	X	---	
4	---	---		---		Standards Ontology (In-house development) - reuse and extend	X	---	
5	---	---		---		Material grade standard content ontologies - develop	x	---	

6	Specify use case	---		---		---		Document processors	
7	Develop modelling patterns and templates be developed.	---		---		---		OTTR template	
8	Tabular input has been provided by Subject matter experts. Industry standards	---		---		---		Tabular data	
9	Define ontology imports	---		---		---		Internal PPR	
10	Create Ontologies	---		---		---		OTTR	
11	Demonstrate	---		---		---		Hermit reasoner	
12	Report	---		---		---		---	

Table 11: self-developed ontologies and tools of UC3

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
O	Material-Core (In-house development) – domain ontology - reuse and extend (O)	---	---
O	Standards Ontology (In-house development) - reuse and extend (O)	---	---
O	Material grade standard content ontologies - develop (O)	---	---

2.3.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 12: demonstrator development steps of UC3

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Use case	85%	85% reported to allow for scope adjustments	Complete
2	Technical specification	85%	85% reported to allow for scope adjustments	Complete
3	Ontology template specifications	TBA	---	---
4	Domain expert input	60%	---	Complete
5	Create initial ontologies	60%	---	Complete
6	QA and test	0%	---	Complete
7	Extend ontologies (04, 05, 06)	60%	---	Complete
8	Demonstrate	20%	---	Complete
9	Report	0%	---	Complete

2.3.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 13: Key Performance Indicators progress of UC3

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	TRL change	1/1+(TRL_end - TRL_start)	(0,1]	3-5
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	Implementation of many principles in every FAIR dimensions

Reduced man-hours comparing specification against stock product properties (target 60%)	Time per product record	Calculation of percentage decrease in man-hours	[0,100]	10%

2.3.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 14: Shall requirements of UC3

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC3_RQ_U_01	Comprehensibility	The complexity of the ontologies shall be comprehensible by a large number of stakeholders with different backgrounds.	**Shall**	Most resources used are from published ontologies	Complete
UC3_RQ_U_02	Address heterogenity of data	heterogenity of the data formats must be handled.	**Shall**	Human interpretation prior to creation of tabular input data.	Complete
UC3_RQ_U_04	Collaboration	Allow different domain experts to collaborate.	**Shall**	Domain and ontology experts are contributing	Complete

				to the Use case	
UC3_RQ_U_06	Quality assurance	Support quality assurance in domain processes and material characterisation.	**Shall**	Ontology consistency check of the ontologies created.	Partly
Maintaining/extension of ontologies					
UC3_RQ_M_01	Maintainability for domain experts	Support domain experts (non-ontology experts) to be involved in the maintenance process of ontologies.	**Shall**	Tabular input is suitable for creation of domain expert input	Complete
Tools for ontology					
UC3_RQ_T_03	Usability and user experience	The tool shall be user friendly for engineers and provide interfaces for use and manage ontologies.	**Shall**	An industrial implementation solution would be required and that is not included in the use case	Partly
Standardisation					
UC3_RQ_S_01	Standardised terms	Glossary from industrial standards.	**Shall**	---	Partly
UC3_RQ_S_02	Standardised terms definitions	The ontologies may use definitions of entities which are standard in the	**Shall**	---	Partly

		domain, if possible.			

2.3.6 TRL Assessment

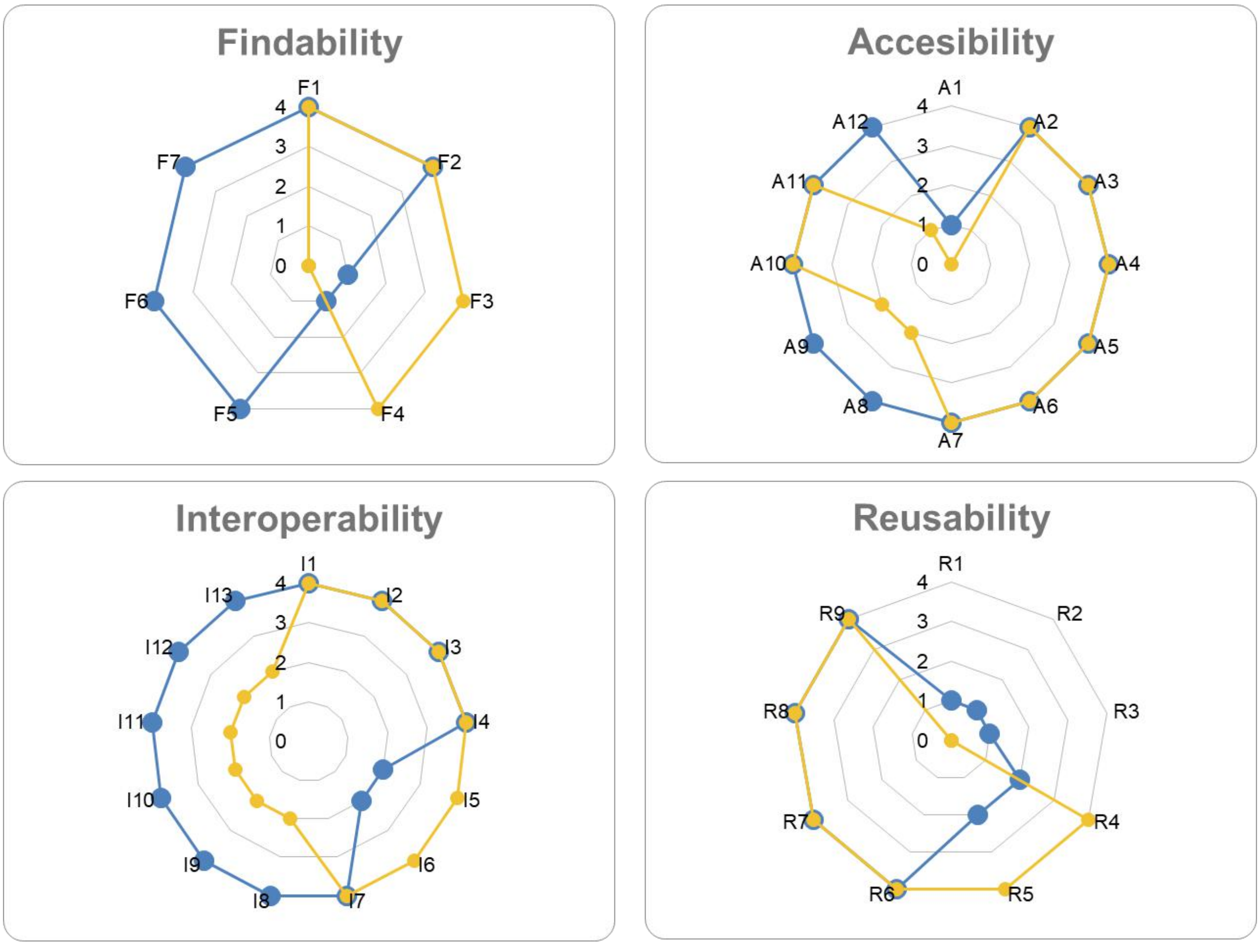
In the overall view, the TRL has increased from 3 for the initial assessment to 3-4 at the end of OntoCommons and is planned to improve further to about 5 within the underlaying project.

2.3.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

During the project, the number of applicable FAIR principles was increased. Especially in the dimensions Findability and Interoperability, FAIRness could be improved. OntoCommons can benefit from the experience gained from Aibel's use case while developing its best practices and the developed best practices can influence the adoption of further principles that are in the planning or implementation phase.

Table 15: FAIR results of the initial survey of UC3 in yellow, final results in blue



2.3.8 Planned further developments

The use case results will be presented to business process owners along with a recommendation for extended use of semantic technology. We do not yet have concrete plans for further development.

2.3.9 Lessons learned

The Aibel Use case is based on ISO-15926-14 as its top-level ontology. In parallel with the OntoCommons Use case work Industrial Data Ontology (IDO) has been developed and was presented as a New Work Item Proposal – for ISO June 2023. IDO is an extension of ISO 15926-14 currently published at https://rds.posccaesar.org/. ISO 15926-14 will remain TLO in the use case.

Access to domain expertise non-business critical development work is a challenge. This has been delayed our progress.

In the development of the use case the contributions from Martin Georg Skjæveland (UiO/Sirius) have very valuable. This has resulted in sophisticated use of OTTR template expansion for building ontologies.

2.3.10 Other comments

Being part of OntoCommons has been inspirational and educational for Aibel employees who have taken part in the use case.

2.4 Demonstrator 4: Materials' Tribological characterization (Tekniker)

2.4.1 Brief description and visual representation

Tribology aims to study friction, wear and lubrication of interacting surfaces. Tribological characterisation is key for understanding the behaviour of a material or combination of them under specific operation conditions, developing new products, and driving new materials into sustainable solutions.

In this context it is particularly relevant to reduce the number and size of experiments, as well as the cost and time, required to identify the behaviour of a material or combination of them under specific operation conditions by exploiting own and third-party available data. However, results from tribological experiments follow heterogeneous formats and data models due to a lack of standards.

The initial process of formalizing the information needed to represent a tribological experiments and the digitalisation of the data gathering process was performed in the framework of i-Tribomat Project (i.e. by means of tribo-connectors) that store data in a non-SQL data repository. Currently, despite progress resulting from the digitisation process it is still quite difficult to exploit and navigate through the available results.

The use case scenario proposes an ontology-based access to materials' tribological information independently from the underlying data structures to

(1) allow a better representation of materials' tribological experiments;
(2) enrich existing data with additional background knowledge;
(3) ease data retrieval and navigation through related resources; and
(4) set the ground for developing more application-independent solutions.

An overview of the use case approach is shown in Figure 5.

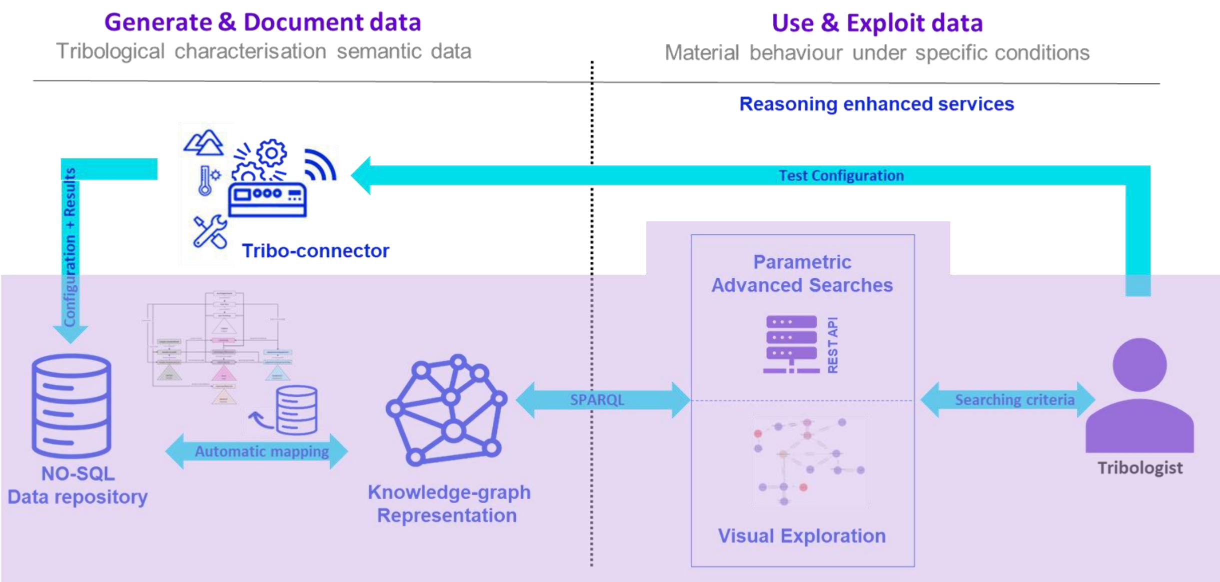


Figure 5: An overview of UC4

The proposed implementation approach provides formal and unambiguous data representation and homogeneous data access based on Semantic Technologies. Main components are:

- Tribo-connector: IT component, collecting (manually /automatically) relevant information of the characterization process and results, and store in a data repository.
- Semantic Repository: aimed to store and make available semantically annotated data, created by direct ontology instantiation and/or mapping other data repositories schemas & the ontology.
- TribOnt Ontology: domain ontology providing a common representation of tribological experiments, aligning to existing TLO/MLO/DLOs for improved interoperability and following a modular approach for increased re-usability.
- Added Value Services: parametric web services and visual exploration of historical data taking advantage of advanced reasoning-based searches.

2.4.2 Ontology level and development during the project Ontologies developed/reused

The use case demonstrator has involved a multidisciplinary working group including both tribologists (i.e., providing domain) and ontology experts, and has followed the guidelines of Linked Open Terms (LOT) methodology. The starting point of the data documentation process was the identification of the key aspects required to describe tribological experiments and their results, performed in the context of i-Tribomat Project. **Error! Reference source not found.** summarises the main steps involved in the demonstrator and identifies, when relevant, the ontologies and tools used in each step.

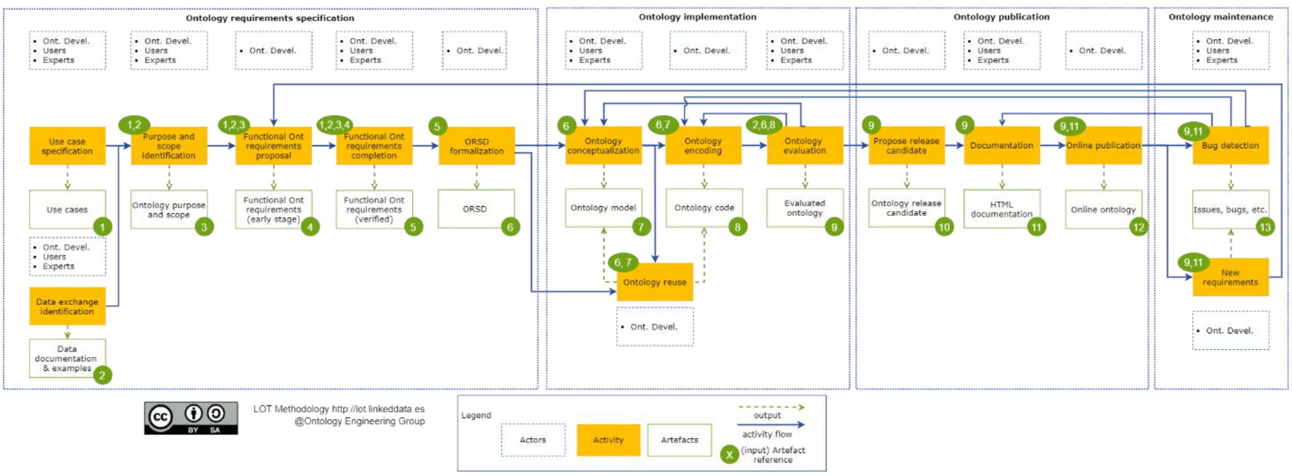


Figure 6: Driving methodology (LOT) of UC4

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 16: Ontologies and tools of UC4

No	Description	TLO (mark if self-developed)	MLO (mark if self-developed)			DO (mark if self-developed)		Tools (mark if self-developed)	
Generate & document data									
1	Identify requirements of tribological experiment and results representation	---		---		---		QSRD- Definition of competency questions.	
2	Conceptualise ontology to cover requirements	---		---		---		Visual Paradigm for representing UML diagrams (i.e., Class Diagrams)	
3	Identify potential candidate ontology for re-use/extension	---		---		TribAin identified as potential candidate (discarded after in depth analysis) *Note: It was identified during the web search as it was not published in any of the other repositories.*		Linked Open Vocabularies (L OV) IndustryPortal MatPortal Web/bibliography search	
4	Encode Ontology including metadata related to ontology as well as to all the classes, and object and data properties (i.e., WIDOCO recommendations)	---		---		TribOnt ontology including Core, Material, Sample and Equipment modules	X	Protégé 5.5.0	

No	Description	TLO (mark if self-developed)	MLO (mark if self-developed)	DO (mark if self-developed)		Tools (mark if self-developed)	
		---	---	isCharacterisedBy___ontology design pattern	X		
5	Check common pitfalls in the ontology (for all modules and ontology design pattern)	---	---	---		OOPS!	
6	Manual instantiation including information tribological experiments	---	---	---		Protégé 5.5.0	
7	Evaluate consistency and inference of the ontology (for all modules and ontology design pattern)	---	---	---		Pellet & Hermit 1.4.3.456 reasoners in Protégé 5.5.0	
8	Evaluate modularity of the ontology (for all modules and ontology design pattern)	---	---	---		Tool for Ontology Module Metrics (TOMM)	
9	Deployment in RDF repository.	---	---	---		OpenLink Virtuoso 8.0	
	Initially in OpenLink Virtuoso 8.0 and finally in DBGraph to take advantage of the provided capabilities related to Visual representation and connection to MongoDB databases.	---	---	---		DBGraph	
10	Validate that the ontology covers all the identified competency questions .	---	---	---		OpenLink Virtuoso 8.0 SPAQL Editor + SPIN (for Rules)	
	Initially by using the SPAQL editor of OpenLink Virtuoso 8.0 and using	---	---	---		DBGraph SPAQL Edito	

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
	SPIN for Rules and finally using the SPAQL editor of DBGraph								
11	Generate HTML Ontology documentation	---		---		---		WIDOCO	
12	Publish Ontology (including all modules and ontology design pattern) in Tekniker's public GitHub. GitHub provides means to maintain the ontology and report on potential bugs and updates.	---		---		---		GitHub	
13	Request publication on Linked Data Vocabularies – answer still pending	---		---		---		Linked Open Vocabularies (LOV) -	
14	Evaluate FAIRness (1) Initial evaluation focusing mainly on Interoperability and Re-usability. To be re-evaluated once it has been published in LOV.	---		---		---		FOOPS	
15	Upload Ontology in IndustryPortal	---		---		---		IndustryPortal	
16	Evaluate FAIRness (2) O'FAIRE integrated in IndustryPortal	---		---		---		O'FAIRE	
17	Align Ontology (including ontology all modules) with relevant ontologies	EMMO) *(work in progress)*		CHAMEO (*work in progress*)		TribOnt TribAin TriboDataFAIR	X	Protégé 5.5.0	

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
18	Align Ontology design pattern and modules) with relevant ontologies	DOLCE Lite				QUDT		Protégé 5.5.0	
Use & Exploit data									
19	Automate the instantiation of the new ontology with information of experiments stored in the MongoDB database (*Proof of concept*)	---		---		---		MongoDB integration feature in DBGraph	
20	Develop and test API REST for abstracting from parameterized SPARQL queries supporting all the relevant competency questions.	---		---		---		Python (development) POSTMAN (testing)	
21	Evaluate usability of Visual Exploration	---		---		---		Visual exploration capabilities I DBGraph	

The following table summarizes the ontologies (I.e., including alignment modules and ontology design patterns) that have been self-developed. Further, details are provided in the following sections.

Table 17: self-developed ontologies and tools of UC4

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
Ontology	TribOnt	TribOnt (Tribological Characterisation Ontology) aims to provide a common representation of tribological experiments, enable enriching existing data with additional background knowledge, and easing data retrieval and navigation through related	https://w3id.org/TribOnt

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
		resources to shorten the time, number and size of experiments required to identify the behaviour under specific operation conditions.	
Alignment module	TribOnt - alignment-TribAIn	Aligns TribOnt to the TribAIn ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/alignments/TribOnt-alignment-Tribain.owl
Alignment module	TribOnt - alignment-TriboDataFAIR	Aligns TribOnt to the TriboDataFAIR ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/alignments/TribOnt-alignment-TriboDataFAIR.owl
Ontology module	Core	Represent the common classes, and object and data properties included in two or more modules of the TribOnt ontology.	https://w3id.org/TribOnt/core
Alignment module	Core-alignment-TribAIn	Aligns Core module to the TribAIn ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Core/alignments/core-alignment-TribAin.owl
Alignment module	Core-alignment-TriboDataFAIR	Aligns Core module to the TriboDataFAIR ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Core/alignments/core-alignment-TriboDataFAIR.owl
Ontology module	Material	Represent the materials that can be involved in the tribological experiments as part of the tested samples.	https://w3id.org/TribOnt/material
Alignment module	Material-alignment-TribAIn	Aligns Material module to the TribAIn ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Material/align

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
			ments/material-alignment-Tribain.owl
Ontology module	Sample	Represents the samples (Sample class) and sample systems involved in the tribological experiments.	https://w3id.org/TribOnt/sample
Alignment module	Sample-alignment-TribAIn	Aligns Sample module to the TribAIn ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Sample/alignments/sample-alignment-Tribain.owl
Alignment module	Sample - alignment-TriboDataFAIR	Aligns Sample module to the TriboDataFAIR ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Sample/alignments/sample-alignment-TriboDataFAIR.owl
Ontology module	Equipment	Represents the equipment hierarchy model involved in the tribological experiments.	https://w3id.org/TribOnt/equipment
Alignment module	Equipment-alignment-TribAin	Aligns Equipment module to the TribAIn ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Equipment/alignments/equipment-alignment-Tribain.owl
Alignment module	Equipment - alignment-TriboDataFAIR	Aligns Equipment module to the TriboDataFAIR ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Equipment/alignments/equipment-alignment-TriboDataFAIR.owl">https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/Equipment/alignments/equipment-alignment-TriboDataFAIR.owl

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
Ontology Design pattern	isCharacterisedBy	Characterises a subject or group of subjects of interest by assigning qualifiable or quantifiable attributes or characteristics.	https://w3id.org/isCharacterisedBy
Alignment module	isCharacterisedBy-alignment-DOLCELITE	Aligns isCharacterisedBy to the Dolce-Lite ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/isCharacterisedBy/alignments/isCharacterisedBy-alignment-DOLCELite.owl
Alignment module	isCharacterisedBy-alignment-QUDT-	Aligns isCharacterisedBy to the QUDT ontology.	https://raw.githubusercontent.com/fundaciontekniker/TribOnt-ontology/main/isCharacterisedBy/alignments/isCharacterisedBy-alignment-QUDT.owl

note: Potential alignment will ontologies already uploaded in IndustryPortal will also be included in there.

2.4.2.1 Ontologies developed/reused

Initially TribAIn (i.e., an ontology in the tribology domain) was identified for potential re-use. But, after carrying out a detailed analysis, it was discarded for its reuse and extension One of the main reasons for making this decision was the TribAIn ontology's quality. The ontology did not meet the ontology quality criteria.

- Having an explicit license that specifies that they can be used and under which conditions.
- Having enough documentation to understand the ontology purpose, domain and fundamentals, and determine whether it describes this domain appropriately or not.
- Having a minimum metadata to help human users and computer applications understand the data as well as other important aspects that describe a data set.

Furthermore, many of the ontology's design choices where not sufficiently described, thus hindering its understanding and reuse. For example, the definition of specific materials in the form of classes (e.g. trib:100Cr6), may derive in punning when defining instances of such classes. Without a proper explanation of this design choice, the potential reusability of the ontology drops.

So, it was decided to develop a new ontology (i.e., Tribological Characterisation Ontology- TribOnt) that covers the defined requirements. However, with a view to contributing to a harmonized ontology ecosystem in the domain, the developed ontology has been aligned with TribAIn and TriboDataFAIR (i.e., a new ontology in the tribology domain that was released while TrinOnt was already in progress). Furthermore, TribOnt (i.e., as well as its undelaying modules) are being aligned with other relevant ontologies to foster interoperability and re-usability (e.g., CHAMEO, EMMO).

The following sections describe the developed TribOnt ontology and the modules that compose it (i.e., Core, Material, Sample, Equipment), as well as the underlying ontology design pattern (i.e., isCharacterisedBy ODP).

TribOnt ontology and composing modules

TribOnt (Tribological Characterisation Ontology) aims to provide a common representation of tribological experiments and results, enable enriching existing data with additional background knowledge, and easing data retrieval and navigation through related resources to shorten the time, number and size of experiments required to identify the behaviour under specific operation conditions.

TribOnt follows a modular approach for increased re-usability, The ontology comprises four modules covering the key elements involved in the tribological experiments for material characterization. For that purpose, it imports Sample and Equipment modules.

Figure 7 includes an overview of the involved modules along with the main classes represented in each of them, and the common ontology design pattern. Different colours have been used to identify the modules and ontology design `patterns as well as the main classes included in each of them (i.e., *TribOntCore*: pink, *TribOntMaterial*: yellow, TribOntSample: green, TribOntEquipment: blue, and isCharacterisedBy grey).

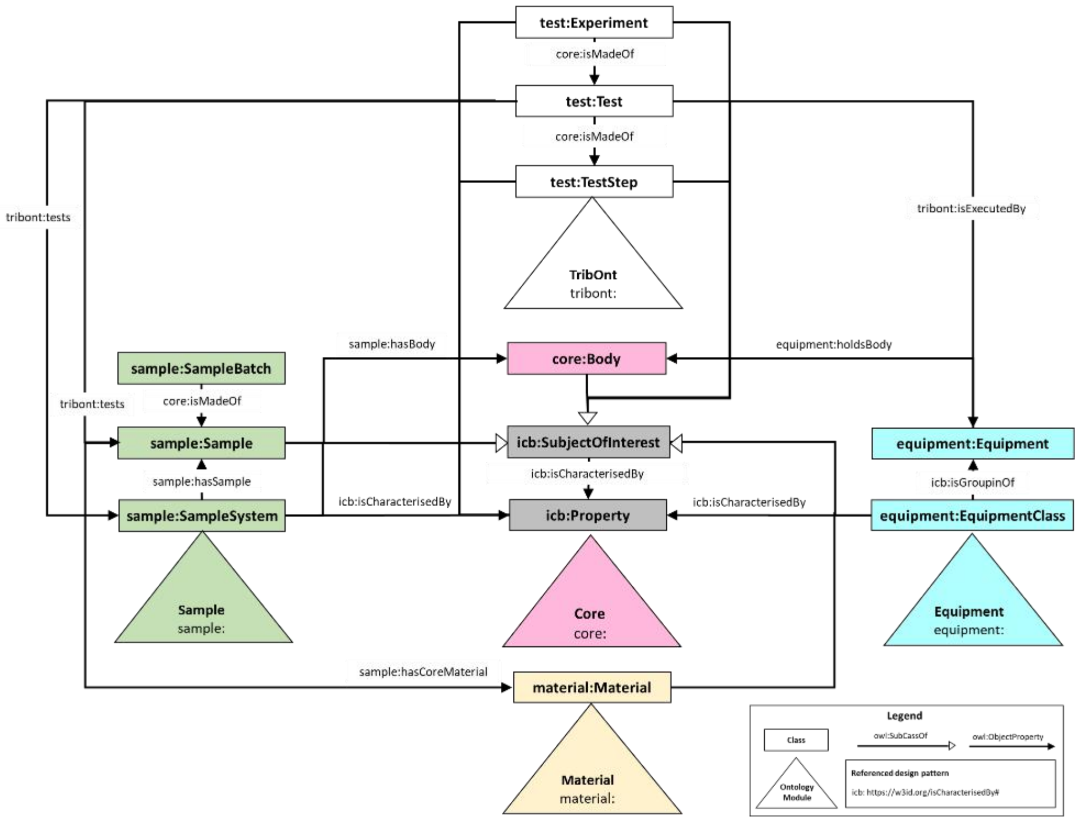


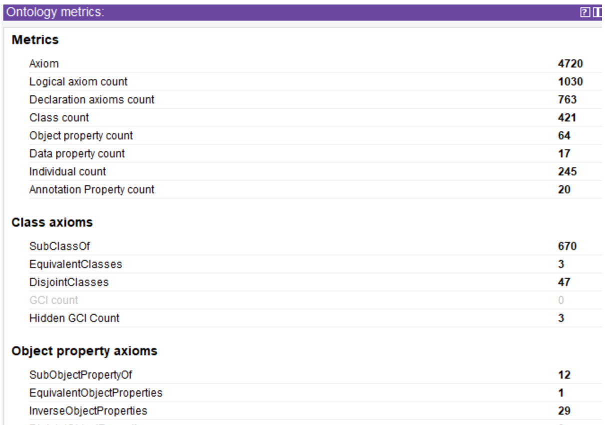
Figure 7 TribOnt Ontology Overview (UC4)

An experiment (*Experiment* class) to perform the tribological characterisation of a material can be defined by a set of tests (*Test* class, *isMadeOf* object property) following a specific procedure represented by a dependency flow (*hasDependency* object property). In some cases, the tests involved in the experiment follow a specific sequence (*hasAfterEndDependency* object property, specialisation of *hasDependency*) but in other cases they are performed in parallel (*hasNofollowDependency* object property, specialisation of *hasDependency*). In turn, each test can be made of a set of test steps (*TestStep* class) following a specific procedure, as described previously.

Each test is executed by an equipment (*isExecutedBy* object property). and can be characterised by a set of configured operation conditions (*isCharcaterisedByOperationCondition* object property) that can comply or not with a given standard (*compliesWith* object property). Furthermore, tests can be characterised by the evolution of a set of operation conditions (*isCharacterisedByOperationMeasure* object property) during its execution, and the measures of the specific set of technical properties (*TechnicalProperty* class) resulting from it (*isCharacterisedByOutputMeasure* object property). Analogously each test step can be characterised by a set of configured operation conditions, the evolution of a set of operation conditions and the specific set of technical properties measured as result of the test step. The values of the measured technical properties represent mean or termination values (i.e., *value* data property), all the intermediate values of the technical properties, along with the values of the operation conditions measured throughout the tests or tests steps, are compiled in specific output files (*TestOutputDocument* class).

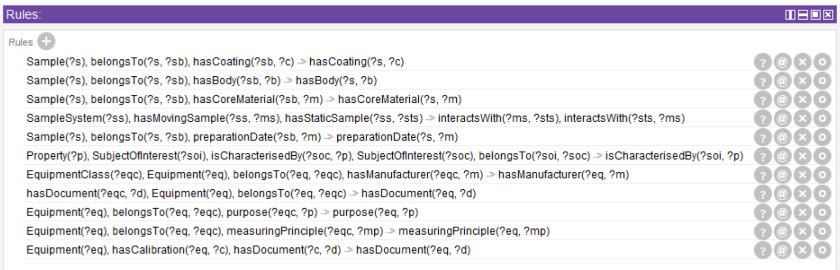
Tests can apply either to a sample or a sample system (*tests* object property). Tribological tests (*TribologicalTest* class) aim to assess one or more tribological characteristics (*TribologicalProperty* class) of a given sample system, while Measuring tests (*MeasuringTest* class) aims to measure one or more characteristics of a given sample.

TribOnt (i.e., including all modules) specifies 421 classes, 64 object properties, 17 data properties, 11 rules and 246 individuals.


Ontology metrics:

Metrics	
Axiom	4720
Logical axiom count	1030
Declaration axioms count	763
Class count	421
Object property count	64
Data property count	17
Individual count	245
Annotation Property count	20
Class axioms	
SubClassOf	670
EquivalentClasses	3
DisjointClasses	47
GCI count	0
Hidden GCI Count	3
Object property axioms	
SubObjectPropertyOf	12
EquivalentObjectProperties	1
InverseObjectProperties	29

Figure 8 TribOnt Ontology metrics – Protégé (UC4)


Rules:

Rules

Sample(?s), belongsTo(?s, ?sb), hasCoating(?sb, ?c) -> hasCoating(?s, ?c)
Sample(?s), belongsTo(?s, ?sb), hasBody(?sb, ?b) -> hasBody(?s, ?b)
Sample(?s), belongsTo(?s, ?sb), hasCoreMaterial(?sb, ?m) -> hasCoreMaterial(?s, ?m)
SampleSystem(?ss), hasMovingSample(?ss, ?ms), hasStaticSample(?ss, ?sts) -> interactsWith(?ms, ?sts), interactsWith(?sts, ?ms)
Sample(?s), belongsTo(?s, ?sb), preparationDate(?sb, ?m) -> preparationDate(?s, ?m)
Property(?p), SubjectOfInterest(?soi), isCharacterisedBy(?soc, ?p), SubjectOfInterest(?soc), belongsTo(?soi, ?soc) -> isCharacterisedBy(?soi, ?p)
EquipmentClass(?eqc), Equipment(?eq), belongsTo(?eq, ?eqc), hasManufacturer(?eqc, ?m) -> hasManufacturer(?eq, ?m)
hasDocument(?eqc, ?d), Equipment(?eq), belongsTo(?eq, ?eqc) -> hasDocument(?eq, ?d)
Equipment(?eq), belongsTo(?eq, ?eqc), purpose(?eqc, ?p) -> purpose(?eq, ?p)
Equipment(?eq), belongsTo(?eq, ?eqc), measuringPrinciple(?eqc, ?mp) -> measuringPrinciple(?eq, ?mp)
Equipment(?eq), hasCalibration(?eq, ?c), hasDocument(?c, ?d) -> hasDocument(?eq, ?d)

Figure 9 TribOnt Ontology rules – Protégé (UC4)

Figure 10 and Figure 11 include an UML diagram representing the main classes and object properties.

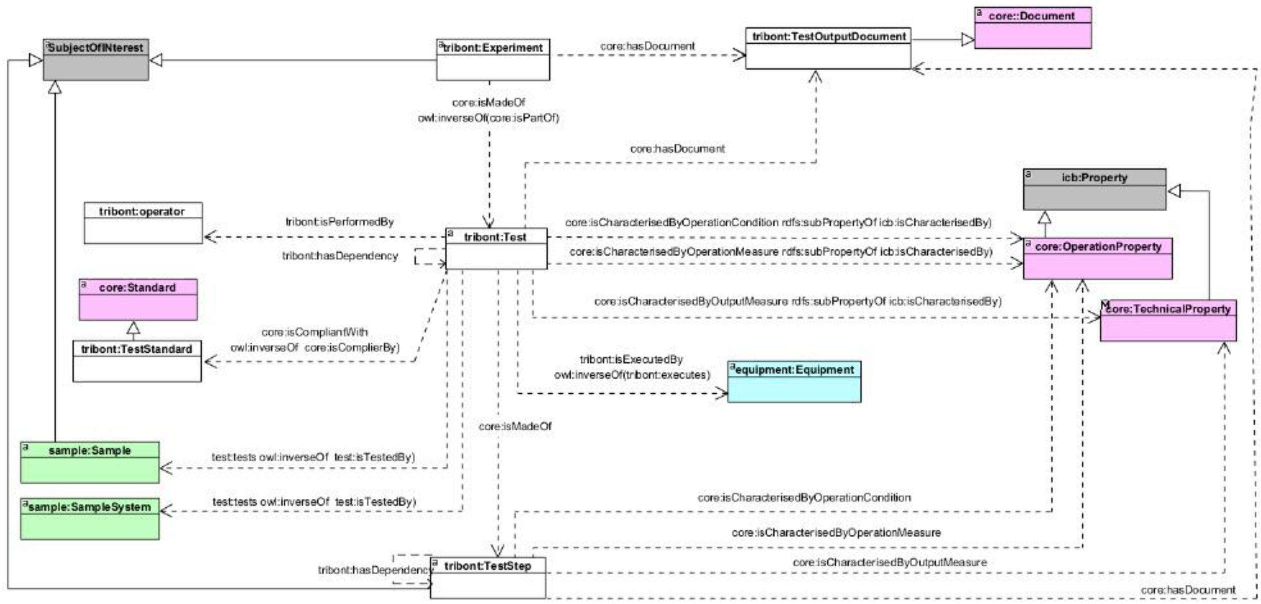


Figure 10 TribOnt Ontology: Test Module Overview (1) (UC4)

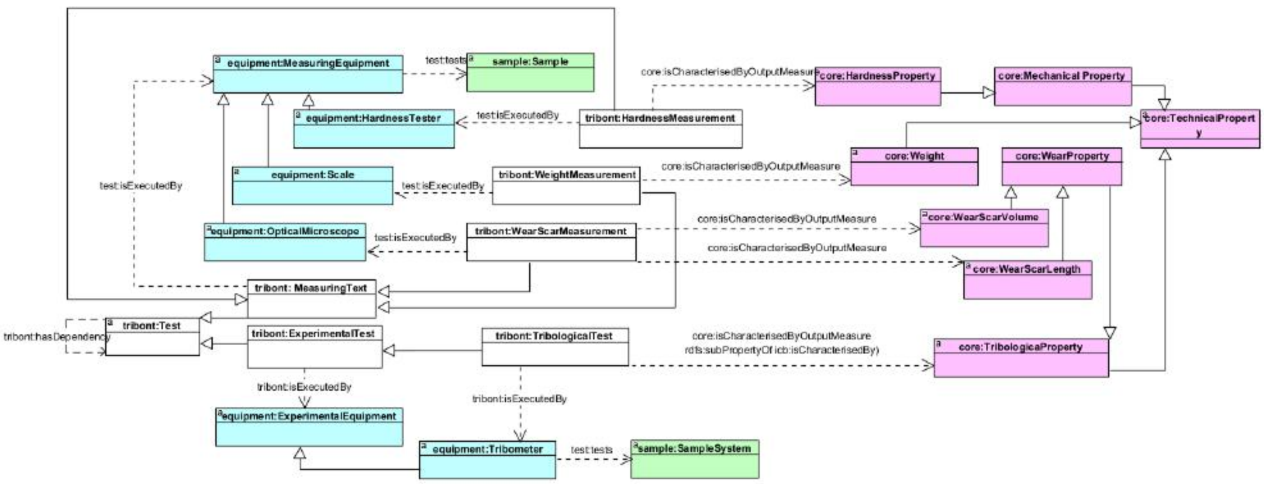


Figure 11 TribOnt Ontology: Test Module Overview (2) (UC4)

As stated before, TribOnt, and its underlying modules, have been aligned with TribAIn and TriboDataFAIR ontologies for increased re-use and interoperability. Further alignments with relevant ontologies in the Material and Manufacturing domains are in progress (e.g., CHAMEO, EMMO)

Core module

The goal of the *Core* module is to represent the common classes, and object and data properties included in two or more modules of the TribOnt ontology. For that purpose, it imports *isCharaterisedBy* ontology design pattern (ODP).

The Core module includes the *Body* class that is used in both the Equipment (i.e., referring to the body configuration of the sample that can be hold by an equipment) and Sample (i.e., representing the body of a sample) modules. Furthermore, it includes the *TechnicalProperty* (i.e., representing qualifiable or quantifiable technical attribute, or characteristics that are used in the Material, Sample and Test modules) , *SystemProperty* (i.e., representing qualifiable or quantifiable attribute, or characteristic of a sample system tata are used in Sample and Equipment modules) and *OperationProperty* (i.e., representing quantifiable operation attribute, or characteristic that are used in Equipment and Test modules) classes which are specialisations of the *Property* class. Each of these classes in turn includes a series of specialisations. For example, the *OperationalProperty* includes as specialisation, along with others, the *EnvironmentProperty* class which in turn includes the *Pressure*, *Humidity*, *Temperature*, etc. classes. In addition, it includes *Organisation*, *Document* and *Standard* classes which are used in several modules.

Figure 12 includes an UML diagram representing some of the main classes and object properties linked to the *Core* module.

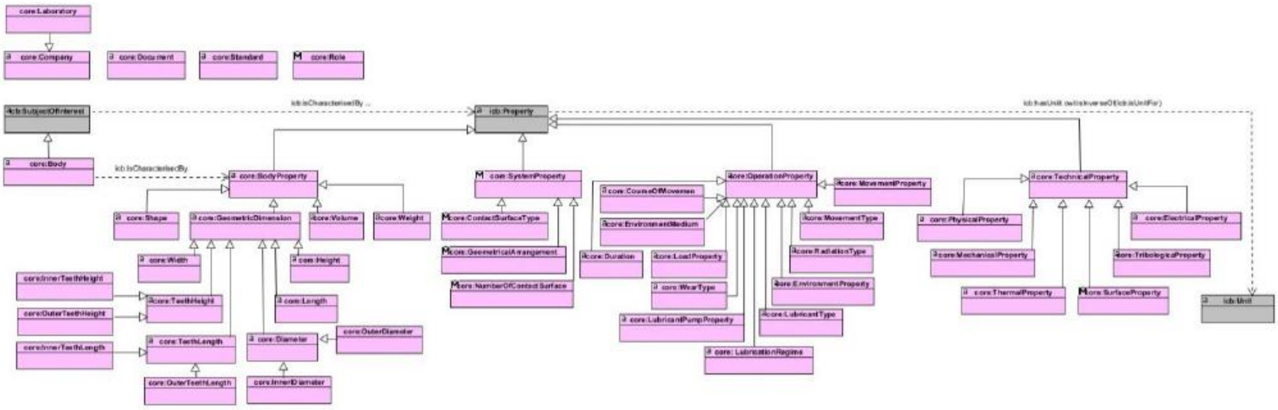


Figure 12 TribOnt Ontology: Core Module Overview (UC4)

<u>Material module</u>

The goal of the Material module is to represent the materials (*Material* Class) that can be involved in the tribological experiments as part of the tested samples. For that purpose, it imports *Core* module.

The *Material* class represents the elements of the material hierarchy model. Specific specialisation classes represent the classification of the materials (e.g., SolidMaterial class, LiquidMaterial class, etc.). All the materials can be characterised by the concentration of elements of which it is composed (*ElementConcentration* class), and a different set of technical properties (*TechnicalProperty* class) depending on the type of material (i.e., *Solid, Liquid*). Furthermore, each element concentration can be classified according to its type (*ChemicalElementConcentation* class, *PolymenElementConcentation* class, *OtherElementConcentation* class) and can play a different role (*ElementRole* class), such as *basic*, *filler*, or *additive*.

In addition, each material can be identified based on a naming (*MaterialNaming* class) according to a specific standard (*Standard* class) and/or a trade name (*MaterialTradename* class) defined by the company supplying it (*Company* class), as well as the description of its typical application(s) (*MaterialApplication* class).

Figure 13 and Figure 14 include an UML diagram representing the main classes and object properties linked to the material module.

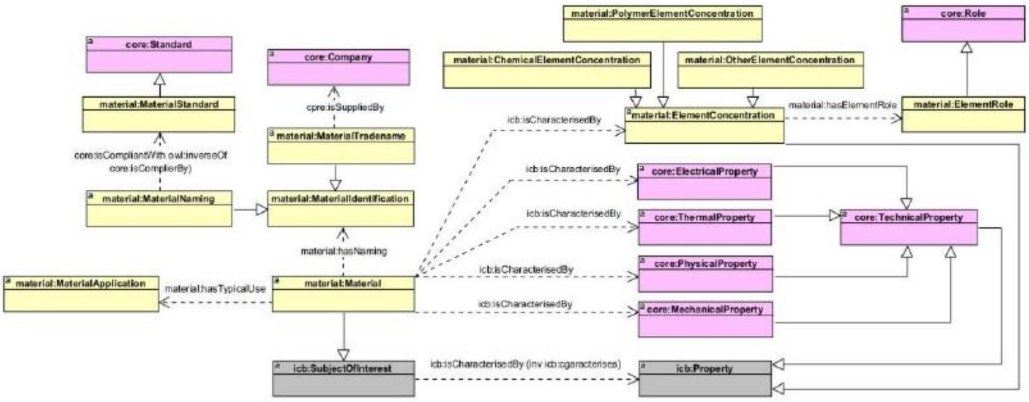


Figure 13 TribOnt Ontology: Material Module Overview (1) (UC4)

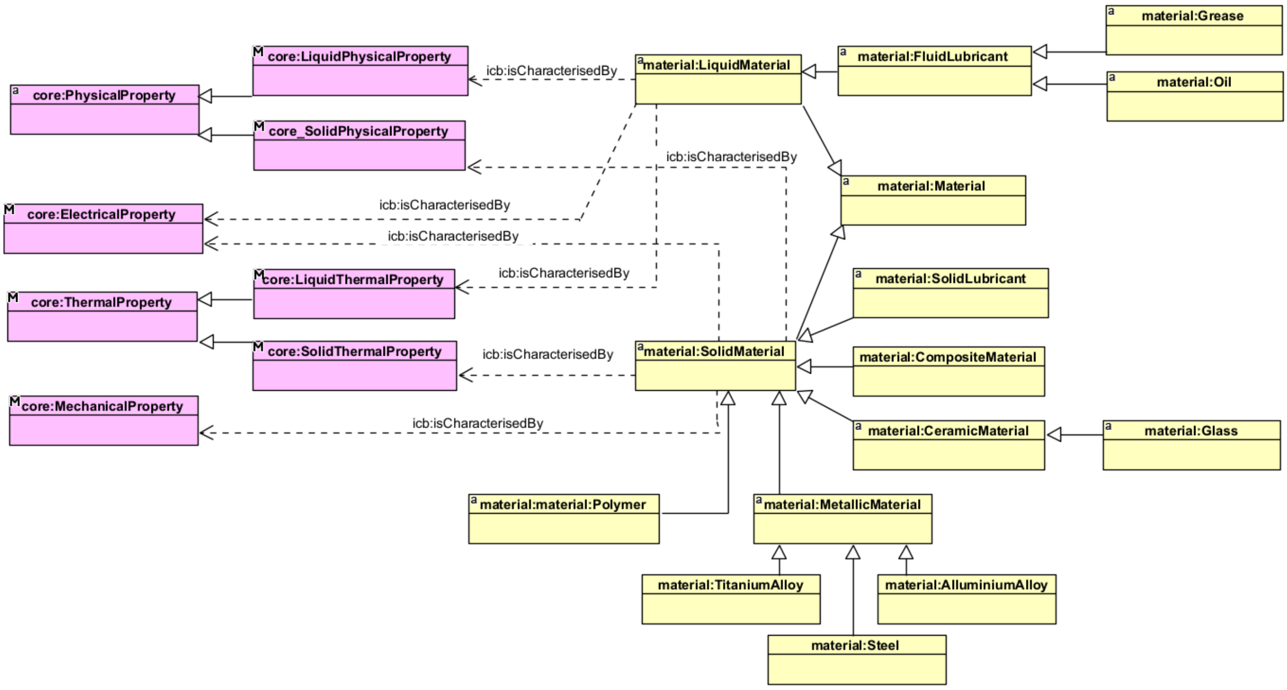


Figure 14 TribOnt Ontology: Material Module Overview (2) (UC4)

Sample module

The goal of the *Sample* module is to represent the samples (*Sample* class) and sample systems (*SampleSystemclass*) involved in the tribological experiments. For that purpose, it imports the Material module.

The *Sample* class represents the elements of the sample hierarchy model involved in the tribological experiments. A sample has always a specific body configuration (*Body* class), it is made of a specific core material (*hasCoreMaterial* object property) and can be characterised by a set of technical properties (*TechnicalProperty* class). Furthermore, a sample can have a coating (*Coating* class, *hasCoating* object property), be made of a specific core material (*hasCoreMaterial* object property) and characterised by specific properties (*CoatingProperty* class) such as thickness (*CoatingThickness* class) or type (*CoatingType* class). Both the *CoatedSampel* (i.e., representing the samples which include a coating) and *LubricationSample* classes (i.e., representing the samples used as lubricants) are a specialisation of the *Sample* class.

The *SampleBatch* class describes a grouping of samples which have been prepared at the same time following the same procedure and have similar characteristics. Each sample belonging to a sample batch inherits the entire representation of the *SampleBatch* class and can be further particularised.

The *SampleSystem* class represents the tribological system involved in the tribological experiments that includes two or more static (*hasStaticSample* object property) and moving (*hasMovingSample* object property) samples (*Sample class) that interact (interactsWith* object property) with each other. In addition, a sample system can include a lubricant *(hasLubricationSample* object property). Sample systems are characterised by specific properties *(SystemProperty* class) such as the geometrical arrangement (*GeometricalArrangement* class) describing the geometrical combination of bodies belonging to the tribological system (e.g., ball on disc), the type of contact surfaces *(ContactSurfaceType* class) or the number of contact surfaces *(NumberOfContactSurface class). LubricatedSampleSystem* class is a specialisation of the SampleSystem class representing the sample systems that include a lubricant.

Figure 15 includes an UML diagram representing the main classes and object properties linked to the Sample module.

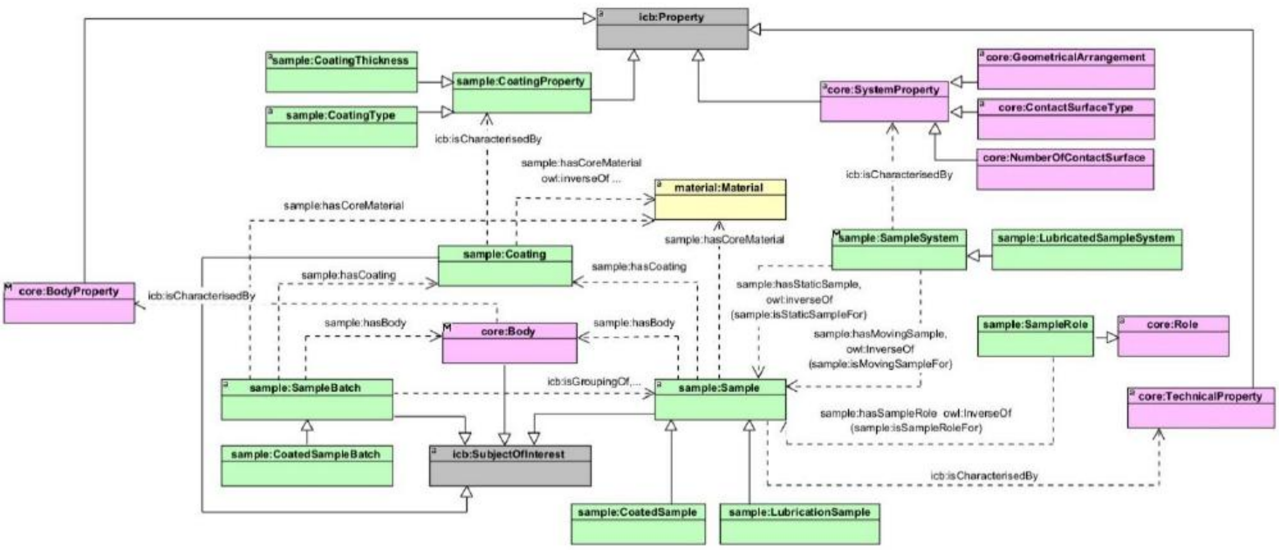


Figure 15 TribOnt Ontology: Sample Module Overview (UC4)

Equipment module

The goal of this module is to represent the equipment hierarchy model involved in the tribological experiments. For that purpose, it imports the *Core* module.

The *Equipment* class represents the elements of the equipment hierarchy model. Specific specialisation classes represent experimental (*ExperimentalEquipment* class) and measuring (*MeasuringEquipment* class) equipment. The *Tribometer* class is a specialisation of the *ExperimentalEquipment* class and the *AbrasionTester*, *HardnessTester*, *OpticalMicroscope*, *OpticalProfilometer* and *Scale* classes are a specialisation of the *MeasuringEquipment* class. An equipment is manufactured (*hasManufacturer* object property) and owned (*isOwnedBy* object property) by a specific company (*Company* class) and has associated technical documentation (*TechnicalDocument* class) which can include the machinery book (*MachineryBook* class) and the manufacturer data sheet (*ManufacturerDataSheet* class) which are specialisation of the *Document* class. In addition, each equipment should be calibrated (*Calibration* class) according to a specific standard (*Standard* class, *compliesWith* object property), Each calibration activity should identify the execution date and validity period (*executionDate* and *validityDate* data properties) and keep evidence of any relevant information (*CalibrationDocument* class).

An Equipment is located in a company (*hasLocation* object property) and can be characterised by the operation conditions that can be configured to perform a specific activity (*OperationProperty* class, *isCharacterisedByOperationCondition* object property), the operation conditions whose evolution can be measured throughout the performed activity (*OperationProperty* class , *isCharacterisedByOperationMeasure* object property), and the specific technical properties that can be measured as result of it (*TechnicalProperty* class, *isCharacterisedByOutputMeasure* object property). Each equipment specialisation can measure a specific set of technical properties. For example, a tribometer measures tribological properties (*TribologicalProperty* class) while a hardness tester measures hardness properties (*HardnessProperty* class). Furthermore, an equipment can hold different sample bodies (*Body* class) with specific characteristics (*BodyProperty* class). Tribometers can hold either moving (*holdsMovingSampleBody* object property) or static (*holdsStaticSample* object property) bodies.

The *EquipmentClass* class describes an aggregation of equipment with similar characteristics. Each equipment belonging to an equipment class inherits the entire representation of the *EquipmentClass* class and can be further particularised. For example, if a specific equipment (e.g., SRV3_TEK) belongs to a group of equipment with common characteristics (e.g., SRV3), then SRV3_TEK will be characterised by the same properties of SRV3 (e.g., min and max Load operation conditions supported by the equipment) but could also include new properties if needed.

Figure 16 includes an UML diagram representing the main classes and object properties linked to the equipment module.

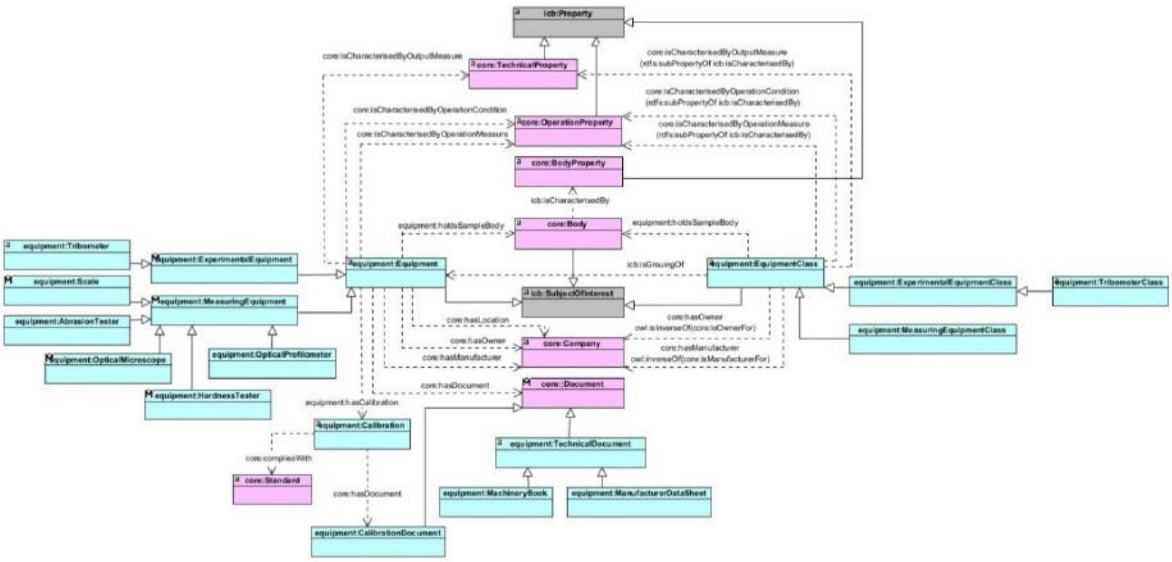


Figure 16 TribOnt Ontology: Equipment Module Overview (UC4)

isCharacterisedBy Ontology Design Pattern (ODP)

isCharateristedBy ODP aims to characterise a subject or group of subjects of interest (*SubjectOfInterest* class) by assigning qualifiable or quantifiable attributes or characteristics (*Property* class). Quantitative prosperities can be described by a set of properties such a specific value (*value* data property) or a range of values (*minValue*, *masValue* data properties) including the unit of measure (*Unit* class and *hasUnit* object property). A property cannot exist without characterising at least a subject of interest. If a *SubjectOfInterest* class represents an aggrupation, the subjects of interest belonging to the group inherit all the properties that characterise it and can be further particularised.

isCharacterisedBy ODP specifies 3 classes, 6 object properties, 5 data properties and 1 rule.

Error! Reference source not found. includes an UML diagram representing the main classes and object properties linked to the *isCharacterisedBy* ODP.

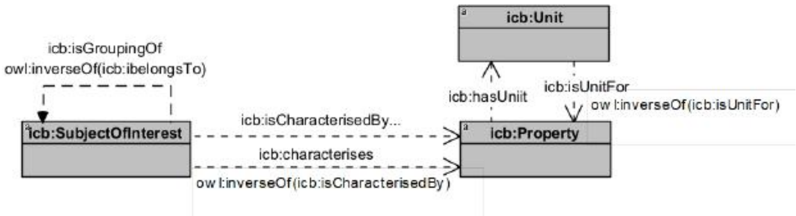


Figure 17 isCharacterisedBy ontology design pattern overview (UC4)

isCharacterisedBy has been aligned with DOLCE Lite and QUDT.ontologies for increased re-use and interoperability.

2.4.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 18: demonstrator development steps of UC4

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Identify requirements of tribological experiment representation *Covers item 1 in Table 15*	Finished	---	Complete
2	Develop, evaluate, and publish ontology covering requirements	Finished	TribAIn was identified as potential candidate for its reuse and	Version 1.0 of TribOnt ontology implemented and evaluated (OOPS!, TOMM, FOOPs, O'FAIRE) published

	Covers items 2 to 16 in Table 15		extension, but it was discarded after analysing it. Alignments to TribAIn must be generated.	in Tekniker GitHub, LOV and IndustryPortal
3	Align ontology (and underlying modules and ontology design pattern) with relevant ontologies *Covers items 17 and 18 in Table 15*	Work in progress Currently, alignment with TribAin, TroboDataFAIR, DOLCE Lite and QUDT finished. Aliment with CHAMEO and EMMO in progress.	---	Alignment modules (in OWL format) between TribOnt (and modules) and TribAin, TroboDataFAIR, CHAMEO and EMMO available. Alignment modules (in OWL format) between isCharacterisedBy (and modules) and DOLCE Lite and QUDT available.
4	Automate the instantiation of the new ontology with information of experiments stored in the DB *Covers item 19 in Table 15*	Finished proof of concept.	Our objective was to try to access the data stored in their original NoSQL DB via SPARQL queries to avoid data duplication, but we have discovered that ontology-based data access (OBDA) for NoSQL DBs is not as consolidated as for SQL DBs. Initially we used as OpenLink Virtuoso as semantic	Proof of concept of automate instantiation from MongoDB using integration feature in DBGraph

			repository but we encountered some difficulties when accessing data in MongoDB (Phase 1) so we moved to GraphDB to take advantage of their plugin with MongoDB (as well as knowledge graph visualisation capabilities) in Phase 2. However, to be able to apply reasoning capabilities it is necessary to store materialized triples in the RDF Store taking advantage of these mappings.	
5	API REST for abstracting from parameterized SPARQL queries *Covers item 20 in Table 15*	Finished	---	API REST supporting parametrises SPARQL queries covering key competency questions.

2.4.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 19: Key Performance Indicators progress of UC4

KPI	Metric	Function	Range	Estimated value at the end of

				OntoCommons in 10/2023
TRL improvement	• TRL change	– *1/1+(TRL3_end-TRL5_start)*	(0,1]	TRL5
FAIR improvement	• average score in each FAIR dimension	- For each dimension, average based on final surveys	[0,4] for each dimension	increase expected for each dimension is: - F1: +2 - F2: +1 - F3: +2 - F4: +2 - F5: +2 - F6: +2 - F7: +0
Reduction in time of the design of materials (20%)	• Time taken to design new material	- Calculation of the percentage reduction in time	---	We will not be able to measure real representative metrics by the end of OntoCommons.
Reduction in costs of the design of materials (20%)	• Costs to design new material	- Calculation of the percentage reduction in time	---	We will not be able to measure real representative metrics by the end of OntoCommons.

2.4.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 20: Shall requirements of UC4

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC4_RQ_U_01	Ontology-based data access	Access the experiment data stored in NoSQL database (MongoDB) via SPARQL queries	**Should**	We have already performed a proof of concept: to automate the instantiation of the new ontology with information of experiments stored in the No-SQL DB. And we have tried to keep data only in the NoSQL database but to apply reasoning knowledge graphs must be materialized in the semantic repository to apply reasoning.	Partly
Development of ontologies					
UC4_RQ_D_01		Develop and align a new ontology to	**Shall**	A new ontology is required because	Complete

		represent the tribological experiments and their results.		TribAIn has been analysed and discarded for re-use and extension. Refer to UC4_RQ_M_01)	
Maintaining/extension of ontologies					
UC4_RQ_M_01	Extend reused ontologies	Analyse if current ontologies are enough to describe tribological experimental set-ups and results, otherwise, extend them	**Shall**	TribAIn has been analysed and discarded for re-use and extension One of the main reasons for making this decision was the TribAIn ontology's quality. The ontology did not meet the expected ontology quality criteria. So, a new ontology has been developed (TribOnt). However, to contribute to a harmonized ontology ecosystem in the domain, the developed ontology has been aligned with TribAIn and TriboDataFAIR (i.e., a new	Partly. Previous ontology has not been re-used but the developed ontology has been (od is being) aligned to relevant ontologies for increased interoperability. Furthermore, the possibility to use IOF.CORE to extend the Sample Module (to describe the preparation process of the Sample Batch) is being analysed.

				ontology in the tribology domain that was released while TrinOnt was already in progress). Furthermore, TribOnt are being aligned with other relevant ontologies to foster interoperability and re-usability (e.g., CHAMEO, EMMO).	
Tools for ontology					
UC4_RQ_T_01	Develop REST APIs to access data	Ease interaction with ontologies via REST APIs instead of SPARQL queries for retrieving data	**Should**	We have already developed, and tested API REST supporting parametrises SPARQL queries covering key competency questions.	Complete

2.4.6 TRL Assessment

In the overall view, the TRL has increased from 3 for the initial assessment to 5 at the end of OntoCommons. The developed ontology and the overall approach have been validated in relevant environment by achieving manual instantiation of four complete experiments and implementing and executing all the defined competency questions to validate the complete coverage. Furthermore, the usability of the visualisation capabilities offered by DBGraph to navigate through related resources has been investigated to evaluate its potential as user interface.

2.4.7 FAIR Assessment

2.4.7.1 **FAIRness Assessment using FOOPs**

An initial FAIRness assessment has already been performed by using FOOPS. that is an Ontology Pitfall Scanner for the FAIR principles.

The assessment has involved the TribOnt ontology and its modules (i.e., Core, Material, Sample, Equipment), as well as the isCharacterisedBy ontology design pattern.

In general terms the FAIRness results according to the attributes measured by FOOPs are quite good and will improve once the ontology (and composing modules and ontology design pattern) will be included in a public registry as LOV. It is planned to include other metadata as the DOI and this will further increase the value rate of the Reusable dimension and the overall rate.

Even if they could be increased if a unique id for each version is defined and maintained or including some other extra metadata. At the moment the introduction of a unique ID for each version is not foreseen.

Find below some details about the result of the FAIRness assessment performed with FOOPs.

TribOnt ontology

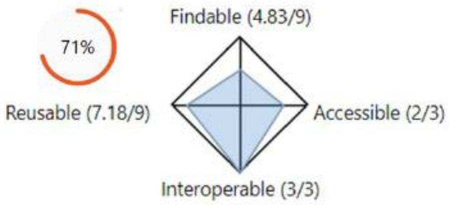


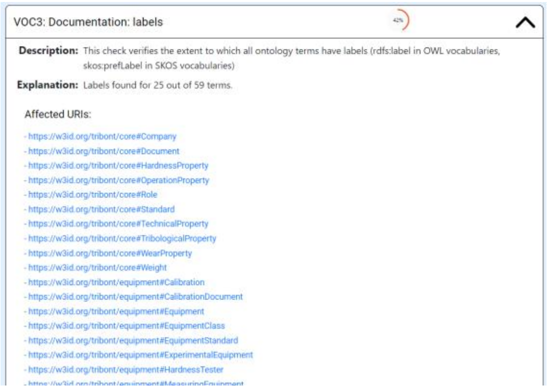
Figure 18 TribOnt ontology – FOOPs results (*) (UC4)

Findable: Current rate of the Findable dimension is conditioned by the values (i.e., currently rated 0%) of the attributes: VER1(Version IRI), VER2 (Version IRI resolves), FIND2 (Prefix is in registry), and FIND3 (Ontology in metadata registry). VER1 and VER2 will not improve as we do not use and unique id for each ontology version but FIND2 and FIND3 should **be updated to 100% once the ontology is included in LOV registry (i.e., inclusion has already been requested)**. This should increase the rate value of the Findable dimension from **4.83/9 to 6.83/9** which is considered as a good result.

Accessible: Current rate of the Accessible dimension is conditioned by the value of A2 (metadata are accessible, even when the data are no longer available) that is set to 0% while the value of these attributes is 100%. **Once ontology is included in LOV registry this attribute should be updated to 100% and the final rate should move from 2/3 to 3/3**.

Interoperable: The Interoperable dimension has already the highest score value (3/3).

Reusable: Current rate of the Re-usable dimension is conditioned by the values of OM3 (Detailed metadata, rated 33%), VOC3 (Documentation: labels, rated 42%), and VOC4 (Documentation: definitions, rated 42%). It must be noticed that the justification of the low rate of VOC3: is that descriptions have been found for 25 out of 59 terms but all the terms that are identified as not found belong to imported modules**, however all these terms are properly documented** as can be seen from the evaluation of the corresponding modules. The same applies to VOC4 so **the current ratio value should be 8.33/9 instead of 7.18/9 (*).**). The value of the Re-usable dimension can be improved by including some other metadata as as the DOI.



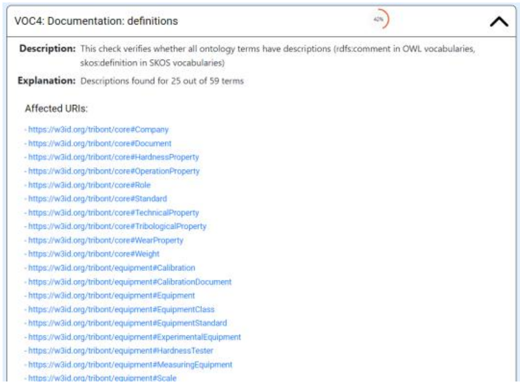


Figure 19 TribOnt ontology – FOOPs results – comments on VOC3 and VOC4 attributes (UC4)

Composing modules (Core, Material, Sample, Equipment modules) and ontology design pattern (isCharacterisedBy)

All the results from all the modules and the ontology design patterns are analogous.

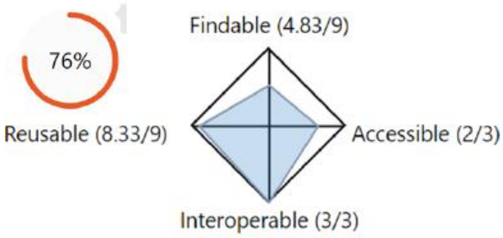


Figure 20 Core nodule– FOOPs results (UC4)

Findable: -Current rate of the Findable dimension is conditioned by the values (i.e., currently rated 0%) of the attributes: VER1(Version IRI), VER2 (Version IRI resolves), FIND2 (Prefix is in registry), and FIND3 (Ontology in metadata registry). VER1 and VER2 will not improve as we do not use and unique id for each ontology version but FIND2 and FIND3 should **be updated to 100% once the ontology is included in LOV registry (i.e., inclusion has already been requested). This should increase the rate value of the Findable dimension from 4.83/9 to 6.83/9** which is considered as a good result.

Accessible: Current rate of the Accessible dimension is conditioned by the value of A2 (metadata are accessible, even when the data are no longer available) that is set to 0% while the value of these attributes is 100%. **Once ontology is included in LOV registry this attribute should be updated to 100% and the final rate should move from 2/3 to 3/3.**

Interoperable: The Interoperable dimension **has already the highest score value (3/3).**

Reusable: -Current rate of the Re-usable dimension is conditioned by the values of OM3 (Detailed metadata, rated 33%). VOC3 (Documentation: labels, rated 100%), and VOC4 (Documentation: definitions, rated 100%) indicate that all descriptions have been found (as it was explained when referring to TribOnt ontology). The value of the Re-usable dimension can be improved by including some other metadata as the DOI.

2.4.7.2 FAIRness Assessment using OntoCommons survey

Another way to assess FAIRness has been to complete the survey "*OntoCommons FAIR data Guidelines Compliance*". The main conclusion from the survey is that the use case is overall well-rounded in all dimensions as described below. In the Findability dimension, all the principles have been fully implemented or are in progress. Same goes for the Accessibility dimension, where 12 out of 13 principles have been fully implemented or are in progress. In that case only D.12 (Data is accessible through an access protocol that supports authentication and authorisationthe) that has not been considered and t have been considered as not applicable. Regarding Interoperability 7 principles have been fully implemented, 1 has not been considered yet and 5 have been considered as not applicable to the use case. Considering Reusability 6 principles out of 9 have already been fully implemented, 1 is already planned and only 2 principles have not been considered for implementation.

Findable: All the principles in the Findable dimension have been fully implemented or are in progress (the inclusion in LOV public repository has already been requested).

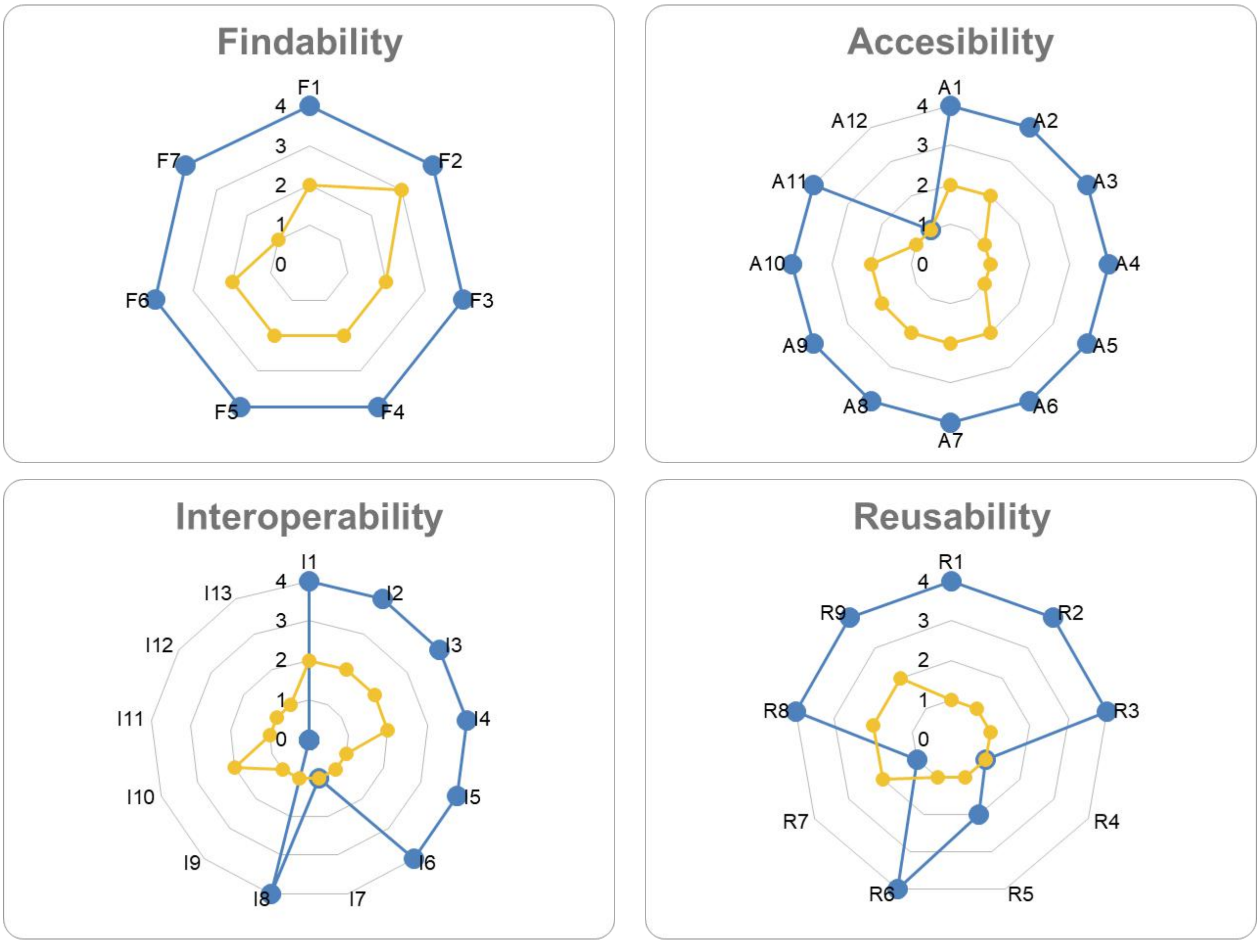
Accessible: 12 out of 13 principles have been fully implemented or are in progress (the inclusion in LOV public repository has already been requested). only D.12 (Data is accessible through an access protocol that supports authentication and authorisationthe) has not been yet considered for implementation.

Interoperable: 7 principles have already been fully implemented (E1, E2, E3, E4, E5, E6, E8) , 1 has not been considered yet (E.7 Metadata includes references to other metadata) and 5 other, related to other data or metadata, have been considered as not applicable to the use case (E9, E10, E11, E12, E13)

Reusable: 7 principles out of 9 have already been fully implemented (F1, F2, F3, F6, F8, F9), 2 principles have not been considered yet (F.4 Metadata includes provenance information according to community-specific standards, F7 Data complies with a community standard) and another one is under consideration (F5. Metadata includes provenance information according to a cross-community language).

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Table 21: FAIR results of the initial survey of UC4 in yellow, final results in blue



2.4.8 Assessment of further benefits

The use case enables formal and unambiguous data representation and homogeneous data access based on Semantic Technologies and validates the potential of advanced and extended data retrieval and navigation through related resources by taking advantage of reasoning capabilities.

TribOnt ontology provides a formal representation of tribological experiments and their results to ensure that all the relevant data are collected following a homogenous format and data model and enriches data with additional background knowledge. TribOnt has been aligned with other ontologies in the tribology subdomain to contribute to a harmonized ontology ecosystem in this sub domain. Furthermore, TribOnt it being aligned with other relevant ontologies (e.g., CHAMEO, EMMO) to foster interoperability and re-usability. In addition, the current activities leading to the extension and alignment with IOF- CORE to represent the sample preparation process will further increase interoperability and re-usability.

2.4.9 Planned further developments

It is planned that the material's tribological characterization use case will be further developed beyond the framework of OntoCommons. We intend to put the developed ontology and the overall approach in production to take real advantage of the results of our previous tribological experiments (as well as third-party data when available).

To that end we need to further investigate how to enable co-existence with non-semantic repositories (e.g., no-SQL) to avoid data duplication during operation as well as to improve visualisation and navigation capabilities to support end users.

Furthermore, the activities performed in the use case pave the pathway towards materials data sharing across value chain as shown in Figure 21.

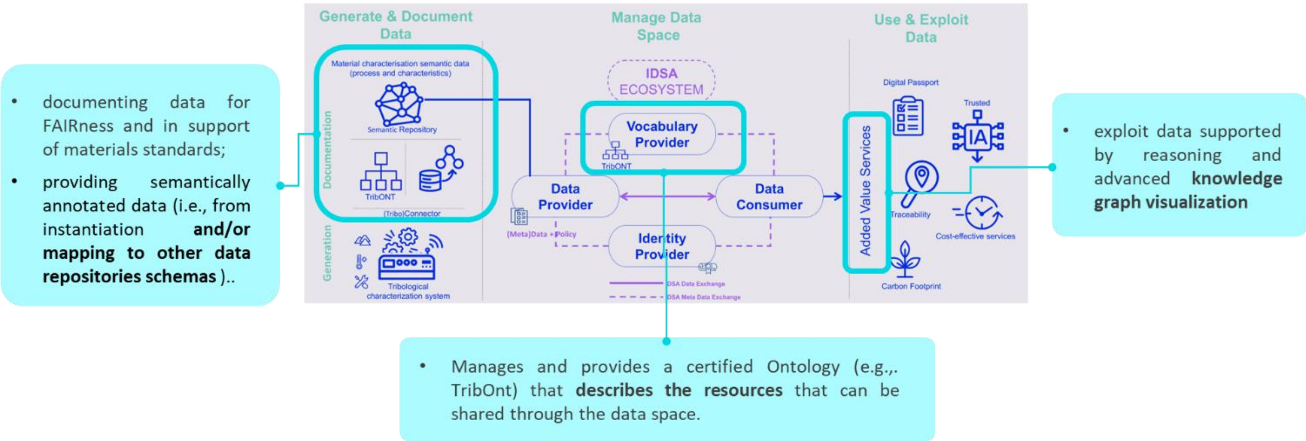


Figure 21 Towards materials data sharing across value chain (UC4)

2.4.10 Lessons learned

Lesson learned can be considered from a twofold point of view as described below.

I. Lessons learned from the introduction of sematic technologies to support material's tribological characterisation

<u>Instantiation</u>

Generally, in real life industrial cases, data are collected through company's legacy systems which store them in the own non-semantic repositories. This is the case for the tribological data collected at Tekniker that are stores in a MongoDB database. Our objective was to access the data stored in their original NoSQL DB via SPARQL queries to avoid data duplication while taking advantage of reasoning capabilities. However, we have found that to be able to apply reasoning capabilities it is necessary to store materialized triples in the RDF Store (i.e., DBGraph).

Further support needed: Means and tools to enable co-existence with non-semantic repositories during operation while avoiding data duplication

<u>Interaction</u>

In the framework of the use case we have investigated to different ways to retrieve and exploit data.

- Use of Parametric REST web services implementing the predefined competency questions,

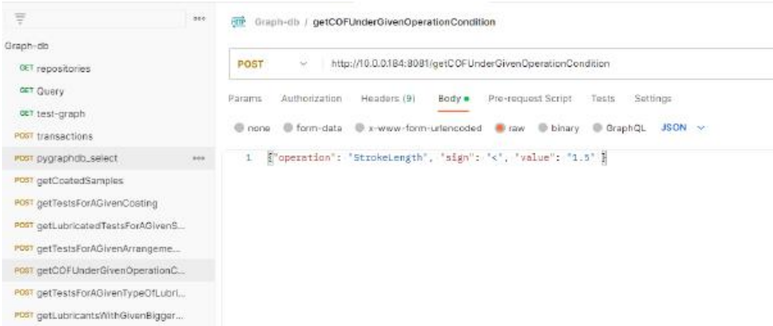


Figure 22 Test of parametric API REST web services using POSTMAN (UC4)

Find below a summary of the main PROS and CONS.

Table 22: Use of Parametric REST web services: Pros and Cons

Pros	Cons
• allows to cover predefined typical questions (CQs),	• requires ad-hoc development, • does not support navigation through related resources.

- Visual exploration of knowledge graphs

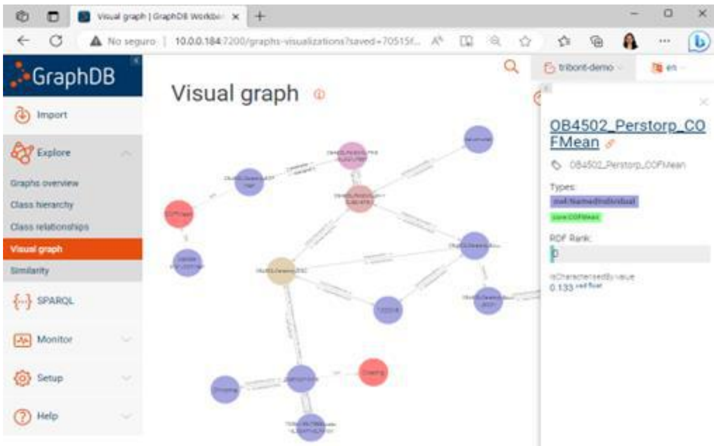


Figure 23 Test of visual exploration using DBGraph capabilities (UC4)

Find below a summary of the main PROS and CONS.

Table 23: Use of visual exploration: Pros and Cons of UC4

Pros	Cons
• more intuitive, enables more flexible approach, • allows navigation through related resources,	• still complex for end users

Considering the key findings of the validation phases the most promising of these two approaches seems to be visual exploration but there is still a lack of tools enabling easy and intuitive visualization & navigation.

Further support needed: There is still a need of tools, end user oriented, to enable easy and intuitive visualization and navigation among resources.

II. Lessons learned from the use of OCES methods/tools?

In the use case we have followed LOT methodology/tools that have been demonstrated to be helpful to support the ontology engineering process and ensure that the ontology meets the user requirements and promote reuse.

GAP: There is still a need of further methods and tools to "put ontologies in production" and exploit them in real industrial applications.

Currently the information sources to identify potential ontologies for re-use in the industrial domain are fragmented (e.g., LOV, MatPortal, IndustryPortal, Bibliography, etc.) which makes the process difficult and time consuming. IndustryPortal can help to identify candidate ontologies for reuse and easy the alignment with existing ontologies, but still includes a limited set of available ontologies.

GAP: A one stop entry point, aggregating registers, to search available candidates for re-use and alignment, considering the target competency questions (CQs) will be useful.

FAIRness is a critical aspect to be addressed. During the use case FAIRness has been assessed using different tools (e.g., FOOPs, O'FAIRE integrated in Industry Portal., OntoCommons FAIR data Guidelines Compliance survey which cover different aspects and represent results in a different way.

GAP – Further support needed: A standardised way to assess FAIRness should be needed to support a common FAIRness certification process (e.g., FAIRness label)

2.5 Demonstrator 5: EVMF - European Virtual Marketplace Framework (UKRI & GCL)

2.5.1 Brief description and visual representation

The main goal of this use case is to extend and improve the VIMMP (Virtual Materials Marketplace Project) Ontologies [8] which are in the core of the VIMMP platform that aims to support interoperability between different services and marketplaces in NMBP domains.

The use case will build on a concrete implementation of the EVMF realized within the VIMMP platform and will improve the EVMF based on the input from the OntoCommons ecosystem and a wider community. It will also create a basis for discussing the alignment with the EMMO top-level ontology of various domain ontologies in the materials domain. An example simple scenario would be: providing a description of a Materials modelling software tool for inclusion in a virtual marketplace.

Another example would be integrating the descriptions of MM experts across two different marketplaces (e.g., VIMMP and the MarketPlace projects).

During the course of OntoCommons, the scenario of digital ontology-based marketplaces projects (in materials and manufacturing) has moved on: the VIMMP project has ended (June 2022), the Marketplace project is finishing soon (June 2023) whereas DOME 4.0 is half-way through. Accordingly, while building on the legacy and outcomes of the previous two, we will focus on the interactions with DOME 4.0 [DOME 4.0 Ref] and the alignment of its “Ecosystem ontology” (cf. DOME 4.0 Deliverable 3.2 [DD3.2 Ref]) to the OCES.

2.5.2 Ontology level and development during the project Ontologies developed/reused

The following table shows details of the demonstrators used or developed ontologies and tools.

Table 24: Ontologies and tools of UC5

No	**Description**	**TLO (mark if self-developed)**		**MLO (mark if self-developed)**		**DO (mark if self-developed)**		**Tools (mark if self-developed)**	
1	Description of a MM software tool	EMMO		---		VISO, OSMO, SWO		Zontal Space platform (where the VIMMP marketplace is implemented). Owlready2 Python package	

2	---	---		---		OTRAS, EVMPO, MAEO		---	
3	Integration of web-based data sources	EMMO		EVMPO		DOME Ecosystem Ontology (cf. DOME 4.0 Deliverable 3.2)		---	

Note: The development of most of the domain ontologies above (that is, all except SWO) has been led by us at UKRI and GCL. The main developments took place within and supported by the respective projects (VIMMP, DOME 4.0, etc.).

2.5.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 25: demonstrator development steps of UC5

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1.1	Identify "software" properties to be shown in the (VIMMP) platform	Advanced/Done	---	Complete
1.2	Support the technical connection of ontologies and (VIMMP) platform	Advanced	---	Complete
1.3	Ingest MM software examples on the (VIMMP) platform	Advanced	---	Complete
1.4	Gather feedback	Initial	---	Settled version, always open for feedback
2.1	Identify key "expert" properties from both domain ontologies on MM expertise	Initial	---	Discontinued
2.2	Map examples for "expert" from one domain ontology to the other	Initial	---	Discontinued
2.3	Formalize mappings between key concepts	To be done	---	Discontinued

	of two domain ontologies on MM expertise			
3.1	Discuss and improve alignment of DOME 4.0 Ecosystem Ontology to OCES	Existing (cf. DOME 4.0 D3.2)	---	Complete

2.5.4 *KPIs Assessment*

In use case 5, improvements were achieved in the KPIs FAIR and TRL. Improvements were also targeted in the areas of "Described Software Tools" and "Number of initiatives/projects adopting our approach". However, these could not be quantified in the last period of the project.

2.5.5 *Evaluation of shall-requirements*

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 26: Shall requirements of UC5

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC05_RQ_U_01	Documentation of Materials Modelling software	Capture the key aspects of MM software (capabilities, requirements, i.e., libraries and operating systems, licensing).	**Shall**	Use RoMM and MODA concepts when possible.	Complete
UC05_RQ_U_02	Description of a use-case for Materials Modelling	Capture the key aspects of an industrial use-case problem for a user to propose it to “translators”/modellers who can solve it.	**Shall**	Re-use concepts from MODA when possible.	Complete

UC5_RQ_U_03	Description of a Materials Modelling expert	Capture key aspects of an expert in this field.	**Shall**	Use concepts from RoMM and MODA when possible.	Discontinued (But complete within two independent approaches)
Maintaining/extension of ontologies					
UC5_RQ_M_01	Review the alignment of DOME Ecosystem Ontology to EMMO/OCES	Review the existing alignment module and ensure compliance with OCES recommendations	**Shall**	---	Advanced/Completed (Note: DOME 4.0 project will continue till October 2024)
Standardisation					
UC05_RQ_S_01	Wider agreement	Consultations with the community and related H2020 projects, for example via the EMMC Focus areas on digitalisation and interoperability.	**Shall**	---	Complete

2.5.6 TRL Assessment

In the overall view, the TRL has increased from 3-4 for the initial assessment to 5 at the end of OntoCommons.

DO: Recent changes and probably coming up ones will concern aspects related to the user interface. In particular, the creation of appropriate SKOS lists for drop-down menus in Zontal. E.g., a recent one concerned having pref-labels for the “software tool feature” entries to include extra information (e.g., parent class) so to be easily readable as a single flat list (see also GitLab repository).

Currently no significant update on the TRL level in the framework. Domain ontologies have reached to TRL 5. (they have been validated in the VIMMP environment).

The DOME 4.0 Ecosystem Ontology is used within the DOME 4.0 platform (TRL4-5). The project is evolving, so we can expect updates in the ontology, as required by use-cases and core platform needs. By October 2023 we expect the TRL will be ~5.

2.5.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

The DOME 4.0 Ecosystem Ontology is available on the project website (documentation and source).

Yes, all VIMMP Ontologies are more findable and accessible: now they are available on a GitLab page (https://gitlab.com/vimmp-semantics/vimmp-ontologies/), where the development has been recently moved, and they have also been uploaded on MatPortal (https://matportal.org/ontologies/VIMMP_ONTOLOGIES). Both tools are free, users only need to register to contribute and/or make suggestions: this enables all interested parties to participate in the development and to track discussions. The MAEO ontology from the MarketPlace project is now also available on GitHub (https://github.com/emmo-repo/MAEO-Ontology).

Findable: 3 of the 7 principles in the Findable dimension are in progress and have been improved. Findability has increased (two web locations added, one for development and one for main releases only for VIMMP ontologies, and development page added for MAEO)

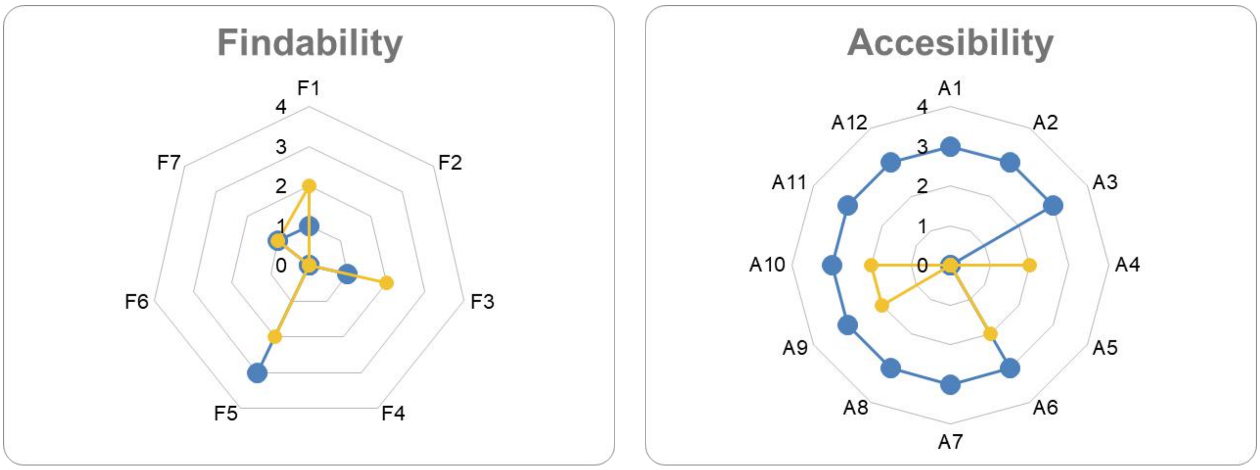
Accessible: 10 of the 12 principles in the Accessibility dimension have been implemented and improved. Aaccessibility has increased (before the ontologies files were also available, but only in correspondence of releases and were mostly provided as attachments to papers/reports)

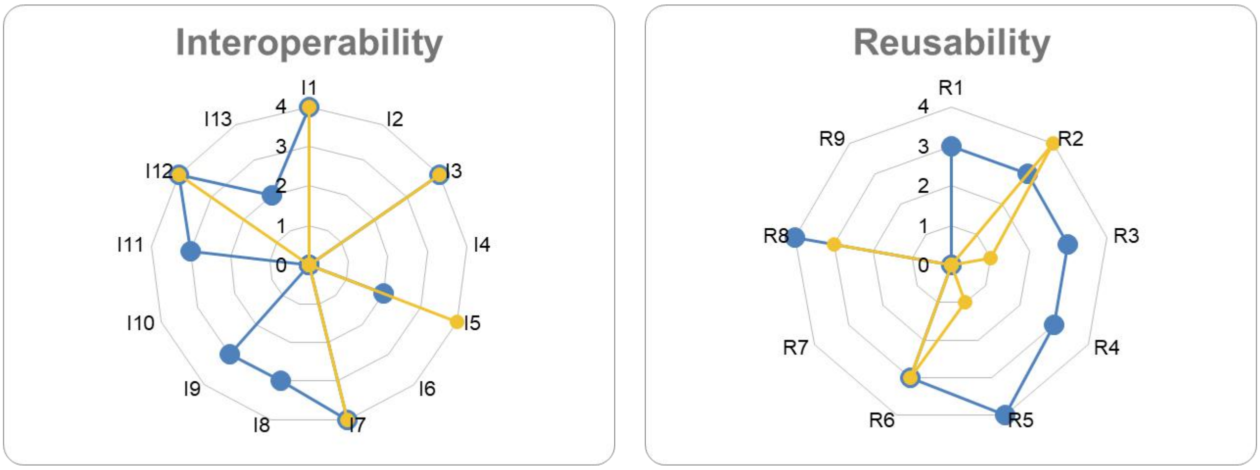
Interoperable: 10 of the 13 principles in the Interoperability dimension have been implemented and improved.

Reusable: 7 of the 9 principles in Reusability have been implemented and improved.

The use case has many non-applicable principles at this stage, because there are still some Intellectual Property (IP) issues to be resolved. Nevertheless, it is already mature from the perspective of Interoperability (which is expected due to the nature of the use case) and the other dimensions are mostly in the planning phase, which opens up a nice path for OntoCommons project results to influence the FAIR compatibility of the data and metadata of the use case.

Table 27: FAIR results of the initial survey of UC5 in yellow, final results in blue





2.5.8 Assessment of further benefits

We think one important benefit of this use-case for OntoCommons is that it provides prototypical concepts needed in materials and manufacturing digital marketplaces and an opportunity to discuss their inclusion/alignment with OCES.

2.5.9 Lessons learned

- Semantics is an important part of the solution, but not the whole story. Syntactic does matter too (e.g., concrete/technical implementations and the constraints they carry)
- It is difficult to find a right balance between expressivity and usability. For example, less expressive and lightweight models can be tackled by a wider number of tools/technologies and are less computationally expensive. There is also a lower barrier in using them. On the other side, of course, more expressive models allow to implement more complex constraints.
- If interfaces are meant for humans too, they need to be friendly to them (for example, dropdown menus need to be easy to navigate and read through and should not contain hundreds of entries)
- Within a complex system, is not unlikely that ontologies need to be used by multiple applications/components having different and possibly incompatible requirements. It is important to involve all relevant actors in the design phase so that these requirements are explicit and jointly discussed.

Additional references:

[DOME 4.0 Ref] https://dome40.eu/. “Digital Open Marketplace Ecosystem 4.0” (DOME 4.0) project (Horizon 2020 programme, Grant agreement No 953163).[DD3.2 Ref] S. Chiacchiera *et al*, “DOME 4.0 Deliverable D3.2 - “Ecosystem information model ontology”, available at https://dome40.eu/sites/default/files/2022-11/DOME%204.0%20D3.2%20Ecosystem%20information%20model%20ontology%2030.11.2022%20PU.pdf . The ontology source files are also available on the DOME 4.0 website.

2.6 Demonstrator 6: Ontology based yard management (OAS)

2.6.1 Brief description and visual representation

The main goal of the use case is to improve the automation of yard management starting with the setup/configuration of a yard site. Yard management, plant logistics, and dispatch automation covers the planning, organization, control, processing, and supervision of the entire flow of materials and goods. The use case will make use of semantic technologies to assist in a first place in the yard setup process and secondly in the decision-making process regarding the yard management, for example inferring the next action of a lorry in the yard given various logistics data and ontologies describing that data.

The demonstrator within OntoCommons aims at improving the efficiency in yard site planning and the effectiveness and responsiveness of decision-making in logistics control systems based on data sharing built around big volume data streams semantically described by dedicated PSS ontologies.

The OAS scenario has 2 sets of steps:

- Setup set of steps. One that is to be done in the setup phase, primarily in the scope of OntoCommons, and is related to the creation/update of use case relevant ontologies and yard setup inference rules as well as preparation of the used SW within the demonstrator to use said ontologies, restrictions and rules. The ontologies model all the elements in a yard and the restrictions and rules model the basic configuration of a yard (e.g., there is a gate before a scale) as well as the behaviour of the SW and actors in the system (e.g., when a truck is carrying dangerous materials, it should be redirected to the special load/unloading area). This set of steps is revisited seldom at runtime.
- Runtime set of steps. The second set is the one that relates to the use of the SW and ontologies at runtime in the scope of a yard/site configuration. This will be prepared, tested and evaluated within OntoCommons and will be further exploited within OAS further work.

The demonstrator partly applied LOT methodology.

2.6.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 28: Ontologies and tools of UC6

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
Steps to be done in scope of setup phase to configure the OAS SW									
1.1	Study PSS Ontology and	BFO		IOF		PSS Ontology reused and		Protégé	

	update if needed for OAS purposes					extended in the OAS ontology			
1.2	Study Supply chain and Logistics Ontology and update if needed for OAS purposes	BFO		IOF		SC Ontology partly reused and extended in the OAS ontology		Protégé	
1.3	Study relation with Material Ontology for special treatments of loads	---		---		---		---	
1.4	HW Data Input & Ontology Compliance Check	BFO		IOF		OAS application specific PSS ontology	x	Protégé	
1.5	Study currently used data sources (see below for details) and semantically enhance the data sources	---		---		Study was used to make the extensions of the existing ontologies into the OAS ontology	x	Protégé	
1.6	Define generic rules that are not dependent on the possible instances of the yard configuration	---		---		Generic rules are defined based on previous yard configuration processes (and user knowledge and experience) and included in the OAS ontology	x	---	
1.7	Adapt the OAS SW used for the yard configuration and management to the updated semantic data sources	---		---		OAS Application specific PSS ontology used for wizards	x	New wizard based tool developed to support the yard configuration and setup process.	
Steps to be done in the runtime phase at the time of site configuration (for each client)									
2.1	Service Workflow Configuration	BFO		IOF		PSS Ontology		---	

	Based on the Ontology for a particular site/yard					Supply Chain and Logistics ontology			
2.1.1	Services are yard management, and logistic process definition services	BFO		IOF		PSS Ontology Supply Chain and Logistics ontology		---	
2.2	Definition / update of restrictions and rules based on the OAS ontology for the specific site	BFO		IOF		PSS Ontology Supply Chain ontology		Restrictions/necessary conditions defined between elements in the OAS ontology. Rule engine that can handle rules such as (t.b.d.): - If we have a container transportation truck then we need to weigh the truck at arrival - Rules with the sequence of HW points	
2.3	OAS System Operation based on defined Workflow and Rules.	---		---		---		---	

Table 29: self-developed ontologies and tools of UC6

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
Ontology	OAS ontology	The OAS ontology imports the IOF PSS ontology and IOF Supply Chain	Not open (for now)

		ontology to model the yard ecosystem elements and relations/rules that govern the basic scenarios to feed the yard setup solution and later on the yard management solution.	
Tool	OAS setup solution	Wizard like tool that is used by OAS worker when setting up a new yard site. This is to be used when interviewing the Yard Customer and configuring yard management system	Not open

2.6.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 30: demonstrator development steps of UC6

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1.1	Study PSS Ontology and update if needed for OAS purposes	Study concluded	---	PSS ontology is reused
1.2	Study Supply chain (scro) and Logistics Ontology (LOGO) and update if needed for OAS purposes	Study concluded	---	Supply Chain ontology is reused
1.3	Study relation with existing material	Study concluded	Currently still limited number	No materials ontology selected, the demonstrator

	ontologies for special treatments of loads	but use left for further extensions of the solution.	of material options.	uses the OAS pool of data, Using on material ontology planned in future extension of the solution
1.4	HW Data Input & Ontology Compliance Check	Study concluded	---	Ontology compliant with OAS HW components
1.5	Study currently used data sources (Pylod and Logis SW sources) and semantically enhance the data sources	Study concluded	---	Data from the currently used sources was used to model the basis set of yard independent knowledge, restrictions and rules.
1.6	Define generic Rules that are not dependent on the possible instances of the Yard configuration	A bottom-up approach is being used by analysing an existing yard configuration, a full set of rules is extracted and finally the extrapolation to a generic setting made.	---	A full set of rules is completed, tested and validated and updates on the rules based on the tests are implemented
1.7	Adapt the OAS SW used for the yard configuration and management to the above listed selected and updated semantic data sources	New tool for yard setup is being developed and tested (iteratively)	---	A new wizard like tool that is used by OAS workers when setting up a new yard site is tested and in use. The output is a standardized technical specification file.
2.1	Service Workflow Configuration based on the Ontology for a particular site/yard	Basic workflow is done	---	Basic workflow done

2.1.1	Update the services yard management, and logistic process definition services	Identification of what to update done	---	Basic implementation done
2.2	Definition / update of Rules based on the Ontology for the specific site	Initial set of rules defined	---	Basic set of rules tested for 1 site
2.3	OAS System Operation Based on defined Workflow and Rules.	Identification of what to update done	---	Basic implementation done

2.6.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 31: Key Performance Indicators progress of UC6

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	• TRL change	– *1/1+(TRL_end-TRL_start)*	(0,1]	6
FAIR improvement	• average score in each FAIR dimension			The Interoperability and Reusability dimensions have improved considerably.
Shorten time to make a new yard configuration for a new client/ site/ domain	• % of time spent in new site configuration	– Calculation of the percentage reduction in time	[0,100]	30% improvement
Shorten time to make decisions in the Yard re-configuration	• % of time needed to make decisions on re-configuration	– Calculation of the percentage reduction in time	[0,100]	Around 25%

Time to identify errors in the process (e.g., vehicle with specific load missing, or sent to a wrong lane, vehicle load not the expected, driver not authorized to enter, etc.)	• Average Time need to identify error in the process	---	[0,...)	Not possible to estimate this at the moment, only in a few months at project end once system is used
Ontologies should support standardization of yard management services; yard sites do differ from each other leading to very individual solution for each site	• % of standardized components	– Calculation of increase in the standardized components	[0, 100]	60% standardisation of the basic elements/ equipment to be installed in a yard system
Security management of the yard	• % reduction of security problems in the yard	– Calculation of reduction of security problems	[0, 100]	Not possible to estimate this at the moment, only in a few months at project end once system is used

2.6.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 32: Shall requirements of UC6

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023

Use/application of ontologies					
UC6_RQ_U_02	Application Specific Rules	The ontologies shall allow for easy adding/updating of application specific rules among the entities	**Shall**	---	Complete
UC6_RQ_U_06	Non ontology expert user	The ontologies shall be usable by non-ontology experts. The natural language definitions of entities and relations shall be understandable by domain experts without knowledge on ontology science.	**Shall**	---	Work in progress (natural language definitions are improved when necessary, taking suggestions into account)
UC6_RQ_U_08	Data structuring and documentation	The ontologies shall allow to structure and document data related to Yard management services	**Shall**	---	Complete
Development of ontologies					
UC6_RQ_D_01	Ontology Scope	The ontology shall model the components needed for the UC6 services of the yard management system.	**Shall**	---	Complete
Tools for ontology					

UC6_RQ_T_01	OWL Requirement	The tool for edition and maintenance of the ontologies shall be able to edit the OWL files.	**Shall**	---	Complete

2.6.6 TRL Assessment

In the overall view, the TRL has increased from 4-5 for the initial assessment to 5 at the end of OntoCommons. The TRL has evolved since the first half of the project. The main ontologies to be used were identified, applied in the new OAS ontology and associated semantic elements (restrictions, relationships and rules) are being tested in the new yard setup tool. The tool is being updated based on these tests. It is expected to achieve TRL 5 by the end of the project.

2.6.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: 6 of the 7 principles in the Findability dimension have been implemented and slightly improved. The demonstrator is currently working on the step where "Metadata is offered in such a way that it can be harvested and indexed".

Accessible: 11 of the 12 principles in the Accessibility dimension have been fully implemented and fulfilled. The step for "Data can be accessed manually (i.e. with human intervention, for example, after looking at documentation)" is not applicable (because all the data is created / updated and used within a specific workflow, and this workflow is defined purposively).

Interoperable: 11 of the 13 principles in the Interoperability dimension have been implemented and improved. The demonstrator is currently working on the step to have "Data include references to other data".

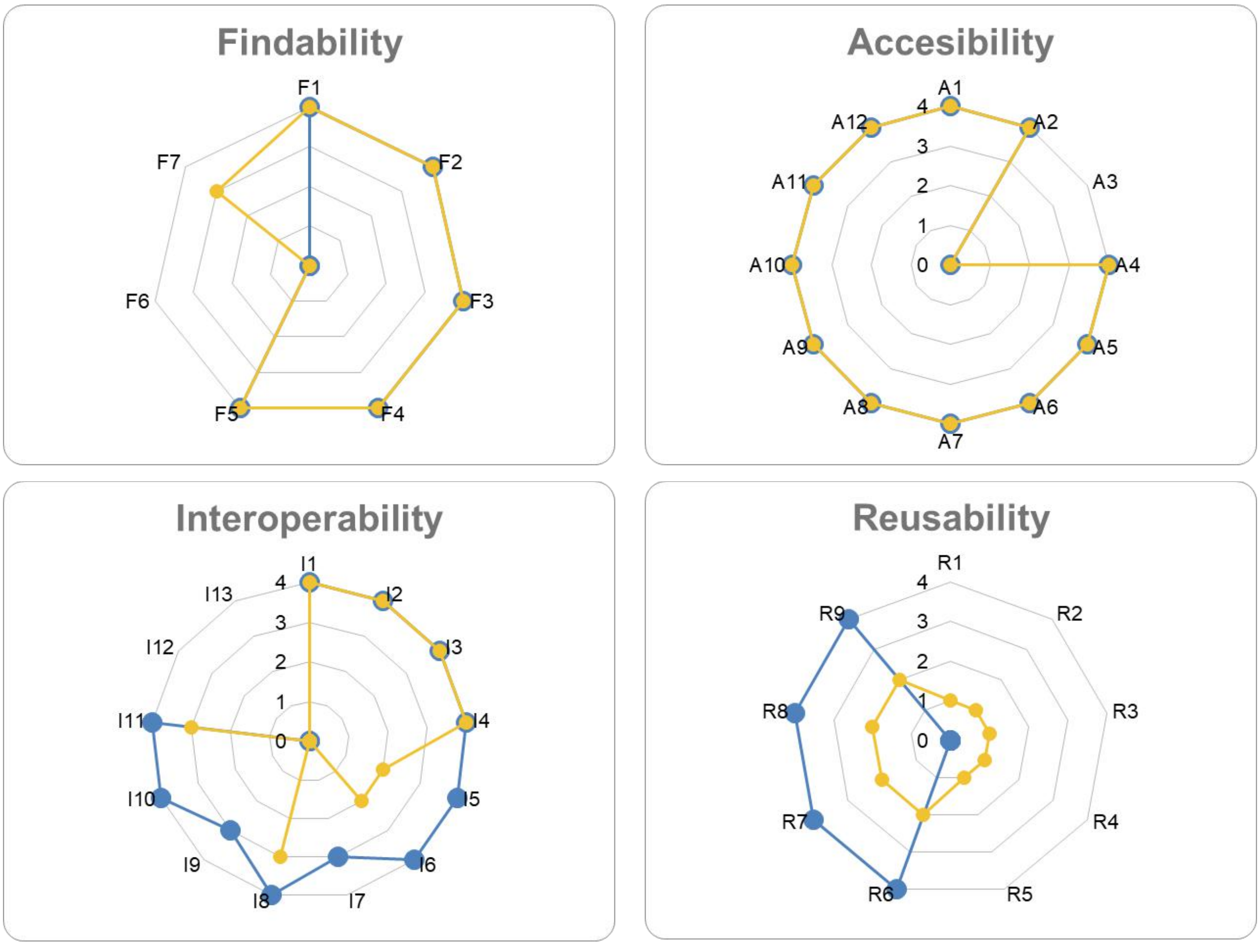
Reusable: 4 of the 9 principles in the Reusibility dimension have been implemented. The demonstrator is currently working on "Metadata and Data is expressed in compliance with a machine-understandable community standard (e.g., an ontology)".

The main step is the introduction of ontologies in the yard management and site design services. In particular currently the demonstrator is:

- Starting to use OntoCommons LOT methodology and other recommended OntoCommons tools to refine and extend the PSS ontology that will form the metadata basis of the Yard Management ecosystem data
- Using ontologies to facilitate both
    - Interoperability (by using qualified references to other metadata) and

Reusability (by expressing metadata and data with community standards)

Table 33: FAIR results of the initial survey of UC6 in yellow, final results in blue



2.6.8 Planned further developments

The standardized technical specification file of a new yard that is the output of the newly developed wizard yard setup tool (using adopted PSS ontology and open set of rules), will be used in the OAS yard management tools to support the deployed services in a yard.

2.6.9 Lessons learned

Several lessons were learned while working on the demonstrator, especially on the definition of rules:

- No clear guidelines about the level of abstractions of the restrictions and rules in order to make them effective/useful for a yard/site configuration. Several iterations are needed to reach a good basic (yard independent) set of restrictions and rules.
- Relation to mid- level ontology (and indirectly TLO) useful to generalise and keep entities open for diverse configurations but requires more time (especially when the middle level ontology is still not stable)
- Selection of tool for rules definition is challenging in the phase when the initial set of rules is still not stable.

Based on the current experience in the application of the LOT methodology, the demonstrator team finds the LOT methodology being useful as a well-structured approach for the methodology development/refinement. It seems that several guidelines/tools proposed are well applicable in the industrial environment. However, some guidelines (see above) may appear to be too complex and not practicable for use in the teams that require strong cooperation with on-ontology experts. More detailed and user-friendly guidelines/tutorials could help domain experts to follow the methodology. The overall LOT methodology needs to be adapted to the conditions in the specific application domains. Although the definition of the activities and steps of the methodology contributes to clear and consistent approach, it is likely that in the industrial practice more iterative approach is needed, blurring the formal boundaries among the key activities and steps.

2.6.10 Other comments

Using material ontologies (related to the material transported by vehicles in a yard) is left for the post project phase. The current set of materials transported in the yard systems, serving as references for the ontology and rules definition, is limited and therefore an application of material ontologies is not practicable. The demonstrator focused on the definition of the initial set of rules and their investigation and acceptance by the practitioners. In the post project phase, the rules will be extended to cover diverse types of materials transported in a yard, and the use of material ontologies will be further investigated.

2.7 Demonstrator 7: Feedstock quality assurance (IFAM)

2.7.1 Brief description and visual representation

The main focus of this use case is improving feedstock quality assurance. The mixing of metal powders and polymeric binder components (feedstock) is a crucial part of the metal injection molding process, as well as to produce parts via extrusion. The process depends on the source materials (chemical composition, quantity of the components, shape and size of the metal powder particles). The quality (homogeneity, reproducibility…) of the feedstock not only influences the following production steps, but also has a strong influence on the produced parts (e.g., dimensions, homogeneity, mechanical properties). So far, the quality of feedstock is not objectively quantifiable. A shared formal specification like an ontology could help to identify the main process and material parameters that allow describing the quality in an objective way.

The use case will be demonstrated on a decision support system, where a feedstock developer feeds the relevant data and the ontology (describing material characteristics and the mixing process) to the system and an upon triggering by an operator, the system will decide on the proper mixing process configuration and measure the conditions of the mixing process. The main expected benefits are:

- digital representation of the entire mixing process,
- recognition of previously unknown correlations,
- deciding on adjustable process parameters,
- consistent quality of feedstock.

The use case has the following workflow (Figure 24**Error! Reference source not found.**).

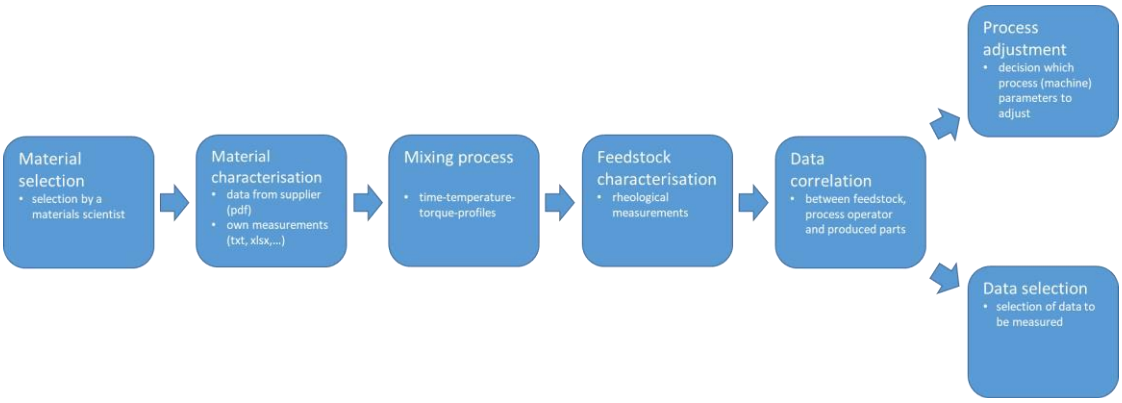


Figure 24: An overview of UC7

2.7.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 34: Ontologies and tools of UC7

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Small, upper-level ontology that is designed for use in supporting information retrieval, analysis and integration in scientific and other domains	BFO		---		---		---	
2	BWMD is an ontology developed by Fraunhofer IWM. It is modularized in an upper ontology (BFO 2.0), a mid-level ontology regarding basic concepts for material science and a domain ontology regarding different domain applications like mechanical experiments and microscopy.	---		BWMD		---		---	
3	new DLO "FeedMix" based on BWMD	---		---		FeedMixOntology (FMO)	x	---	
4	Ontology development	---		---		---		Protégé	
5	check consistency of ontologies, compute the classification hierarchy, explain inferences, and	---		---		---		Pellet reasoner (part of Protégé)	

	answer SPARQL queries								
6	Online KnowledgeBaseBuilder for the description of the production process	---		---		---		InfoRapid KnowledgeBase Builder Web Edition	
7	Integration of ontology and knowledge graph	---		---		---		Template provided by project partners	
8	Data processing and analyzation	---		---		---		Excel, Python	
9	Reasoning over sensor data	---		---		Semantic Sensor Network - to represent sensor data		Pellet reasoner Purpose: OWL DL reasoning	
10	Mixing process							Software of mixing equipment	
11	Material characterization	---		---		---		Rheological software	
12 (future)	(Live process adjustment: application of ontology)	---				---		Software: AI	

Table 35: self-developed ontologies and tools of UC7

Ontology / tools (O/T)	**Name**	**Description**	**Publishing link (if applicable)**
Ontology	FeedMixOntology	A DLO for the mixing of metallic powder with a polymeric binder system	

2.7.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 36: demonstrator development steps of UC7

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Reasoning over sensor data	List of available data prepared	Not much data available (temperature, torque, time, speed)	completed
2	Ontology decision	Decision on BWMD ontology as MLO Adaption of BWMD to create our domain ontology « FeedMix » and integration in MLO BWMD		completed
3	Ontology integration	Integration of DLO into MLO BWMD		completed
4	Manual data extraction from mixer	Manual data extraction		complete
5	Automatic data extraction from mixer	In preparation		partly
6	Manual data correlation	Manual data correlation		complete
7	Automatic data correlation	In preparation		partly
8	Automatic determination of relevant	In preparation		partly

	process parameters			
9 (future)	(Live process adjustment: application of ontology)			Further development

2.7.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 37: Key Performance Indicators progress of UC7

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	TRL change	1/1+(TRL_end - TRL_start)	[0,1]	TRL4 (+1 since start)
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	Approx.2-3 due to the implementation of a TLO/MLO

2.7.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 38: Shall requirements of UC7

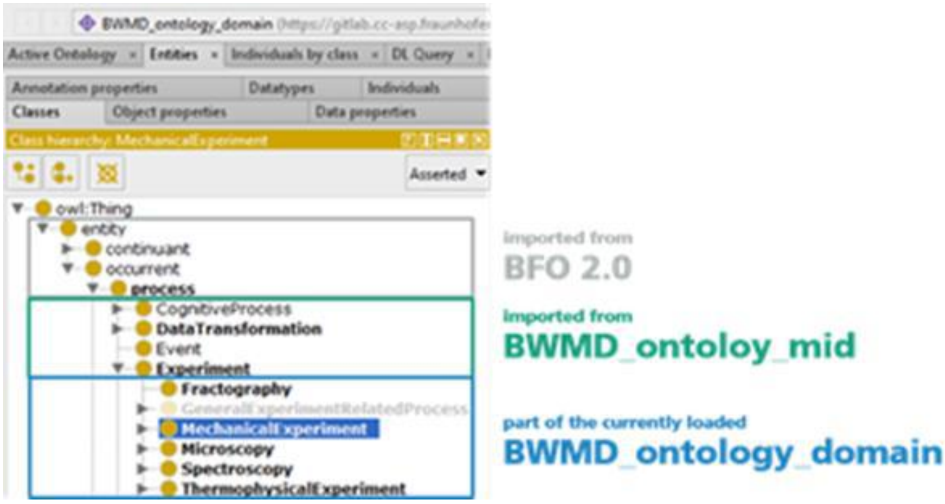
UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC7_RQ_U_01	Feedstock quality	The ontology shall support the production of feedstock with high and	**Shall**	Considered within the TLO and MLO	Completed

		reproducible quality.			
UC7_RQ_U_03	Data sources selection	The ontology shall support the selection of data to be measured to ensure the quality of the feedstock.	**Shall**	Considered within the MLO and DLO	Completed
Standardisation					
UC7_RQ_S_01	Standards source materials	Source materials that are mixed for feedstock preparation shall/should meet certain standards that could be analysed (e.g., particle size analysis by laser granulometry ISO 13320, mesh analysis DIN ISO 4497, specific surface BET DIN 66131, bulk or apparent density DIN ISO 3923-1, bulk or apparent density DIN ISO 3923-2, density determination by gaspycnometry DIN 66137-	**Shall/Should**	The values for the materials are covered within TLO, MLO and DLO via base units (e.g., mass, volume, ...)	Completed

		1 and DIN 66137-2)			

2.7.6 TRL Assessment

In the overall view, the TRL has increased from 3 for the initial assessment to 5 at the end of OntoCommons.



Ontology by level	TRL	Info
Top-level ontology: BFO 2.0	4	Already implemented
Mid-Level ontology: BWMD_ontology	4	Already implemented with other domains for material experiments
Domain ontology	4	Following the instructions from BWMD-ontology for development of domain ontology

2.7.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

- After selection of TLO and MLO ontology, the FAIR principles increase to "in implementation phase" (Level 3) or higher, since the FAIR principles highly dependent on the used ontologies
- BFO and BWMD ontology fulfil FAIR principles

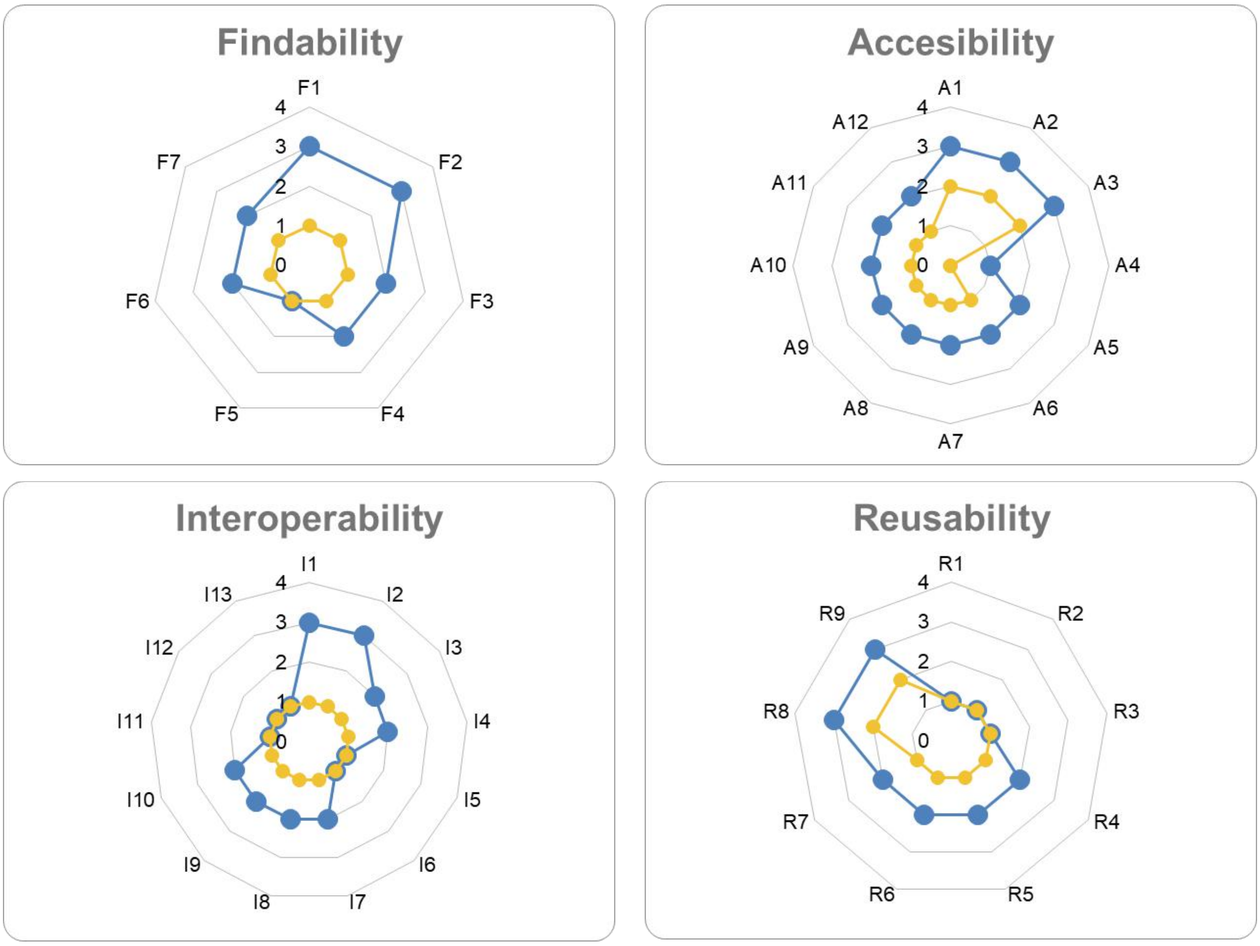
Findable: All the principles in the Findable dimension have been implemented and improved.

Accessible: 11 of the 12 principles in the Accessibility dimension have been implemented and improved.

Interoperable: All the principles in the Interoperability dimension have been fully implemented and 8 of them have been improved.

Reusable: All the principles in the Reusability dimension have been implemented and 6 of them have been improved.

Table 39: FAIR results of the initial survey of UC7 in yellow, final results in blue



2.7.8 *Assessment of further benefits*

The development of domain ontologies can be adapted to other processing techniques e.g., extrusion, 3D printing, metal binder jetting, …

2.7.9 *Planned further developments*

To work as a decision-making system to improve the material and process development, the data extraction, analyzation and correlation must work automatically. Further development will focus on that.

2.7.10 *Lessons learned*

The implementation/development of DLO just with domain knowledge (e.g. material science) is difficult. Guidelines for the development are quite "technical" (written for ontology experts). For us, this meant the adaption of an existing ontology (BWMD) to our needs. This ontology already implemented BFO as TLO.

2.8 Demonstrator 8: NanoMaterials Characterisation (IRES)

2.8.1 Brief description and visual representation

The main goal of the use case is to bridge the gaps between material characterization and nanosafety domains. In the use case, the data collected from exposure and emission measurement devices collected by a risk analyst and the experimental data collected by a nanoindentation engineer will be integrated via domain ontologies and top-level ontologies like EMMO in a tripe store with reasoning capabilities. Afterwards, the potential causal relationships between the nanomaterial characterization process and safety risks will be analysed via inference and querying. An overview is given in Figure 25.

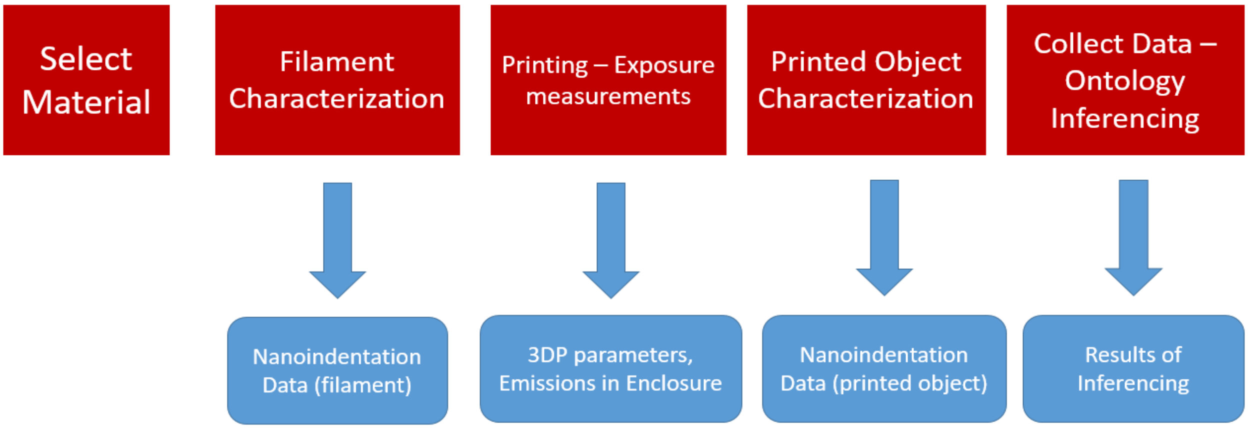


Figure 25: An overview of UC8

2.8.2 Ontology level and development during the project Ontologies developed/reused

The following table shows details of the demonstrators used or developed ontologies and tools.

Table 40: Ontologies and tools of UC8

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Data collection from By Risk analyst from all instruments: From nanoindenter:	---		---		---		3D Printer Software, 3D Printer Software, Nanoindenter Software	

	hardness, elastic modulus From 3D printer: temperature: particle concentration Material scientist is involved step 1								
2	Data Processing and storage Saved in Dropbox as CSV and text files	---		---		---		Python scripts, Automated software system	
3	Material characterization Data Integration	EMMO		---		OYSTER Mechanical Testing Ontology		Nanoindenter Software	
4	3D Printing Data Integration	BFO		---		Additive Manufacturing Ontology		3D Printer Software	
5	Printed Object characterization Data Integration	EMMO		---		OYSTER Mechanical Testing Ontology		Nanoindenter Software	
6	EMMO	EMMO		---		eNanoMapper		Exposure measurement instruments	
7	Reasoning over data Finds rule-based or ontology-based relations between the collected measurements and characteristics and impact on the safety	---		----		---		Protege plug-in reasoners Triplestore with reasoning support	

2.8.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 41: demonstrator development steps of UC8

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Selection of filaments for 3D printing	Done	---	
2	Nanoindentation measurements on the filaments	Done	---	Complete
3	3D printing on selected filaments	Done	---	Complete
4	Nanoindentation on 3D printed objects	Done	---	Complete
5	Taxonomy selection for the ontology of the use case	Done	---	
6	Domain ontology development	In progress	Connect BFO with EMMO.	Complete
7	Triple store development	In progress	---	Complete

2.8.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 42: Key Performance Indicators progress of UC8

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	• TRL change	– *1/1+(TRL_end-TRL_start)*	[0,1]	TRL4-6, different for ontology or tools

FAIR improvement	• average score in each FAIR dimension	– For each dimension, average based on final surveys	[0,4] for each dimension	2
Cost reduction of the manufacturing process.	• working hours needed to complete data analysis of an experiment	– Calculation of the percentage of cost reduction	[0,100]	10

2.8.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 43: Shall requirements of UC8

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC8_RQ_U_01	Data Integration	Integrate data extracted from exposure measurement with nanoindentation data using the required ontologies.	**Shall**	---	Complete
Standardisation					
UC8_RQ_S_01	Harmonisation of ontologies that are based on different top-level ontologies.	Input from WP1. Moreover, a relevant webinar or workshop could be organised.	**Shall**	---	Partly

2.8.6 TRL Assessment

In the overall view, the TRL has increased from 4 for the initial assessment to 4-6 (different for ontologies or tools) at the end of OntoCommons.

1. **TLOs:** The Top-level ontologies used for the Use Case have been decided

- BFO
- EMMO

(TRL 4 – TLOs are utilized as an extension of the DOs. No further updates will be made in the TLOs employment)

2. **for DOs employment:** The DOs that will be used for our Use Case have been determined:

- OYSTER Mechanical Testing Ontology
- eNanoMapper
- Additive Manufacturing Ontology

In addition, we have decided upon the terms from these ontologies that are relevant to our use case.

The ontology to be used in the use case has been developed. Possible alterations and additions to the ontology may occur through the use case progress and the analysis of the results.

3. **for tools deployment:** The system that collects and integrates data to a database has been automated with the use of python scripts (TRL 6 - the system has been updated and verified).

4. **Investigation of the optimal triple store solution about our use case.**

2.8.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: 6 of the 7 principles in the Findability dimension have been implemented. Due to data privacy no actions have been made to improve findability for other users.

Accessible: 11 of the 12 principles in the Accessibility dimension have been implemented. Due to data privacy no actions have been made to improve accessibility for other users.

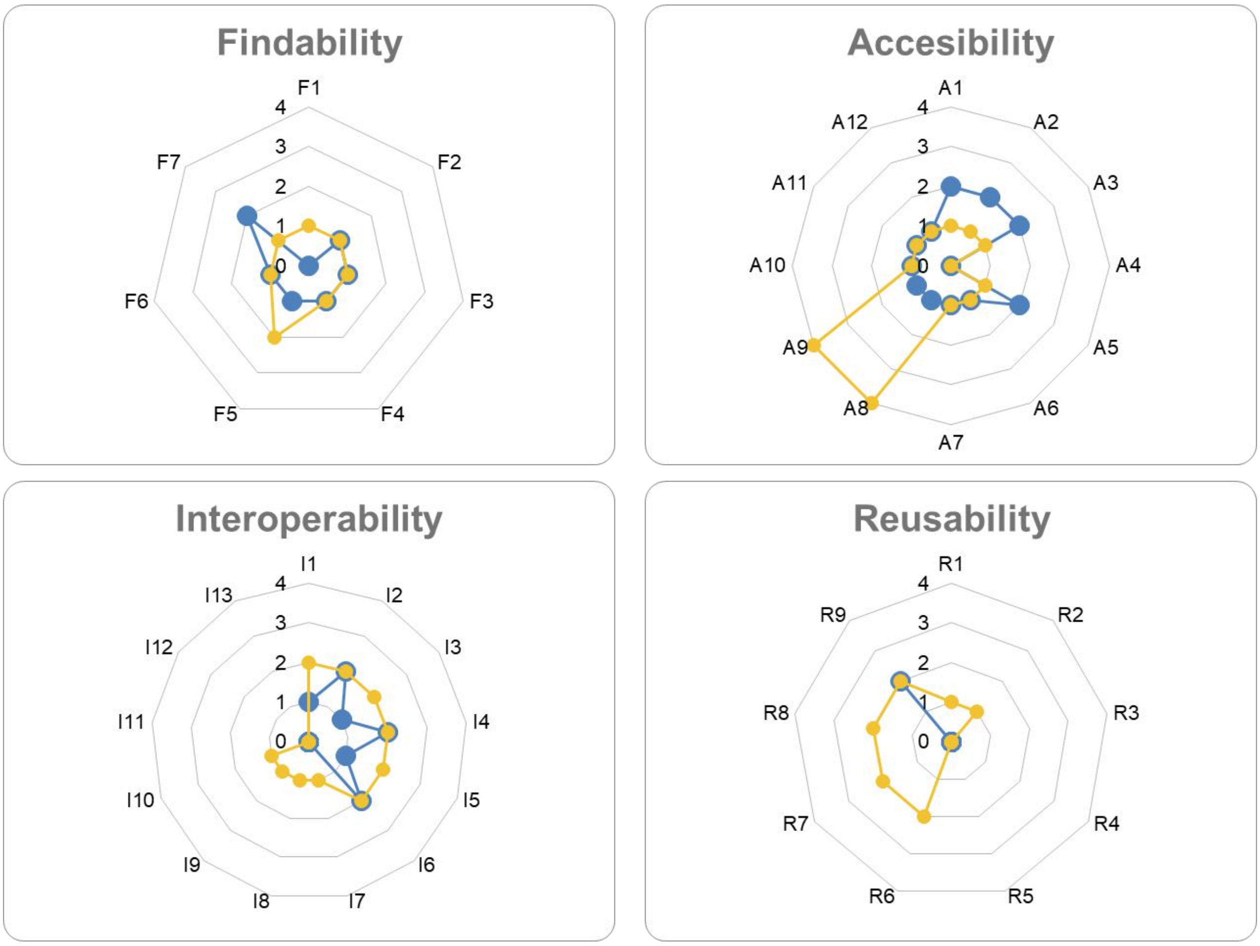
Interoperable: 6 of the 13 principles in the Interoperability dimension have been implemented. Ontologies integration has started in order to enhance data interoperability. Terms (e.g., nanoparticle concentration, nozzle temperature, etc.) used for triple store schema selected.

Reusable: only 1 of the 9 principles in the Reusability dimension has been implemented. Ontologies integration has started in order to enhance data reusability.

The use case has already implemented the principles regarding machine-accessible metadata and data. Several other principles in Interoperability and Reusability dimensions are in the planning phase. The OntoCommons best practices can influence the further development of these principles in the use case.

The demonstrator needs to improve the FAIRness of the metadata, so information about the data can be discovered. The data of the use case are not to be shared with third-party, so actions taken should regard the improvement of findability, accessibility, interoperability and reusability among in the organization level.

Table 44: FAIR results of the initial survey of UC8 in yellow, final results in blue



2.8.8 Assessment of further benefits

Our use case provides the know-how to anyone interested in inferring knowledge between the material mechanical properties and nanoparticle emissions during additive manufacturing processes.

2.8.9 Planned further developments

IRES' use case requires a number of specific object properties (relations) that are not easily aligned with the ones present in EMMO and BFO. We are investigating ways of integrating the relations in the EMMO and BFO ontologies.

2.8.10 Lessons learned

There are some challenges in connecting concepts from ontologies that are based on different upper ontologies (BFO/EMMO). New classes and relations will be created, so that all components coming from BFO-based ontologies are compatible with the EMMO ontology.

2.9 Demonstrator 9: Ontology-based Maintenance (Adige)

2.9.1 Brief description and visual representation

The main goal of the use case is to create a common formal terminology for diagnosis and repair of the machines manufactured by Adige SpA. To that end, an ontology that covers part of the machine technical information, possible malfunctions' reasons and diagnosis, as well as maintenance processes and their relationships will be developed in the scope of the use case. This ontology will be then used to annotate samples of malfunction reports from clients, their possible reasons and machine parts relevant to the malfunction will be listed. Such a formal report can be also used for purposes like semi-automated analysis of malfunctions and their comparison.

2.9.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 45: Ontologies and tools of UC9

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Client reports malfunction to Adige maintenance service	NO (only unstructured data)		NO (only unstructured data)		NO (only unstructured data)		Phone, email, apps	
2	If necessary, the technician searches for information about similar malfunctions, in order to better diagnose the relevant issues	DOLCE		NO (possibly considered in future)		DO, to be developed and aligned with DOLCE, about machine functions, structures and malfunctioning, here used for its ability to encode malfunctions		An ad choc search engine developed by a third party for Adige spa.	
3	If the malfunctioning could not be solved remotely, an on-field	DOLCE		NO (possibly considered in future)		The above DO ontology used to suggest the list of faulty components		An early prototype uses Protégé.	

	intervention is scheduled and a list of spare parts that could be used to replace (possible) faulty components is selected								
4	The intervention is carried out and the exact malfunction is determined and solved.	NO (unstructured data)		NO (unstructured data)		NO (unstructured data)			
5	The spare parts used are charged to the client and the others are returned. A report of the activity is filled out by the technician.	DOLCE		NO (possibly considered in future)		The above DO ontology is updated with the malfunction data		An ad-hoc interface, developed by a third party for Adige spa, is used to insert the data in the ontology.	

Table 46: self-developed ontologies and tools of UC9

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
O	Machine components vocabulary	Ontology-based vocabulary of machine-tool components	---
O	Machine functions vocabulary	Ontology-based vocabulary of machine-tool functions	---
O	Machine malfunctions vocabulary	Ontology-based vocabulary of machine-tool malfunctions	---
T	(POC) Tool for automatic alignment between tabular data format and rdf	(POC) Tool for automatic alignment between tabular data format and rdf	---

T	(POC) Tool for basic NLP tasks (e.g., autocomplete, spell checker, etc.) using the vocabulary	(POC) Tool for basic NLP tasks (e.g., autocomplete, spell checker, etc.) using the vocabulary	---

2.9.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 47: demonstrator development steps of UC9

No.	Development Step	Progress	Issues (if any)	Your plans given in the last survey, just as a reminder, do not put further information in.	Estimated final state at the end of OntoCommons in 10/2023
1	Machine vocabulary development (M1-18)	100% - Literature review of modelling of engineering systems approaches carried out. Ontological analysis at a good point (development and testing of already-developed ontological-modules for engineering systems modelling).	Poorly developed engineering and ontological literature about systems, machines, and components terminology entails that we must carry out foundational studies before developing application-ready material (though this is more a state of affairs than a real issue)	---	Further expansion and testing of the vocabulary is useful. That said, the vocabulary schema is complete and filled with numerous records.

		Conducted preliminary analysis of relevant existing software applications for the maintenance domain (e.g., for vocabulary management and extraction, or for working report management) Published some research papers containing a preliminary DLO related to the machine vocabulary.			
2	Function vocabulary development (M12-24)	100% - Literature review and analysis of existing functional modelling methodologies and vocabularies at a good point	---	---	---
3	Data collection reorganization to use	50%	---	---	A POC pipeline for

	the vocabulary (M18-36)				feeding data to the vocabulary will be devised
4	Testing of the vocabulary with data (M24-36)	50%	---	---	The vocabulary will be tested w.r.to e.g., maintainability, facility of update, facility of use.

2.9.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 48: Key Performance Indicators progress of UC9

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	• TRL change	– For each case above: TRL_end - TRL_start	Integer	For DO employment and tools deployment level 4/3 from levels 1/2
FAIR improvement	• Average score in each FAIR dimension	– For each dimension, average based on final surveys	[0,4] for each dimension	The increments previously stated are confirmed. In addition, some other indicators are considered to increase. They are listed in the relative survey
Time for ticket resolution	• Change in average time used by service	– Difference between the averages before	A temporal value	Will be calculated after the project end

	technicians to close a client issued ticket	and after the introduction of the ontology-based application		
Returned spare parts	• Change in average number of spare parts sent to a field intervention for a repair and not used	– Difference between the averages before and after the introduction of the ontology-based application	A rational number	Will be calculated after the project end

2.9.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 49: Shall requirements of UC9

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC9_RQ_U_02	Alignment	The ontology-based glossary shall be developed according to and aligned with the DOLCE ontology.	**Shall**	The ontology-based glossary is part of an ontological system and must be seamlessly aligned with the DOLCE ontology to ensure conceptual clarity and interoperability	Complete
Development of ontologies					

UC9_RQ_D_01	Ontology-based glossary of product parts	Vocabulary covering machine parts	**Shall**	It shall cover Adige SpA machinery	Complete
UC9_RQ_D_02	Ontology-based glossary ontology of maintenance processes	Vocabulary covering maintenance processes	**Shall**	It shall cover Adige SpA maintenance processes	Partly
UC9_RQ_D_03	Ontology-based glossary of engineering functions	Vocabulary covering engineering functions	**Shall**	It shall cover main functionalities of Adige SpA machinery parts	Complete

2.9.6 TRL Assessment

In the overall view, the TRL has increased from 1 for the initial assessment to 3-4 (different for ontologies or tools) at the end of OntoCommons.

- for different scenario steps: n/a
- for TLOs employment: 8/9 (no change foreseen)
- for MLOs employment: n/a
- for DOs employment: from 1 to 3 compared to spring 2021; expected 3/4 in the near future

  level 3 → level 4 at project end
- for tools deployment: from 1 to 2 compared to spring 2021; expected 3 in the near future

  level 3

2.9.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: All the principles in the Findable dimension have been implemented and improved.

Accessible: All the principles in the Accesibility dimension have been implemented but were not improved during the project.

Interoperable: All the principles in the Interoperability dimension have been implemented and 11 of them have been fully developed.

Reusable: All the principles in the Reusability dimension have been implemented and improved. 3 of them have been fully developed.

Future steps: Introduction of ontology-based FAIRness-compliant vocabulary to describe data and relations between data (I2, I4, I6 indexes should therefore move to levels 3-4 due to introduction of a formalized vocabulary. Moreover, indexes I8 and I11 should also reach level 3-4 due to the use of ontology-specified relations between data.)

Finally, the development of an ontology (also) in OWL language will change R7 and R9 to level 3-4.

Future steps: The ontology-based FAIRness-compliant vocabulary that has been developed must be further tested and expanded.

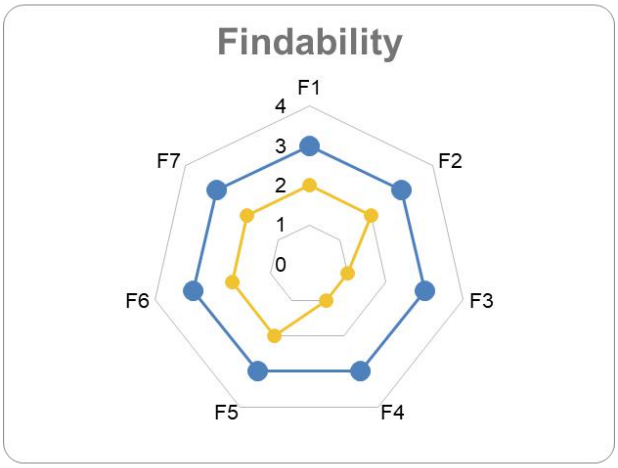
Demonstrators wants to improve: Terminology used in the company (terms should be unique and should be language-independent, the company aims to develop a 'multilingual glossary'). 'Richness' of data in order to simplify their search and comparison.

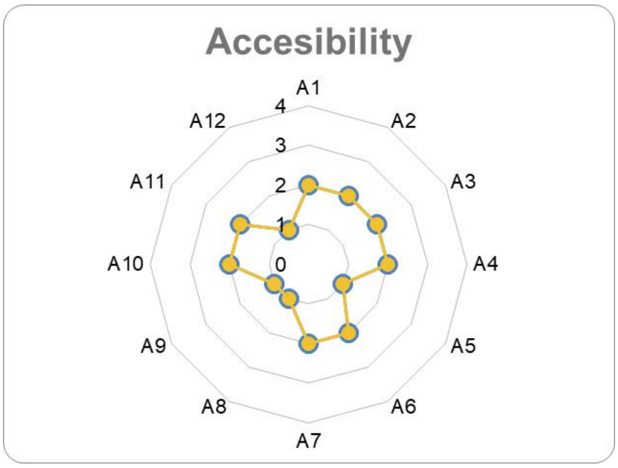
Roadblocks: The demonstrator is currently moving to a new information system. No change in the data structure is possible until after the transition will have taken place. This could take several months. Also, solutions w.r.to FAIRness improvement need to meet business related concerns which may have an impact on the final FAIRness levels.

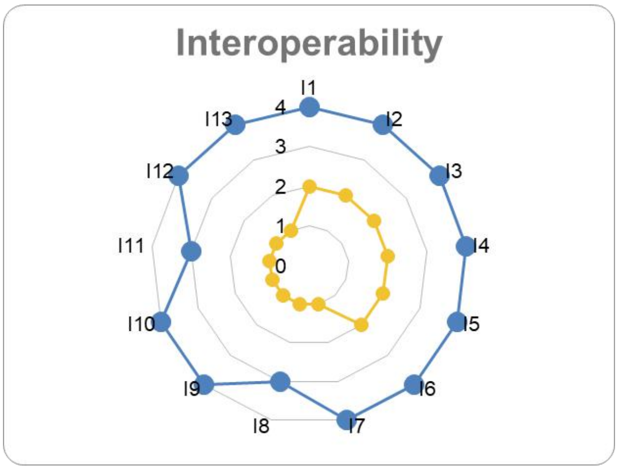
Roadblocks: The demonstrator did move to a new information system, but change in the data structure is extremely costly in such an information system. Therefore, at the moment possibilities are being evaluated how (e.g. through a data fabric architecture) to merge the new FAIRness-compliant schemas with the company's information system(s). This process is under way but is being carried out with the helo of third parties and may take a significant time.

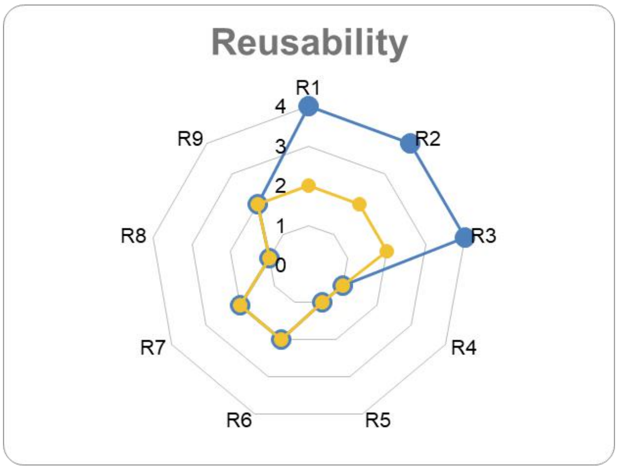
The use case is around the average of all use cases in terms of FAIR adherence. Most of the principles are in the planning phase which can benefit from the OntoCommons best practices. Below you see radar charts drawn for each dimension for your use case based on the initial survey in the first six months of the project.

Table 50: FAIR results of the initial survey of UC9 in yellow, final results in blue









2.9.8 Assessment of further benefits

A further benefit is the (the possible start of a) change of the company's culture with respect to knowledge management towards a more attentive and conscious direction.

2.9.9 Planned further developments

A further expansion of the use of semantic from the company is planned (for the similar reasons to those that started this use case), though not certain.

2.9.10 Lessons learned

Working in collaboration with a company is hard: they have precious little time to spare. It is a difficult issue to tackle, but it should be addressed, explicitly and in advance, in any future project requiring collaboration between academy and industry.

2.9.11 Other comments

The work that has been carried out confirms, on one hand, the difficulties in developing ontologies when one cannot completely reuse previous work, on the other, the potential usefulness that semantic technologies can have in knowledge management.

2.10 Demonstrator 10: Data Integration and Interoperability in Manufacturing (Halcor)

2.10.1 Brief description and visual representation

The use case focuses on the development of data ontologies that will serve as a foundation for a comprehensive data-driven decision support system for the procurement of raw materials (billets) for copper tube production plants. The goal of this use case is to unify data from different departments and entities involved in the procurement process, enabling knowledge preservation, standardization, and ultimately, data integration and interoperability. The project's main objective is to demonstrate the application of semantic technology in representing complex processes and capturing the expertise and knowledge of individual experts. An overview of the procurement process is given in Figure 26.

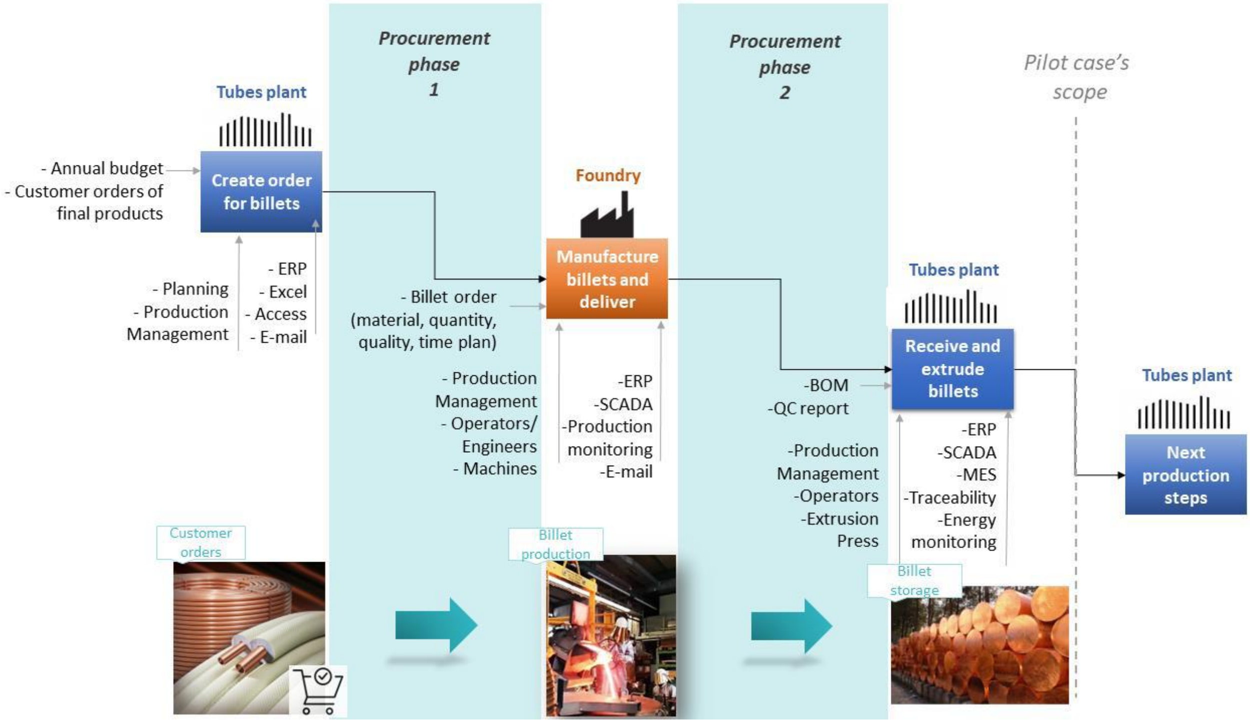


Figure 26: An overview of UC10

In brief, following the above visualization, the procurement process starts in the Copper Tubes Plant with the receipt of customer orders for final products and the annual budgeting process. These inputs are translated into daily and weekly production needs for billets, which are subsequently used to place orders for billet production at the Foundry. The produced billets are then delivered back to the Copper Tubes Plant, where they serve as raw material to produce copper tubes. Depending on the final product properties different qualities of billets are selected.

The project's future vision entails the creation of an ontology-based procurement system for billets that is interconnected with process ontologies. This system will serve as the foundation for the development of a Smart Decision System capable of optimizing product quality, reducing manufacturing costs, and minimizing environmental impact.

Under Halcor's use case, a domain ontology has been developed to represent the procurement process. Due to the lack of domain ontology related to the procurement process, a corresponding ontology was created in advance. This ontology was built upon the upper-level ontologies called BFO (Basic Formal Ontology) and IOF

Core (Information Object Ontology Framework). Additionally, two separate application-level ontologies were created to represent the various entities involved in the procurement process at each plant, namely the Copper Tubes Plant and the Foundry.

In order to achieve this objective, Halcor will provide information regarding the organization's procurement process, including the individuals/departments involved, locations, documents, data, and other relevant aspects. This information will be represented and visualized using diagrams to illustrate the relationships between these elements.

To fulfil this, the following steps should be included:

- Step 1) Specification of Actors
- Step 2) Specification of Procurement Process
- Step 3) Visualization of Procurement Process in Information Flow Diagram
- Step 4) Inclusion of specified actors and inputs in each step/ action of diagram

2.10.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 51: Ontologies and tools of UC10

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	All data collected related to actors and subprocesses of the procurement process have been utilized in the developed ontology pipeline.	BFO		IOF Core		Billet Procurement (In-site developed domain-level ontology)	X	Protegé	

Table 52: self-developed ontologies and tools of UC10

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
Domain-level ontology	Billet Procurement	A domain-level ontology based on the TLO called BFO and MLO called IOF Core. Its role is to represent the procurement process, specifically	This ontology is not publishable due to intellectual property limitations.

		addressing how the two separate plants communicate for the order and delivery of copper billets. Additionally, this ontology incorporates terms that are common to both plants.	
Application-level ontology	Copper Tubes Plant	An application-level ontology adhered to the domain-level. Describes the subprocesses related to Copper Tubes Plant.	This ontology is not publishable due to intellectual property limitations.
Application-level ontology	Foundry	An application-level ontology adhered to the domain-level. Describes the subprocesses related to Foundry.	This ontology is not publishable due to intellectual property limitations.

2.10.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 53: demonstrator development steps of UC10

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Specification of Actors	Completed in a first stage – fine-tuning and finalization pending	Elaborated in *lessons learned*	Possible revision till the end of the project.

2	Specification of Procurement Process	Completed in a first stage – fine-tuning and finalization pending	Elaborated in *lessons learned*	Possible revision till the end of the project.
3	Visualization of Procurement Process in Information Flow Diagram	Completed	---	Possible revision till the end of the project.
4	Inclusion of specified actors and inputs in each step/ action of diagram	Completed	---	---
5	Examine with the guidance of experts the compliance of BFO and IOF Core ontologies to the use case.	Completed	---	Possible revision till the end of the project to check for updates of the ontologies.
6	Search with the guidance of experts a suitable domain ontology.	Completed	---	---
7	Search and analyse documented knowledge about existing procurement systems related to industry in order to extract top terms, thus, to create classes and individuals for the application ontology development.	Completed	---	---
8	Interview with experts and collect their feedback about the application ontology.	Completed	---	---

2.10.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 54: Key Performance Indicators progress of UC10

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	TRL change	– *1/1+(TRL_end-TRL_start)*	(0,1]	TRL 4
FAIR improvement	average score in each FAIR dimension	– For each dimension, average based on final surveys	[0,4] for each dimension	Application of FAIR principles is not feasible at this state.
Quantity	Number of ontologies hosted	– The ontologies can be stored only in-site due to intellectual property limitations.	---	Three ontologies are developed: One domain level for the procurement process and two application-level for the subprocesses of each plant.
Coverage	Number of domains (e.g. production, automation software, etc) + number of tools (e.g. TIA portal)	---	---	The ontologies developed are focused on procurement. Protégé tool has been used.
Adoption	Number of users/contributors for OL	---	---	The BFO and IOF Core ontologies have been utilized.
Standardization Improvement	Improve standardization of terms and meaning of concepts in order to additionally improve communication	---	---	The representation of the complexity of a process is a useful step to possibly

	among distributed departments.			identify factors that may be hindering the process, however, to make changes it's needed to activate additional internal processes.

2.10.5 TRL Assessment

In the overall view, the TRL has increased from 3 for the initial assessment to 4 at the end of OntoCommons.

2.10.6 FAIR Assessment

Halcor's use case is currently in the early stages of implementing FAIR principles in their data and metadata practices. At present, none of the FAIR principles can be considered fully implemented or operational within the project. However, Halcor recognize the importance of making their data findable, accessible, interoperable, and reusable, and they aim to make progress in these areas.

2.10.7 Assessment of further benefits

In addition to the advantages of semantic technologies in terms of interoperability and traceability, the Ontocommons project provided benefits to industry professionals who had limited prior knowledge or awareness of this field. It helped them to gain a comprehensive understanding of what ontologies are, their inherent benefits, and how they can be effectively developed and utilized.

Therefore, one key benefit of OntoCommons project is its role in bridging the knowledge gap and overcoming learning barriers for semantic technology in the industry. It's important to mention that although there are various ontology development methodologies and tools available, there is currently no industry-wide standardization. Furthermore, no significant methodology or tool specific to harmonizing ontologies is available in order to wisely integrate domain- and application-level ontologies with upper-level ontologies (e.g., TLO, MLO).

The guidance provided by ontologists and semantic technology experts associated with OntoCommons has been particularly valuable. Industrial users have received expert advice on the appropriate steps to follow to effectively represent complex processes within ontologies. This guidance has helped them overcome challenges and make informed decisions during the ontology development process.

2.10.8 Planned further developments

Final validation of the developed ontologies should be considered to provide assurance in the quality and reliability of the ontologies before their future deployment. Alternatively, if conducting a full validation is not feasible, efforts should be made to raise awareness among stakeholders about the ontology validation process and available tools. This would help ensure that future users and implementers of the ontologies are aware of the importance of validation and can make informed decisions regarding their deployment.

2.10.9 Lessons learned

At the current stage, establishing connections between ontologies poses challenges due to the limited automation in processes, disconnected or poorly connected Information Systems, and a wide diversity of data format, storage structures and locations. Given these factors, achieving seamless integration and connection of the ontologies is not feasible at this time.

2.11 Demonstrator 11: Digital Manufacturing / Automation Engineering (Siemens)

2.11.1 Brief description and visual representation

The main goal of the use case is to realize a seamless integration of automation engineering data when building up complex manufacturing equipment. Our main objective is to address scenarios of reducing the efforts of factory automation engineers for accessing engineering data from various disciplines, such as electrical engineering, mechanical engineering or automation software. To that end, Siemens will develop an ontology library that covers various relevant domain ontologies as well as ontology transformations of various industrial standards. In particular, this library will cover models for assets in the domains of manufacturing and automation engineering. Based on these models, Siemens will showcase a demonstrator for the integrated access to various otherwise disparate automation engineering artifacts that are combined in a scenario in which integrated automation engineering data is being made accessible to technical users in order to ease their daily work in a heterogeneous landscape of engineering tools.

2.11.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 55: Ontologies and tools of UC11

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	*Upper Ontology for Siemens Ontology Library*	---		Industrial Data Ontology (former ISO 15926-14)		---		---	
2	*Sensor and timeseries Ontology*	---		SOSA/SSN		---		---	
3	*Quantity kinds and Unit Ontology*	---		QUDT		---		---	
4	*Ontology describing Bill of Materials*	---		---		DEXPI Ontology Planned for internal publication on	X	---	

						https://ontology.siemens.com			
5	*Ontology based on DEXPI standards for P&ID diagrams in process industry*	---		---		DEXPI Ontology Planned for internal publication on https://ontology.siemens.com	X	---	
6	*Ontology based on CFIHOS standard for industrial facilities data handover*	---		---		CFIHOS Ontology Published internally by Siemens Energy	X	---	
7	Ontology based on ISA-95 - a standard on manufacturing control functions	---		---		ISA-95 Ontology Published internally on https://ontology.siemens.com	X	---	
8	*Ontology Editing*	---		---		---		Protégé	
9	Ontology documentation	---		---		---		Widoco	
10	Ontology release	---		---		---		SIMPL CLI	x
11	*Data validation*	---		---		---		SHACL	
12	Mapping relational data to RDF	---		---		---		R2RML	
13	*Mapping csv, xml to rdf*	---		---		---		RML	

Table 56: self-developed ontologies and tools of UC11

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
O	DEXPI Ontology	---	Planned for internal publication on https://ontology.siemens.com
O	CFIHOS Ontology	---	Published internally by Siemens Energy
O	ISA-95 Ontology	---	Published internally on https://ontology.siemens.com

T	SIMPL CLI	---	

2.11.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 57: demonstrator development steps of UC11

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Evaluation of integration strategies for heterogenous (non-rdf) content	(1) Integration concept for OPC-UA data via automatic translation to rdf (2) Evaluation of BAMM [1] as a cross-company rdf standard for exchange of asset descriptions	Non-regulated semantics of OPC-UA companions prevents easy data integration	Internal Siemens anchor model developed as a technology-neutral exchange model
2	Evaluating standards for process industry for the purpose of rdf-based data integration	(1) DEXPI [2] Ontology (2) Cfihos (draft ontology aligned with ISO 15926-14 exists)	---	Both ontologies are developed

[1] BAMM Aspect Meta Model https://openmanufacturingplatform.github.io/sds-bamm-aspect-meta-model/bamm-specification/snapshot/index.html

[2] DEXPI – Data Exchange in the Process Industry https://dexpi.org/

3	Ontology Library Platform	New central Siemens-internal platform ontology.siemens.com launched with published ontologies from the building technology, production, and mobility domains	Ontology validation pipeline is still not validating the full set of basic guidelines	Implemented Implemented Ongoing
4	Ontology Guidelines	Basic ontology guidelines for Siemens internally published: naming, versioning, metadata: Development of ontology design guidelines started	---	Ontology design guidelines developed and published for: Type and hierarchy modelling, property modelling and OWL vs SHACL
5	Refactoring of PLM, automation, manufacturing and process industry domains	New structure defined and being implemented	Coordination of stakeholders/developers, high integration efforts	ISA-95 published, production industry domain refactored

2.11.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 58: Key Performance Indicators progress of UC11

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	TRL change	1/1+(TRL_end - TRL_start)	(0,1]	improved
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	All F, A, I, R improved
Quantity	Number of ontologies hosted	---	---	43 ontologies
Coverage	Number of domains (e.g., production, automation software, etc) + number of tools (e.g., TIA portal)	---	---	4 top domains after restructuring
Adoption	Number of users/contributors for OL	---	---	~ 200 users/ ~ 40 contributors

2.11.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 59: Shall requirements of UC11

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC11_RQ_01	Scale usage by enabling domain experts to take ownership of models, easy-to-use tools required	---	**Shall**	---	Partly - Domain Ontology Editor developed at Siemens Energy is being tested at Siemens

UC11_RQ_02	IP sharing and licensing across partner ecosystem necessary	---	**Shall**	---	Partly – it is planned to open source selected ontologies
Standardisation					
UC11_RQ_06	Integration of open data models and industry standards	---	**Shall**	---	Partly – Industrial Data Ontology submitted to ISO – expected publication as ISO standard in 2026

2.11.6 TRL Assessment

- Industrial Data Ontology used in Siemens projects (formerly known as ISO 15926-14) submitted to become a new ISO standard under ISO/TC 184/SC 4 (Industrial data)
- Domain ontology editor that enables development of DOs by domain experts and ensures reuse of modelling patterns from TLO and MLOs is tested for wider adoption at Siemens.

2.11.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: improved through generation of a central Siemens ontology publication platform

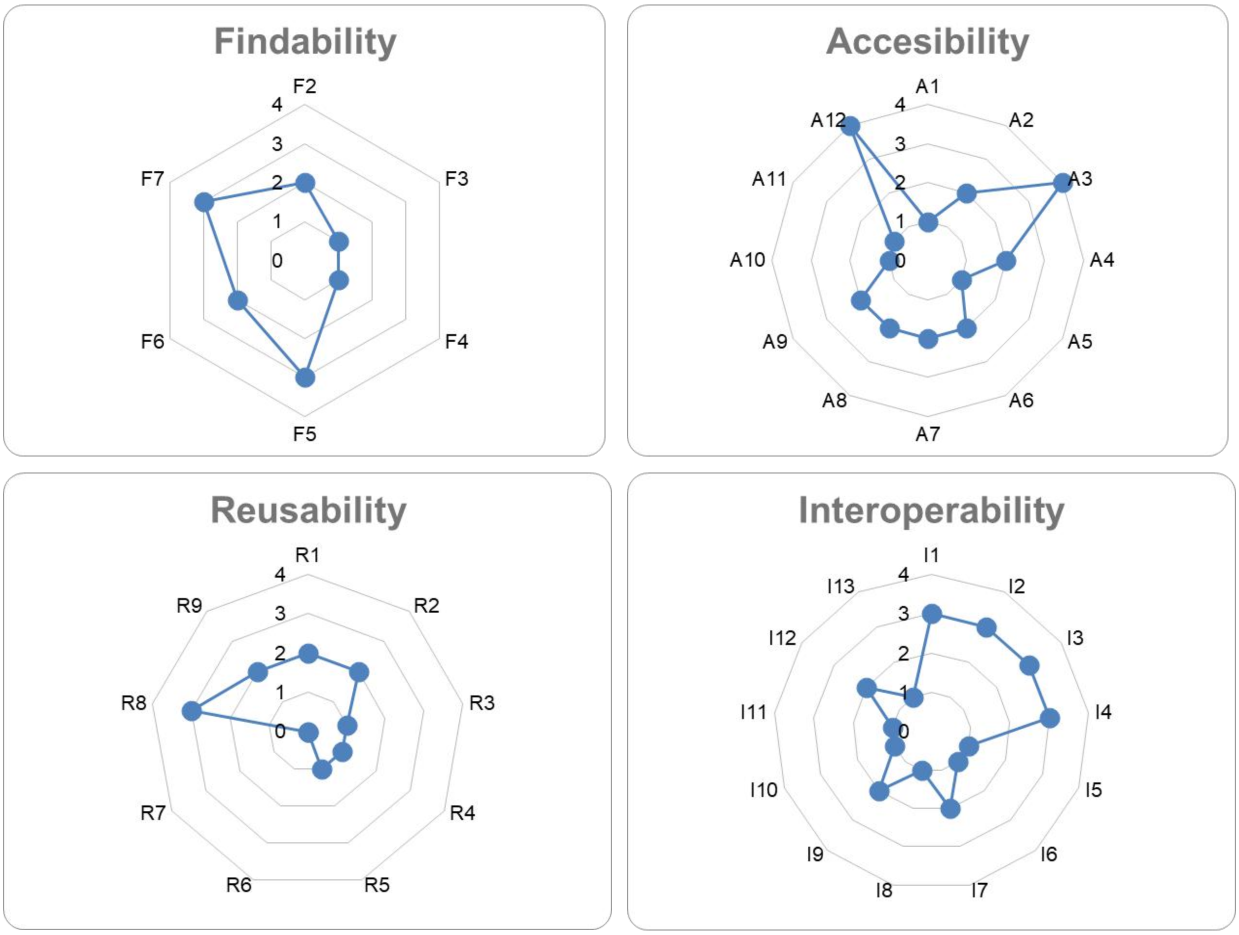
Accessible: improved - all ontology base IRIs and version IRIs are resolvable now

Interoperable: improved - most ontologies aligned with Industrial Data Ontology

Reusable: improved **-** automation software ontology planned for re-use in an electrical planning use case, base ontologies include ISO 3166 countries, ISO 639 languages (re-used across projects)

The use case is around or better than the overall demonstrator average in terms FAIR principles adoption. The use case already uses machine-understandable and linked metadata. Several accessibility and Interoperability principles are currently being implemented or in the design phase.

Table 60: Final FAIR results of UC11 in blue



2.11.8 *Lessons learned*

- Ontology modelling is hard for non-experts – tools tailored to domain experts are needed, both for generation of schemas and instance data
- Standardized methodology needed for modelling product/artefact hierarchies
- Training materials needed for modelling patterns in industrial domain (e.g., based on Industrial Data Ontology)
- Programming frameworks/SDKs and tailored visualization tools needed for manipulation of rdf-based data
- Industrial data Ontology and Asset Information Modelling Framework that are planned as parts of a new ISO multi-part standard “Ontology Based Interoperability” are very promising in providing methodology and frameworks for integration of industrial standards and providing pragmatic operational information models that can be exchanged among stakeholders and managed in SDKs.

2.12 Demonstrator 12: Basajaun (Paramountric)

2.12.1 Brief description and visual representation

Basajaun project builds two demo buildings and will be supported by a software platform. This platform would benefit from having a connection to an ontology layer and to related tools to cater for interoperability with and between supply chain domains and actors.

Buildings are responsible for a great share of energy consumption and emissions from material. Basajaun supports construction and renovation of buildings using innovative wood-based materials and components. This is important considering the urgent need to tackle the energy and climate crisis. How can the different actors (architects, construction companies, building owners, forest owners, process industry actors, manufacturers) in the value chain estimate and collaborate around important information about supply and performance of relevant indicators during the process? How can they know what is really making a difference in the value chain if there is no transparency and shared knowledge about the important key indicators? Some main aspects of this concern the verification and traceability of sustainable efforts along the value chain such as certification and other sustainability measures. The Basajaun F2BDF (Forest to Building Digital Framework) is a system architecture that supports the digital value supply chain and connection between actors using semantic data principles. The architecture is shown in Figure 27.

By streaming data into this IoT enabled architecture using principles of linked data and semantic web technologies, actors can start defining and collaborating around vocabularies. Different interfaces are used to express the supply chain data connected to material streams, such as the example below using nodes and edges.

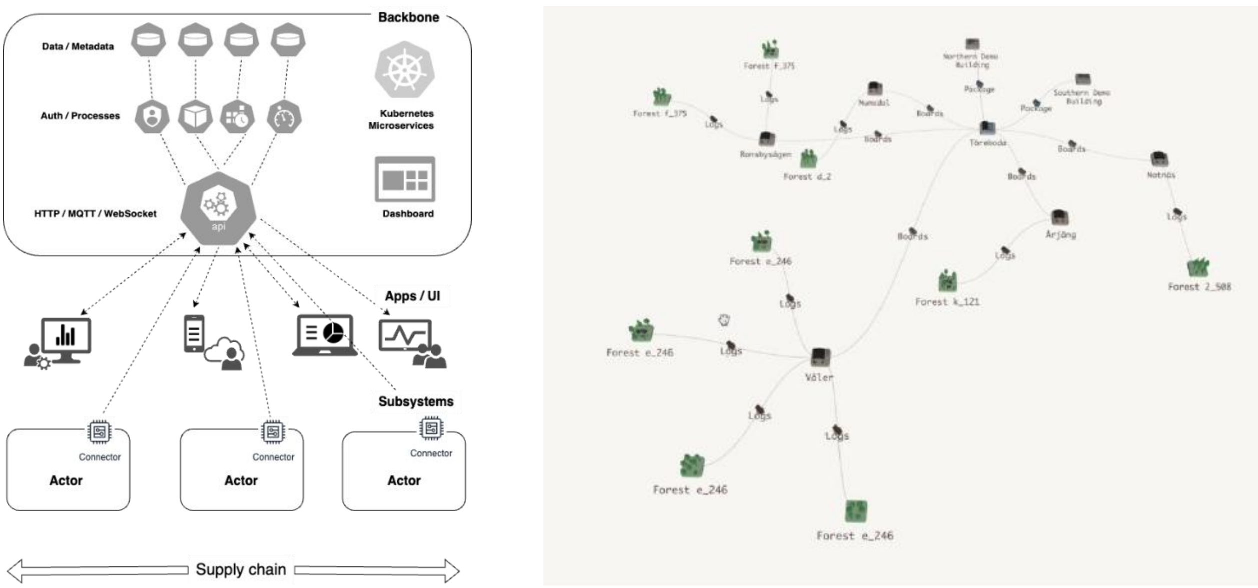


Figure 27: An overview of UC12

2.12.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 61: Ontologies and tools of UC12

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Forestry, harvesting and first transformation for wood products. Custom made forestry pipeline ontology using parts of StanForD, PapiNet and Forestand schemas, connected to SCRO	---		---		---	x	Custom application	x
2	SCRO (Supply Chain Reference Ontology)	---		Reference ontology from IOF	X	---		---	
3	BFO	(from the use of IOF)	X	---		---		---	
4	Building information modelling (BIM)	---		---		Extended ifcOWL, https://content.iospress.com/articles/applied-ontology/ao210254		Custom application	X

Table 62: self-developed ontologies and tools of UC12

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)

Application-level ontology co-creation tool for engineered timber value supply chain	Woodlaunch	Brings together actors along the value chain to analyze data and semantic connection using innovative visualization	https://www.proceedings.com/069179-0586.html
Data management platform using IoT/Digital Twin technology for linked data and federation of data between actors in the supply chain	F2BDF	A backbone for connection to subsystem / local digital twins, and actors to share data for environmental key performance indicators	https://www.proceedings.com/069179-0586.html

2.12.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 63: demonstrator development steps of UC12

No.	Development Step	Progress	Issues (if any)	Your plans given in the last survey, just as a reminder, do not put further information in.	Estimated final state at the end of OntoCommons in 10/2023
1	Data collection from actors	Started	Data is not in a standard format. Decision on data unification is tedious	Use custom visualisation tools to show data collection progress	---
2	Implement a selection of ontologies for direct integration in the platform	Started	How to make this useful for non-technical users. What	Make a first version on how to show and navigate	---

			technology to build upon	types in an intuitive way	
3	Select a few KPIs for initial implementation	Done	---	Evaluate from the collected data what would be most relevant as selection	---
4	Create a registry of indicators in the platform for the user to select between	Done	---	---	---
5	Implement a basic workflow for data management and validation	Done	---	---	---
6	Connect actors in the supply chain through a collaboration workflow	Done	---	---	---
7	Validate effectiveness in horizontal flow and evaluate the performance	Not started	---	---	Deadline March 2024

2.12.4 KPIs Assessment

In use case 12, improvements were achieved in the KPIs FAIR and TRL. Improvements were also targeted in the areas of "Actor collaboration improvement", "Supply chain improvement", "Increase in transparent processes", "Tools improvement" and "System interoperability improvement". However, these could not be quantified in the last period of the project, as the work continues.

2.12.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 64: Shall requirements of UC12

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023

Tools for ontology					
UC12_RQ_T_01	Composition, alignment and extensions of ontologies in a value chain scope	The tools shall support a workflow for continuously assessing and updating the current selection of ontologies.	**Shall**	---	planned (project not yet finished)
UC12_RQ_T_02	Collaboration of multiple stakeholders	The ontology development tool shall allow different stakeholders to work simultaneously.	**Shall**	---	planned (project not yet finished)

2.12.6 TRL Assessment

In the overall view, the TRL has increased from 2-3 for the initial assessment to 5-7 at the end of OntoCommons.

The ontology adoption of the Basajaun project may be implemented as a layer on top of existing layers. This means that the TRL for the overall platform might differ from the implementation that specifically targets the ontology functionality. It can be considered an extra feature of the system that enables actors to collaborate with existing schemas to quickly align or get started with new processes. The underlying system is expected to span between TRL5 and TRL7 depending on where in the supply chain the value proposition is fit to current market demands. The prioritisation will lie in the actors that invest in digitalization and integration with the system. When it comes to the ontology layer, it is expected to reach a slightly lower readiness level. As an example, integration between building construction and facility management could be a sub chain suitable for faster adoption using the existing digitalization in construction using BIM systems with IFC based ontologies and recent advances in smart building technology using BOT ontology as an example.

Having focus on a specific application and user interface that more generally connects actors along the supply chain in an information model co-creation setting, we have been able to reach higher TRL. This takes into account any kind of data referring to how flexible linked data can be used. However, this only considers a lighter educational level of semantics in the data points that the actors collaborate around. We settled at this point to defined "is a" relationships and starting to map "subclass of" relationships. A full ontological level is not reached at this stage. When reaching for full ontological implementation in the system, this might not be exposed clearly for the end user of the produce, merely a way to internally validate data and semantic connections, but also provide some aid for the user to understand logical concepts without necessarily mentioning the ontologies.

2.12.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable: All the principles in the Findable dimension have been implemented and 3 of them have been improved.

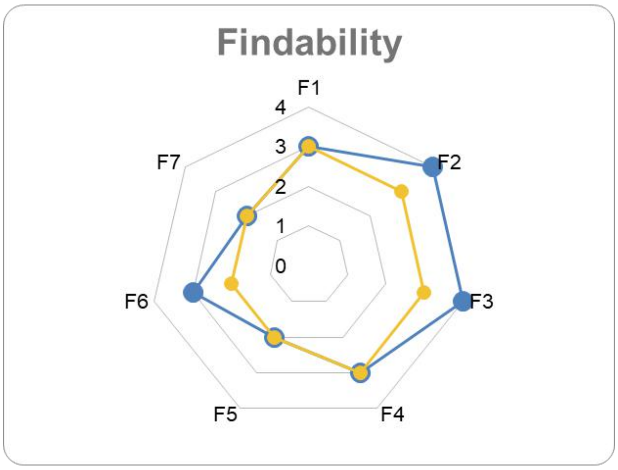
Accessible: All the principles in the Accesibility dimension have been implemented and 7 of them have been improved.

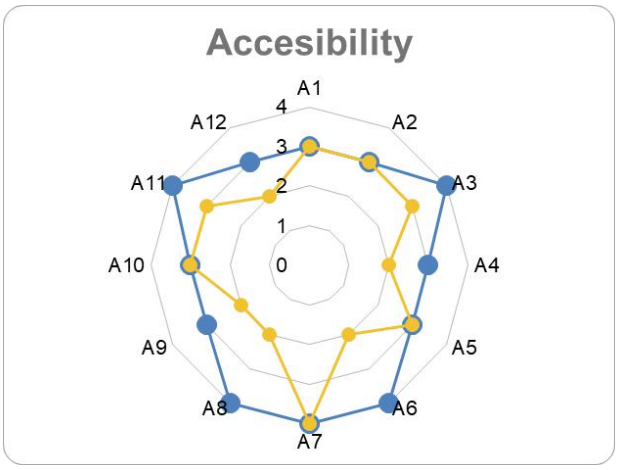
Interoperable: All the principles in the Interoperability dimension have been implemented, 6 of them have been improved and 5 have been fully developed.

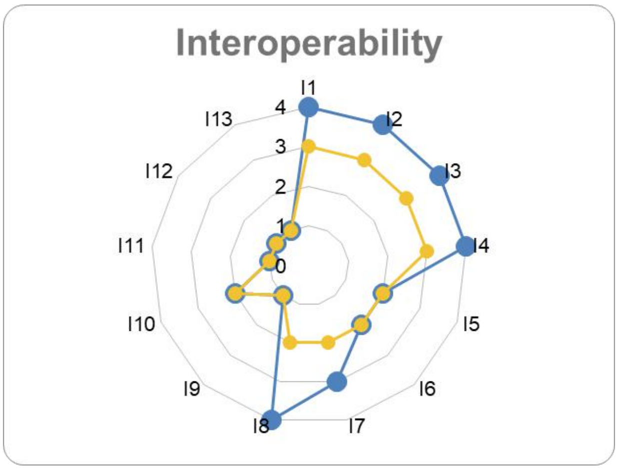
Reusable: All the principles in the Reusability dimension have been implemented and 5 of them have been improved.

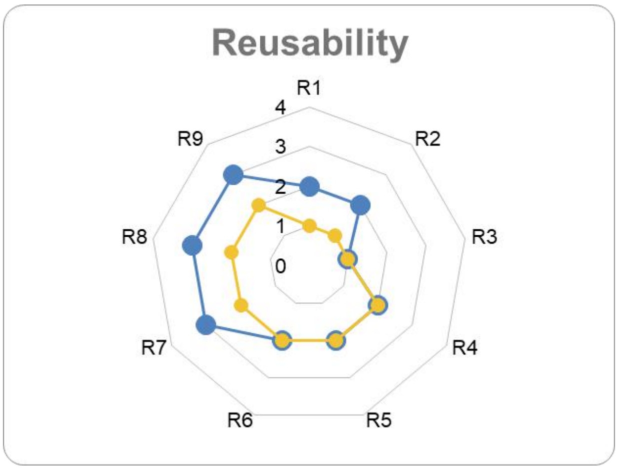
The use case has no not applicable principle and many principles in Findable, Accessible and Interoperable dimensions are in the implementation stage. Given that the Reusable dimension is mostly in the planning phase, we expect a significant improvement as the use case develops further at that dimension.

Table 65: FAIR results of the initial survey of UC12 in yellow, final results in blue









2.12.8 *Assessment of further benefits*

Using a well-defined and complex connection between several ontologies we can explore some functionalities with generative and predictive AI to bring forward complex views of existing and generated instances.

2.12.9 *Planned further developments*

There is still work to be done on connecting domain level ontologies to complete the decision support functionality from several perspectives of the supply chain. Having worked with SCRO/IOF/BFO and the extended ifcOWL/BFO we have some starting points to build upon.

2.12.10 *Lessons learned*

Keep the technical discussions on appropriate level when talking to people from the industry. For example, talking about ontologies, data models and data validation might be counterproductive. Industrial partners must know and understand why added complexity is needed and what direct problems the suggested solution might solve. If the solution is based on future gains given some investment, this should be discussed as mutual understanding from the beginning. Providers of technology (we) must realise that elegant technical solutions and concepts might not be practically applicable at current circumstances and that intermediate solutions might be needed.

Also, to consider is the domain traditionalists vs digitalisation enthusiasts. The covered domains in this demonstrator are traditional and slow changing. At decision level the priorities could be to keep existing procedures and processes, despite ESG drivers. Talking to the wrong people on digitalisation with the aim of automation can have an opposite effect. Especially talking about the potential of applied ontologies. It can have the same effect as AI discussions sometimes have.

2.12.11 *Other comments*

The Basajaun use case is very complex in its need to connect many domains and actors along the supply chain is challenging, and time demanding. An ontology ecosystem can help in this, where principles around harmonisation and alignment should be accessible in tools and guidelines.

Connections between ontology layers can give a flexible way of thinking about this as a process, especially structuring the ontology work from the beginning as a process for involved to learn, embrace and mature in their knowledge as well as being able to assess existing ontologies or improve custom ontologies.

2.13 Demonstrator 13: Life Cycle Sustainability Assessment of a Chemical Product (BASF)

2.13.1 Brief description and visual representation

BASF is part of the ORIENTING [3] H2020 funded project, which aims at integrating different sustainability topics into one single operational methodology for Life Cycle Sustainability Assessment (LCSA). For aligning data structure and conceptually integrate data across the different sustainability topics, the ORIENTING LCSA ontology (ORIONT) was developed. ORIONT builds on the BONSAI ontology (BONT) by Ghose et al.[3]. Within ORIENTING, ORIONT was used as guidance to, for example, assign the differently named data points used in the different sustainability topics to the same or equivalent classes. This was mainly achieved by an ontology visualisation, which was discussed with topic experts within ORIENTING, and is described in one of the project deliverables that will be available in the project´s website[4] and CORDIS[5] once approved.

BASF as an industrial case study partner will perform an assessment of one of their products and thereby test the ORIENTING methodology and the ORIENTING integration tool. This involves primary and secondary data collection. This data has not been linked to ORIONT but is collected and maintained within BASFs own data system.

2.13.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 66: Ontologies and tools of UC13

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	---	---		---		ORIONT ontology. The ontology was used to guide discussions about the integration of different sustainability domains into a common conceptual (data)		---	

[3] ORIENTING has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958231

[4] https://orienting.eu/

[5] https://cordis.europa.eu/project/id/958231/results

						structure for Life Cycle Sustainability Assessment (LCSA).			
2	---	---		---		BONSAI ontology. The ontology was used to build upon as it itself builds on previous ontologies in the sustainability field.		---	
3	---	---		---		---		PowerPoint. PowerPoint was used to create the ORIONT ontology visualization	
4	---	---		---		---		Python and the Owlready2 package. These tools were used to test a transformation of information in Excel to an ontology format.	
5	---	---		---		---		Protégé. Protégé was used to test the technical implementation of the ORIONT ontology (there was no full technical as this was not in	

								the scope of the project)	
6	---	---		---		---		For data collection and calculations: In-house development Various LCA related tools (e.g., Gabi) Excel	

Table 67: self-developed ontologies and tools of UC13

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
O	ORIONT	The ORIONT ontology describes the common conceptual (data) structure for the ORIENTING Life Cycle Sustainability Assessment (LCSA) and its different domains (environmental, social, economic, material criticality, material circularity).	https://orienting.eu/wp-content/uploads/2022/10/ORIENTING_D3.1_Annex-A_ORIONT_V1.zip (note that this is only a test implementation, the main deliverable is a descriptive report as a full technical implementation was not in the scope of the ORIENTING project)

2.13.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 68: demonstrator development steps of UC13

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Data collection	Two alternative products will be compared, one alternative contains a biomass balanced product derived from a recycling process. A n environmental, cost and social Life Cycle Inventory (LCI) dataset in Excel format has been produced.	There are confidentiality issues associated to the disclosure of the economic data. The appropriate handling of this is being discussed in the context of the project, examples of this include: aggregation of costs factors and using prices of raw materials.	Data collection completed.
2	Data processing	The collected environmental data (in Excel) has been processed so that it can be modelled in GaBi. Afterwards data can be extracted	N/A	Completed

		from GaBi and further processed in Excel. The economic and social data collected has been further processed in Excel.		
3	Data implementation	The indoor paint product system has been modelled in GaBi to obtain the life cycle impact assessment results. The results of the LCIA have been extracted to Excel and handled in Excel.	N/A	Completed
4	Connection of case study to ORIONT ontology	None, it was out of the project scope, and we did not have the capacities to push this further.	N/A	Current state: no connection

2.13.4 KPIs Assessment

In use case 13, improvements were achieved in the KPIs FAIR and TRL. However, further improvements are expected as the use case continues after the end of OntoCommons.

2.13.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 69: Shall requirements of UC13

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Development of ontologies					
UC13_RQ_D_01	Ontology Scope	Ontology shall contain definitions to a range of entities that are relevant to and provide agreeable coverage of the selected domain.	**Shall**	---	Complete (since definitions will be used in other deliverables due by 10/2023. However, the transfer of final definitions to the ontology is not planned)

2.13.6 TRL Assessment

In the overall view, the TRL is 1-2, meaning basic research and/or prove of feasibility level.

2.13.7 FAIR Assessment

The ORIONT ontology was developed guide ORIENTING project internal processes. Although it was entered in Protégé, it is not yet findable. The current state of the ontology is accessible via https://orienting.eu/wp-content/uploads/2022/10/ORIENTING_D3.1_Annex-A_ORIONT_V1.zip. Interoperability would still need to be tested and reusability be proved.

2.13.8 Planned further developments

The case is finished.

2.13.9 Lessons learned

Concerning the ontology:

- The development of the domain ontology (for Life Cycle Sustainability Assessment according to ORIENTING) was feasible at a simple level visualizing classes and relationships. A further technological development in a fully online accessible and reusable ontology allowing to produce knowledge graphs would need further efforts and help from ontology experts.

Concerning data collection and processing:

- Primary and secondary data are needed to be implemented with different levels of details known. Only some products in the final paint are produced by BASF. The biomass balance approach is a new approach to address materials from the circular economy (i.e., products derived from a recycling process) and needs further understanding. The biogenic carbon uptake is not fully established in the PEF methodology and therefore it will be implemented according to ISO 14067. The indoor paint will stay for a longer time on the wall which can have a positive contribution to the reduction of GHG emissions.
- The details of costs data are difficult to provide due to confidentiality reasons and availability reasons.
- Social aspects will be handled on a qualitative level to create meaningful information that can be compared to each other and that give results that can be interpreted and used.

The overall aggregation of the different types of data will be a challenge in the LCSA. Normalization and weighting approaches are not fully implemented and will be tested.

2.14 Demonstrator 14: Architecture design and ontology definition for Onboard Maintenance System of Aircraft (COMAC BATR)

The last update of the demonstrator can be found in deliverable D5.5. Some of the demonstrators have different schedules than the OntoCommons project, and, therefore, progress and reporting on the demonstrator might differ from the surveys within OntoCommons.

2.15 Demonstrator 15: Monitoring human operators' safety and well-being via semantic data integration in an automotive manufacturing setting (CPSosaware Consortium)

The last update of the demonstrator can be found in deliverable D5.5. Some of the demonstrators have different schedules than the OntoCommons project, and, therefore, progress and reporting on the demonstrator might differ from the surveys within OntoCommons.

2.16 Demonstrator 16: Food Knowledge Graph (Dynaccurate SARL)

2.16.1 Brief description and visual representation

The demonstrator would like to develop a proof-of-concept knowledge graph which is geared for additive or compound discovery in the sector of food processing or agri-science. An example could be using an ontology to link databases available from the European Institutions (such as the Additive Database from DG Sante, the substance database from ECHA, the PubChem database from NIH etc.) with the objective of discovering substitute compounds to be used as additives, as well as potential usage limits etc. The main goal of the use case is to keep ontologies in the knowledge graph consistent after updates and maintenance. An overview of the use case is given in Figure 28.

Figure 28: An overview of UC16

2.16.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 70: Ontologies and tools of UC16

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	---	AgroVoc		---		---		MetaGraph 2.0	
2	---	EuroVoc		---		---		---	
3	---	SNOMED CT (may be used)		---		---		---	
4	---	---		---		FOODON Ontology		---	
5	---	---		---		---		Protege	
6	---	---		---		---		DyPharm / DyMap	x

7	---	---		---		---		Dynacurrate AI	x

Table 71: self-developed ontologies and tools of UC16

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
DyMap	DyMap	Semantic Interoperability tool for aligning ontologies	https://www.dynaccurate.com/dymap

2.16.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 72: demonstrator development steps of UC16

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1 and 2	Load an ontology or an ontology subset	Two compatible Ontologies are now loaded, being Agrovoc and Eurovoc	None	Complete
Load counter party ontology	Initial analysis of ontologies have been performed, and we selected to run a demo using Eurovoc against Agrovoc	We initially planned to use FoodOn to perform the tests, but found that it is still incomplete and lacking mappings. We have now loaded Agrovoc and Eurovoc	None	Complete

3	Load the mappings in a .csv file in SKOS format	The load is complete. Rather than seeking mappings, we have experimented creating our own mappings with a new tool.	There are some small changes we will make to the tool, but in fact the ingestion and mappings has worked very well.	Complete
4	Load an updated ontology or ontology subset, which will 'break' the mappings	We have successfully run the AI on the Eurovoc with excellent results. However, the mappings between Agrovoc and Eurovoc are quite stable.	We have not yet found an older version of Agrovoc. We would benefit greatly from more expert input from the food science domain.	Complete

We moved away from using FoodOn and other ontologies mapped to it. The main reason is that we were able to only find the current version of FoodOn which in itself was lacking. We found several codes without any information (labels, description, hierarchy). Our tool requires this type of information to track changes and propose corrections to mappings, and thus would not be optimal to be used with FoodOn.

Instead, we have decided to use Eurovoc and Agrovoc, since we could find older versions from Eurovoc and its alignment to Agrovoc. This was successful, but the ontologies are fairly stable in the food domain, so there are not many changes which would provide a robust testing of our technology.

However, we can also now introduce new ontologies, such as SNOMED CT, as well as simulate likely changes. We are also now seeking to work with a real-world use case, such as ingredient or compound tracking and substitution, in line with the needs of a food (or food additives or food packaging) producer.

Overall, we found the mapping operation to be highly successful.

2.16.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 73: Key Performance Indicators progress of UC16

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	TRL change	TRL 6 to TRL 7	(0,1]	TRL 8
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	Improvement
Valid mapping of two ontologies by domain experts	Not yet achieved	Mappings are being produced for validation. Awaiting review of domain expert	[0,4] for each dimension	Conducted by non-domain experts
Drastic reduction on time spent on maintaining knowledge graphs in contrast to manual maintenance	Partially achieved, but not yet validated	Initial mapping and remapping functions are working satisfactorily in first review (awaiting validation) Some more technical to be undertaking to optimise workflow.	---	TRL 8 This worked exactly as envisaged

2.16.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 74: Shall requirements of UC16

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					

UC16_RQ_U_01	Reuse of existing ontologies	To provide semantic interoperability, our case study should be re-using ontologies as far as possible.	**Shall**	Validated	Complete
UC16_RQ_U_02	A variety of different ontologies should be mapped	Mapping existing ontologies provides wider utility and proof of concept of the case study	**Shall**	Validated	Complete
Maintaining/extension of ontologies					
UC16_RQ_M_01	Easy maintenance of ontology	This is a key objective of our project – the idea is that our mappings should be automatically updated based on top changes to existing ontologies / terminologies, to show how complex linkings can be managed in the long-term	**Shall**	Validated	Complete
Tools for ontology					
UC16_RQ_T_01	Automated remapping (alignment) of ontologies	The Dynaccurate AI will be used to examine and remap changes to the Knowledge Graph based	**Shall**	Validated	Complete

		on changes to the multiple ontologies in scope			
UC16_RQ_T_02	Producing interoperable results	Tools for ontology development should produce interoperable results (i.e., following standards) that can be used by other tools in the workflow	**Shall**	Partially validated	Partly – certainly for Eurovoc/Agrovoc, the results are Interoperable. However, there are not many other mature ontologies
Standardisation					
UC16_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards, especially in choice of interoperable file types conforming to semantic web norms.	**Shall**	Achieved	Complete

2.16.6 TRL Assessment

In the overall view, the TRL has increased from 5 for the initial assessment to 8 at the end of OntoCommons.

2.16.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

An initial FAIR assessment was not provided. The shown values are the final state at the end of OntoCommons.

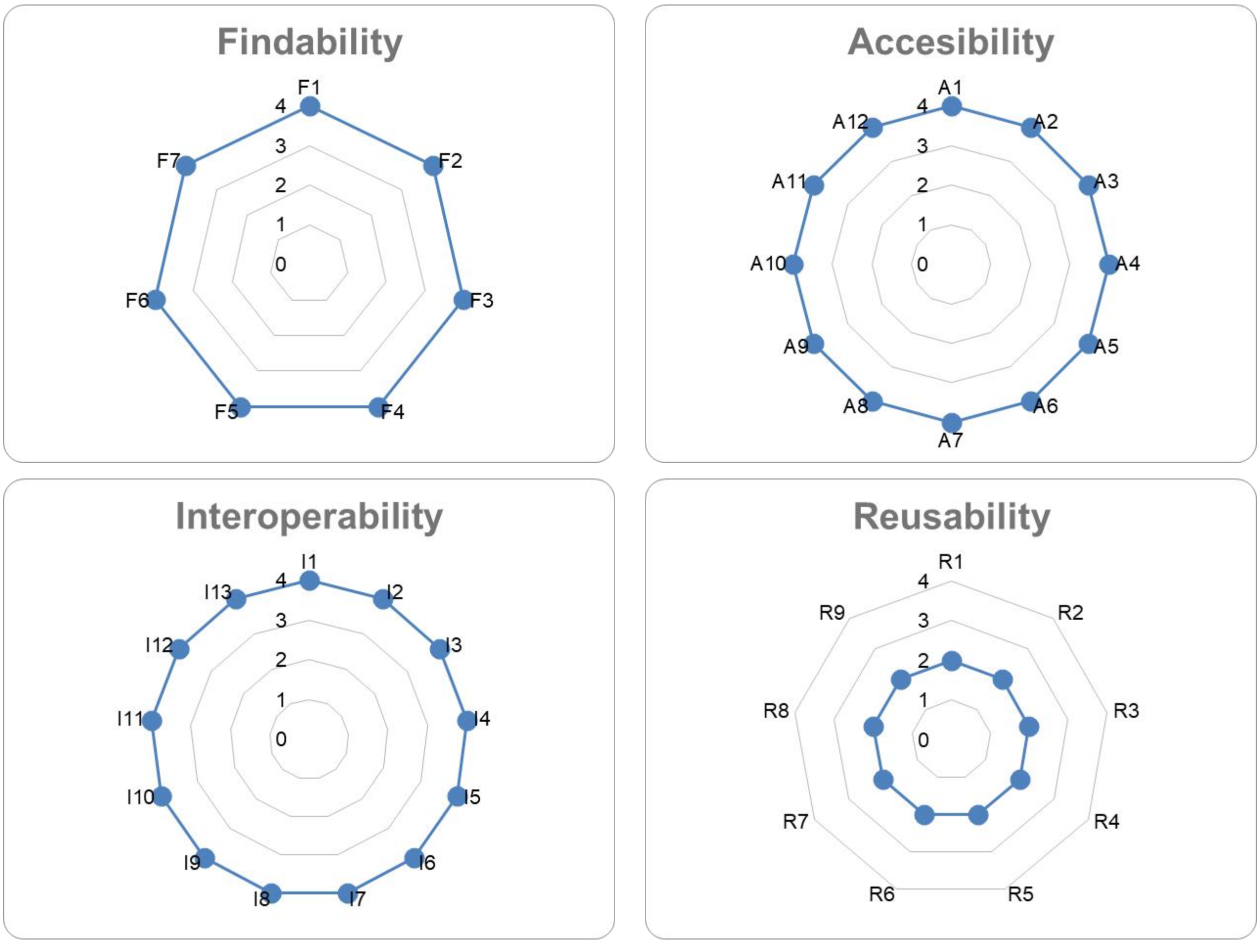
Findable: All the principles in the Findable dimension have been fully implemented.

Accessible: All the principles in the Accessible dimension have been fully implemented.

Interoperable: All the principles in the Interoperable dimension have been fully implemented.

Reusable: All the principles in the Reusable dimension have been implemented.

Table 75: Final FAIR results of UC16 in blue



2.16.8 Assessment of further benefits

The use case functioned as a good case study for commercial use.

2.16.9 Planned further developments

There are further developments planned, but these are confidential.

2.16.10 Lessons learned

While we have shifted to from Foodon to Agrovoc, we are even more convinced of the use case for our technologies. Ontologies continuously evolve, and this requires affordable tools to track changes, especially at scale. This rewards the investment into the ontology creation and use.

At the same time, we note less maturity in food related ontologies than in (for example) other life sciences ontologies. This is to be expected, when we consider that a large-scale clinical terminology such as SNOMED CT is backed by an international organisation and licence fees.

2.17 Demonstrator 17: Using iiRDS in the industrial internet of things (IIoT) with Siemens Industrial Edge (Siemens AG)

The partners implementing this use case have informed us that it has been finished in the meantime. Therefore, there are no changes compared to the status already demonstrated in Deliverable D5.4. Thus, the results presented there are the final ones.

2.18 Demonstrator 18: IKEA Knowledge Graph (Inter IKEA Systems)

2.18.1 Brief description and visual representation

IKEA holds a lot of knowledge and understanding of people's lives at home, needs, wishes, dreams, and problems, as well as solutions to those. This knowledge is spread out and stored in data silos. In order to, serve IKEA's digitalisation transformation efforts, the IKEA Knowledge Graph sets as its goal to connect the data and make it usable throughout IKEA's services and systems.

2.18.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 76: Ontologies and tools of UC18

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	Metaphactory							Bought ontology development tool for managing ontologies, taxonomies and manually inputted instances.	
2	SKOS	Taxonomy description							
3	Product Range Ontology					Self-developed for describing furniture and food products sold by IKEA	X		
4	Home Furnishing Ontology					Self-developed for describing interior designer knowledge	X		

5	Canvas in Metaphactory							Democratisation of creating business rules for non-technical SMEs	x
6	Data Transformation (alternative RML)							Self-developed (planned to release open source) tool for transforming JSON and CSV to RDF as an alternative RML.	x

2.18.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 77: demonstrator development steps of UC18

No.	Development Step	Progress	Issues (if any)	Your plans given in the last survey, just as a reminder, do not put further information in.	Estimated final state at the end of OntoCommons in 10/2023
1	Radical focus on data transformation only	Prototype successfully done	None	Iteratively improve mapping	Finished and prepared for release as open source.
2	SHACL validation for mapping	Does basic check of all function parameters being declared	How to check that property path objects are valid data source values?	Improve it as we progress.	Not the focus at the moment and on hold.,
3	Develop SHACL for validating output triples of ETL pipeline	Initiated		SHACL shapes are created with	First version is live. Second version will

				ontology definitions using metaphactory and saved to git. Then the team maintaining the ETL pipeline use them to validate the output. Development for validation is ongoing.	support multiple SHACL shapes depending on data pipeline. Metaphactory 5.0 can support multiple SHACL definitions and has just been released.
4	Automate data source description (JSON, CSV)	Not started		Not a priority	On hold.
5	Automate implemented functions tests	Not started		Not a priority	On hold.

We are now focusing only on SC-1 and SC-2 is changed so that we do not make use of RML anymore, but rather define our own data transformations. We have now (9/2023) successfully switched to use our own data transformation and are focusing on SC-1 and SC-3.

2.18.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 78: Key Performance Indicators progress of UC18

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	• TRL change	– TRL 6 to TRL 7	(0,1]	TRL 9
FAIR improvement	• average score in each FAIR dimension	– For each dimension, average based on final surveys	[0,4] for each dimension	

Number of consumers for knowledge in the IKG	• Human access • API access • SPARQL endpoint users	- humans: 200 - API: 5 – - SPARQL: 20		humans: +150 API: +4 SPARQL: +15

2.18.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 79: Shall requirements of UC18

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC18_RQ_U_01	Generating RML/R2RML/TARQL mapping from describing data sources	A vocabulary for describing data sources (JSON, relational database, CSV) shall be defined or available. An open-source software project shall be available to generate mapping files instead of manually creating them.	**Shall**		Complete
Development of ontologies					
UC18_RQ_D_01	Ontology Scope: IT Systems	How IT System interact with and relate to	**Shall**		Discontinued

		each other shall be covered in the range of properties. Classes shall reflect nature of different types of IT systems.			
UC18_RQ_D_03	Ontology Scope: Data Sources	Classes and properties shall reflect the structure and makeup of data sources in general such as JSON, SQL database, and CSV.	**Shall**		Complete
UC18_RQ_D_05	Ontology Scope: Sustainable Living	Classes and properties shall reflect the variety of sustainability issues and considerations that have to do with waste, energy, water and how the activities of an individual can create an impact on them.	**Shall**		Discontinued
UC18_RQ_D_06	Taxonomy Scope: Sustainable Living	Life at home vocabulary and sustainability topics shall	**Shall**		Discontinued

		be covered thoroughly.			
UC18_RQ_D_08	Taxonomy Scope: General Objects	All possible objects found in a household shall be reflected in the vocabulary and paired with image data.	**Shall**		Discontinued
Maintaining/extension of ontologies					
UC18_RQ_M_01	Easy maintenance of ontology	The ontology shall be easy to maintain (e.g., adding lower-level terms, additional relations, etc.) from non-ontology experts (e.g., SW engineers).	**Shall**		Complete
UC18_RQ_M_02	Usage instructions	For any ontology and taxonomy, instructions on where to download them, how to use them, how to query them shall be provided to the public.	**Shall**		Partly complete and for internal use only.
UC18_RQ_M_03	SPARQL endpoints	All ontologies and taxonomies shall be	**Shall**		Complete

		available via a secure SPARQL endpoint.			
UC18_RQ_M_04	Graph can be served via APIs	Custom made APIs built on top of the graph with SLAs fitting e-commerce shall be enabled	Shall		Complete
Tools for ontology					
UC18_RQ_T_01	Visualisation	The tools shall support visualisation of ontologies according to IKEA's visual standards.	Shall		Complete
UC18_RQ_T_02	Collaboration of multiple stakeholders	The ontology development tool shall allow different authorised and access-controlled stakeholders to work simultaneously and allow for comment threads for each node so that they can be discussed.	Shall		Complete
UC18_RQ_T_03	Version control and 4-eye principle	Any authorised stakeholder shall be able to create a change to	Shall		Complete

		ontologies and taxonomies and submit that change for a review process before the change is accepted. The proposed version may be visualised and shall be tested against life systems before it is merged as part of the master definition (e.g., like code in a git pull request and staging environment for the PR's branch).			
Standardisation					
UC18_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards (e.g., ISO).	**Shall**		Complete
UC18_RQ_S_02	EU legal framework for sustainability	Any EU requirements for reporting on sustainability shall be covered by taxonomies and	**Shall**		Discontinued

		ontologies developed in OntoCommons.			

2.18.6 TRL Assessment

In the overall view, the TRL has increased from 4 for the initial assessment to 9 at the end of OntoCommons.

2.18.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

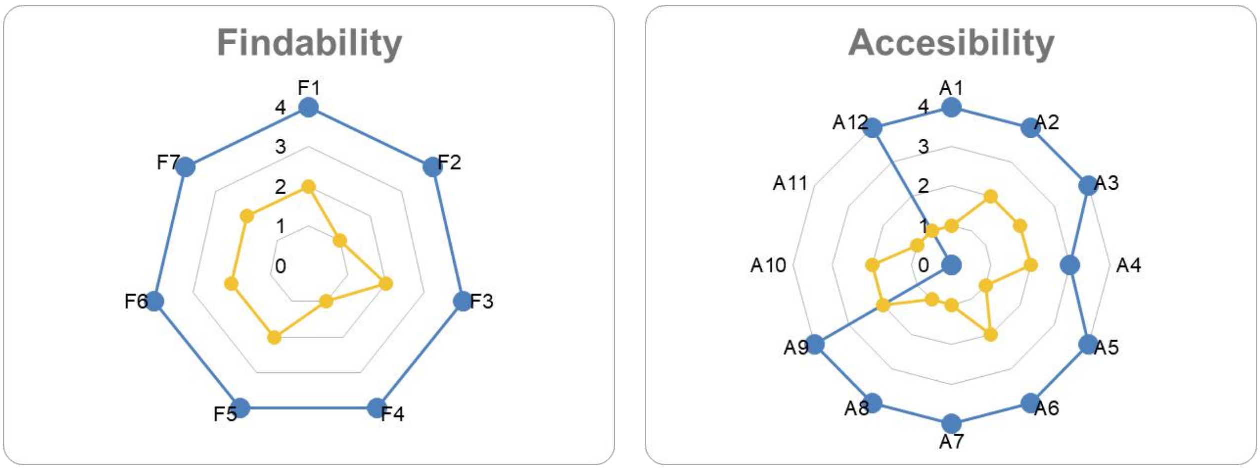
Findable: All the principles in the Findable dimension have been implemented and fully developed during the project.

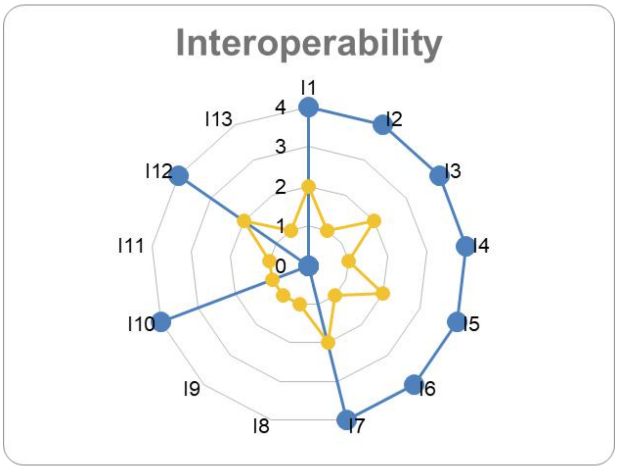
Accessible: 11 of the 12 principles in the Accessible dimension have been implemented and 9 of them have been fully developed during the project.

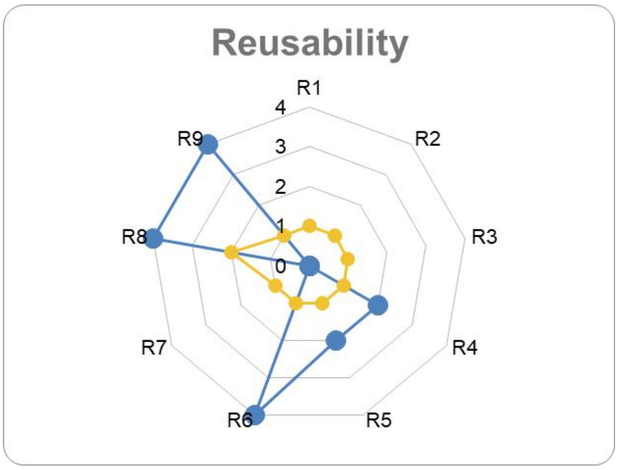
Interoperable: 9 of the 13 principles in the Interoperable dimension have been implemented and 9 of them have been fully developed during the project.

Reusable: 5 of the 9 principles in the Reusable dimension have been implemented and 3 of them have been fully developed during the project.

Table 80: FAIR results of the initial survey of UC18 in yellow, final results in blue







2.18.8 Assessment of further benefits

Our knowledge service is powering product recommendation and upselling APIs but in addition they also serve computer vision algorithms because products that are bought together are also found together, and this reduces the probability space for visual recognition thus improving their accuracy and performance.

2.18.9 Planned further developments

The IKEA Knowledge Graph is constantly being built and developed to serve more and more use cases on IKEA.com as well as for internal information purposes. In the future the product data might be completely determined by ontologies.

2.18.10 Lessons learned

At this point of the semantic web development, we can also rethink the current approach (R2RML, RML) and create new things that suit the current software development industry. Transparency through having everything in GitHub.

We have investigated our self-built data transformation process and compared it to RML. The benefits are the following:

- Hard transformation, such as IRI lookup is possible without SPARQL massaging
- Performance of executing hundreds of files is 4 times faster
- Developer friendlier

Possibility for visual authoring which enable democratisation of data transformation definitions

2.18.11 Other comments

Overall, the IKEA Knowledge Graph project is seen as a very successful project within IKEA, and it is being integrated into the digital capabilities of Inter IKEA Systems B.V.

2.19 Demonstrator 19: Materials Databases Integration using the Materials Design Ontology (Linköping University)

2.19.1 Brief description and visual representation

The Materials Design Ontology (MDO) is used for semantic and integrated access to the computational materials databases in the OPTIMADE consortium, dealing with the heterogeneity of the databases in terms of underlying data models and use of terminology. The developed ontology will be used in ontology-driven data access and data integration for application in the materials design domain. Figure 29 shows an overview of how such an application would work. The framework includes a generic approach that can generate a GraphQL server based on ontologies for data integration. In the early prototype we use Materials Project and the Open Quantum Materials Database as databases to integrate. In addition, we implement a GraphQL client to allow users to easily select queries instead of writing GraphQL queries by themselves.

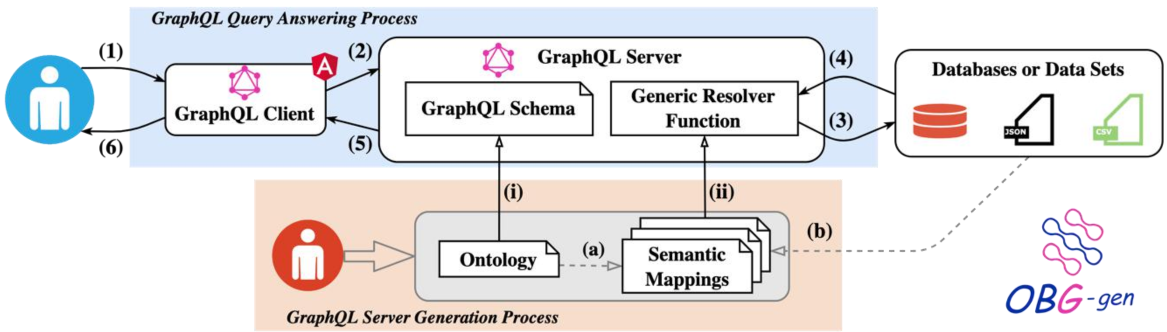


Figure 29: An overview of UC19

2.19.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 81: Ontologies and tools of UC19

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	---	EMMO				---		---	
2	---	---		PROV-O[6]		---		---	

[6] https://www.w3.org/TR/prov-o/

3	---	---		CheBI[7]		---		---	
4	---	---		QUDT[8]		---		---	
5	---	---		---		Materials Design Ontology (MDO)		---	
6	---	---		---		---		Protégé (ontology development)	
7	---	---		---		---		RepOSE (ontology debugging, completing, aligning)	
8	---	---		---		---		Phrase2Onto (ontology extension tool)	x

Table 82: self-developed ontologies and tools of UC19

Ontology / tools (O/T)	**Name**	**Description**	**Publishing link (if applicable)**
Phrase2Onto		Ontology extension tool	https://github.com/LiUSemWeb/phrase2onto
OBG-gen		Data integration framework	https://github.com/LiUSemWeb/OBG-gen

2.19.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

[7] https://www.ebi.ac.uk/chebi/

[8] http://www.qudt.org/

Table 83: demonstrator development steps of UC19

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Basic GraphQL-based framework for ontology-driven access and integration	Done	---	---
2	Extended GraphQL-based framework for ontology-driven access and integration	Concept phase	---	Investigating necessary additions to framework
3	Prototype implementation of the basic GraphQL-based framework using MDO and OPTIMADE databases	Prototype using MDO as ontology and Materials Project and OQMD data	integrate more databases	User interface done
4	Prototype implementation of the extended GraphQL-based framework using MDO and OPTIMADE databases	Not started	---	---
5	Alignment of MDO with top level ontology	In progress	---	Investigate different top level ontologies (possibly including EMMO, DOLCE, GFO and BFO)
6	Extension of MDO (if needed)	Method proposed, extension tool developed	---	---

2.19.4 KPIs Assessment

In use case 19, improvements were achieved mainly in the KPI FAIR as well as slightly in the KPI TRL. However, further improvements are expected as the use case continues after the end of OntoCommons.

2.19.5 Evaluation of shall-requirements

The following table shows details of the demonstrators' requirements based on the finale survey.

Table 84: Shall requirements of UC19

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC19_RQ_U_01	Semantic and integrated access	Provide semantic and integrated access to the OPTIMADE materials databases. We will provide a GraphQL and MDO-based interface to the OPTIMADE databases. It will allow queries using MDO terminology over multiple databases.	**Shall**	---	Partly

2.19.6 TRL Assessment

In the overall view, the TRL is 3 and did not increase until the end of OntoCommons.

2.19.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

An initial FAIR assessment was not provided. The shown values are the final state at the end of OntoCommons.

The FAIR Scores as obtained from IndustryPortal is 242.0.

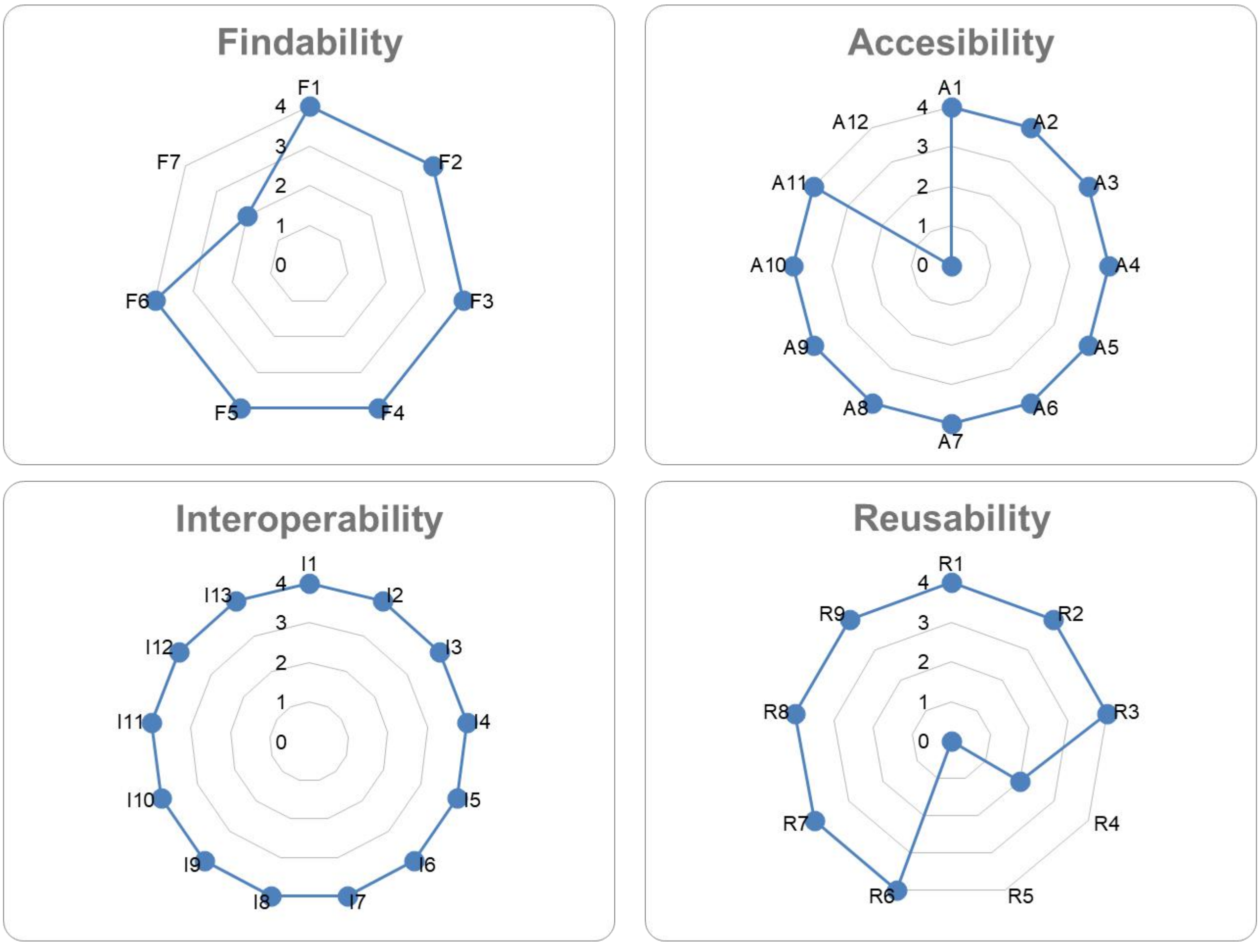
Findable: All the principles in the Findable dimension have been implemented and 5 of them have been fully developed.

Accessible: 11 of the 12 principles in the Accessible dimension have been implemented fully developed.

Interoperable: All the principles in the Interoperable dimension have been implemented fully developed.

Reusable: 8 of the 9 principles in the Reusable dimension have been implemented and 7 of them have been fully developed.

Table 85: Final FAIR results of UC19 in blue



2.19.8 Lessons learned

Based on the basic framework and prototype:

- Using the prototype all competency questions for MDO could be answered. Only using the APIs of the databases did not allow us to do this even though the necessary data was available in the databases.

- In experiments with the prototype and other systems, it was shown that the prototype can answer more questions than several of the other systems. Some of the other systems take less time in answering questions. We note that the implemented prototype has not been optimized.

For aligning our domain ontologies and top-level ontologies, e.g., EMMO, discussions are needed among developers of these ontologies to reach an agreement of what ontological commitments can be aligned. We have initiated meetings for discussion.

2.20 Demonstrator 20: Materials Characterisation Ontology (Goldbeck Consulting Ltd)

2.20.1 Brief description and visual representation

In the NanoMECommons project, the demonstrator is building an ontology of material characterisation to capture potentially any type of materials characterisation method and enable harmonisation. The starting point is a human readable metadata called CHADA and the work is to provide an EMMO compliant ontology (called CHAMEO) to capture the aspects that are in common across the different characterisation techniques. Current status is a beta version of the CHAMEO ontology.

2.20.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 86: Ontologies and tools of UC20

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1	The EMMO is used as a Top-Level Ontology. Protégé is used to visualize and navigate the EMMO ontology.	EMMO				---		Protégé	
2	The EMMO is used as a Middle Level Ontology. Protégé is used to visualize and navigate the EMMO ontology.	---		EMMO		---		Protégé	
3	The CHAMEO ontology is used as a common framework for the characterisation domain, capturing the aspects that are in common across the different characterisation	---		---		Self-developed domain ontolgy CHaracterisation MEthodology Ontology (CHAMEO).		Protégé	

	techniques. Protégé is used as a tool to develop, visualize, navigate the CHAMEO ontology.								
4	Design of the ontology and mapping with TLO/MLO					Self-developed domain ontolgy CHaracterisation MEthodology Ontology (CHAMEO		Miro board	
5	Analysis of requirements Initial creation of taxonomies	---		---		---		Tables	
6	Analysis of requirements Input for the definition of the scope of the ontology	---		---		---		CHADA document template and Competency Questions	
7	Collaborative development of specific characterisation application taxonomies/ontologies, including defining shared annotations of the classes (elucidations, comments, examples)	---		---		Nanoindentation testing domain ontology FIB-DIC domain ontology		Web Protégé	

Table 87: self-developed ontologies and tools of UC20

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
CHaracterisation MEthod Ontology (O)c	CHAMEO	Domain ontology to encompass all materials characterisation methodologies	http://emmo.info/emmo/domain/chameo/chameo

2.20.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 88: demonstrator development steps of UC20

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Definition of the ontology scope	100%	---	Complete
2	First design of the CHAMEO ontology	100%	---	Complete
3	Implementation of CHAMEO in OWL-DL	100%	---	Complete
4	Refinement iterations	Ongoing activity	---	Continuous improvement
5	Alignment with other domain ontologies/taxonomies: - Manufacturing - Materials - Models - Software - Mechanical Testing Characterisation Methods	100%	---	
6	Definition of taxonomies to be linked	80%	---	Completion wrt nanoindentation; ongoing

	with CHAMEO to specialize the generic concepts for the specific characterisation techniques			throughout the project for other application cases

2.20.4 KPIs Assessment

The following table shows details of the demonstrators' KPIs based on the finale survey.

Table 89: Key Performance Indicators progress of UC20

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	[0,1]	Minor TRL improvement, more expected in last part of underlaying project
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	Findable = 2.88 Accessible = 2.66 Interoperable = 4 Reusable = 3.53
Expressiveness	Percentage of Competency Questions (CQ) that the ontology can answer through SPARQL	Answers CQ/Total CQ	[0,1]	0.8

2.20.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 90: Shall requirements of UC20

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC20_RQ_U_01	Method specific ontology development	The CHADA ontology shall allow for the development of method specific ontologies.	**Shall**	---	Complete
Development of ontologies					
UC20_RQ_D_01	Ontology Scope	Ontology shall contain definitions to a range of entities that are relevant to and provide agreeable coverage of the selected domain. The CHADA ontology is not meant to store the measurements' fine-grained data.	**Shall**	---	Complete
UC20_RQ_D_02	Compliance with EMMO	The CHAMEO ontology shall be compliant with the EMMO TLO and MLO.	**Shall**	---	Partly
Maintaining/extension of ontologies					
UC20_RQ_M_01	Easy maintenanc	The ontology shall be easy to maintain	**Shall**	---	Not applicable and currently lack of tools to make this possible

	e of ontology	(e.g., adding lower-level terms, additional relations, etc.) from non-ontology experts (e.g., SW engineers).			
Tools for ontology					
UC20_RQ_T_01	Visualisation	The tools shall support visualisation of ontologies.	**Shall**	---	Possible with standard tools (not developed in this UC)
Standardisation					
UC20_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards (e.g., ISO).	**Shall**	---	Complete

2.20.6 TRL Assessment

In the overall view, the TRL is 3 and did not increase until the end of OntoCommons. The increase in TRL is a next part of underlaying project.

There are no significant improvements on the TRL. In the nanoMECommons project we are in the phase of defining specialised concepts for industrial use cases. Afterwards, the ontology will be used to document real experiments in lab and the TRL will be increased.

2.20.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

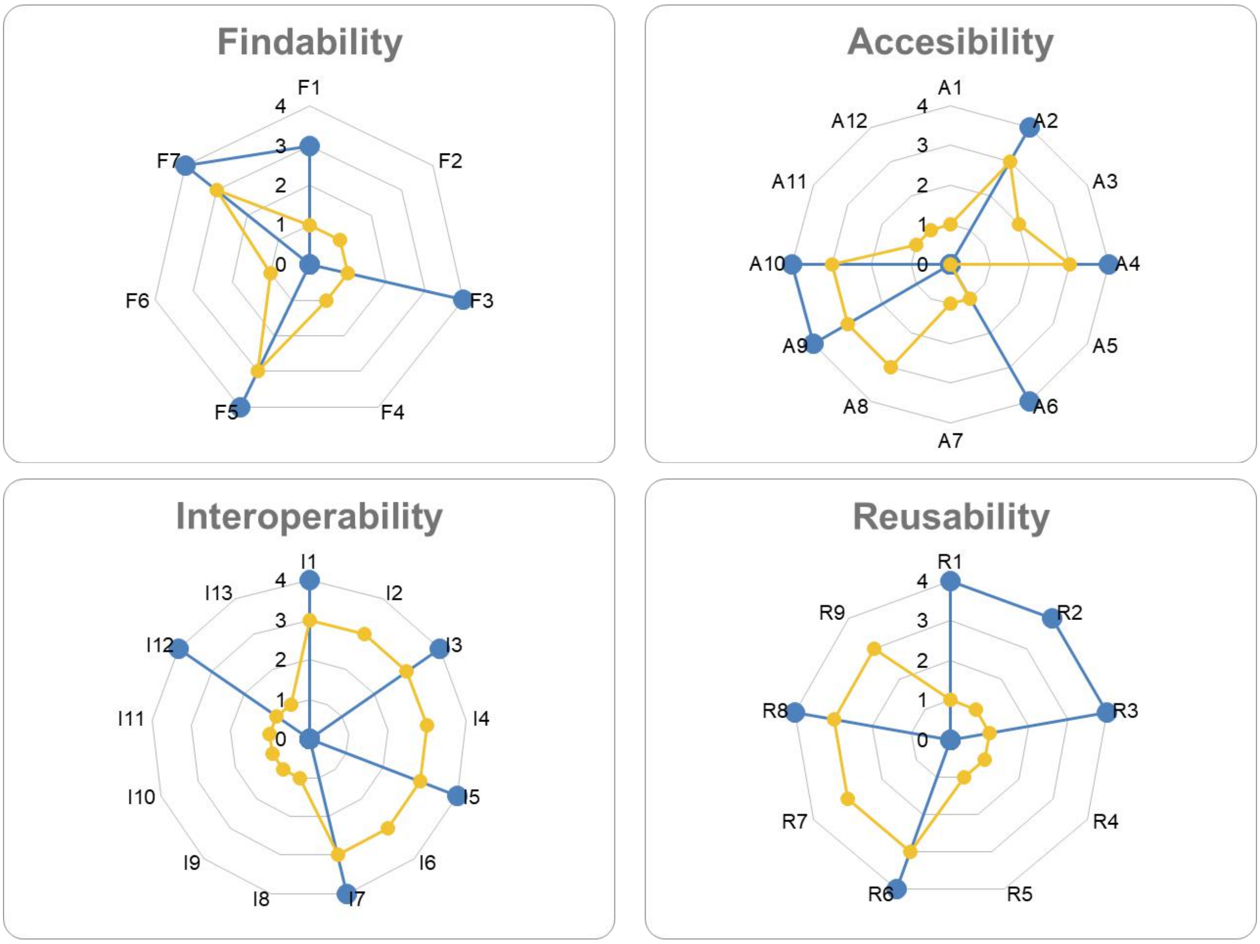
Findable: 4 of the 7 principles in the Findable dimension have been implemented and 3 of them have been fully developed during the project. Ontology metadata has been improved.

Accessible: 5 of the 12 principles in the Accessible dimension have been implemented and fully developed during the project. The ontology is available in HTML and OWL-DL (Turtle syntax).

Interoperable: 5 of the 13 principles in the Interoperable dimension have been implemented and fully developed during the project. Ontology reuses existing vocabulary for declaring metadata.

Reusable: 5 of the 9 principles in the Reusable dimension have been implemented and fully developed during the project. Description of the ontology terms has been improved.

Table 91: FAIR results of the initial survey of UC20 in yellow, final results in blue



2.20.8 *Assessment of further benefits*

Collaborative terminology development with domain experts. Introducing materials science experts to taxonomy and ontology development.

2.20.9 *Planned further developments*

Domain ontologies related to specific characterization techniques will be developed based on CHAMEO.

2.20.10 Lessons learned

The approach we have adopted to design the ontologies for materials' characterisation is based on modularisation. This allows to maximise interoperability, having the knowledge shared at different levels of abstraction. On the other hand, this requires a lot of effort to define the concepts held in an ontology like CHAMEO, which is conceived to model the aspects of a generic characterisation methodology, in order to provide a reference framework for the development of ontologies for the specific characterisation methods. One of the challenging aspects of the CHAMEO design is that its constructs should be comprehensive and at the same time generic to embrace the different characterisation techniques, avoiding constraints which would affect its applicability in some cases. Moreover, the definitions of concepts and properties must be acceptable in the different characterisation domains. The use of EMMO as a TLO framework has been useful to express the different potential perspectives on the entities in characterisation (for example the perspective of characterisation as a process or that of characterisation consisting of parts that have certain roles, and the perspective of the material as a physics entity. However, since the perspective depends on the application and intended user, it is not always clear at the domain level which perspectives will be required.

The application of the domain ontology to specific cases requires lengthy interactions with domain experts to arrive at suitable taxonomies and ontology. We have tried a range of approaches and tools to make this easier, ending up with Webprotege as the currently best compromise between ease of use and machine-readable formats.

2.21 Demonstrator 21: Lubricant Design (Scienomics SAS)

The last update of the demonstrator can be found in deliverable D5.5. Some of the demonstrators have different schedules than the OntoCommons project, and, therefore, progress and reporting on the demonstrator might differ from the surveys within OntoCommons.

2.22 Demonstrator 22: Automated production of a nutrient solution for soilless culture application (UFRGS)

2.22.1 Brief description and visual representation

Automated production of a nutrient solution is of paramount importance for soilless culture applications, e.g., hydroponics agriculture techniques. This can be accomplished by monitoring the environment and remote controlling a sequence of processes. The use of heterogeneous IIoT devices equipped with different sensors and actuators allows this to happen. These devices can use distinct communication protocols and data structuring, which increases interoperability problems. The demonstrator is developing an industry 4.0 oriented ontology, based on the IEEE 1872 international standard to mitigate these problems. An overview is given in Figure 30.

Three communication protocols were selected for testing the developed middleware: DDS, OPC UA, and MQTT. The OPC UA and DDS protocols are widely adopted in industrial applications as they are Industry4.0 standards. Each communication protocol follows a different communication pattern; OPC UA is based on the client-server communication paradigm, while DDS uses the publish-subscribe. Furthermore, the MQTT protocol is chosen since it is broadly used in IoT applications and has been widely deployed in industrial settings due to its ease of implementation and wide range of compatible de- vices. By selecting industrial communication protocols that follows different communication schema, it was possible to demonstrate the flexible and interoperable way the middleware can be configured.

Three simulated devices were defined to validate the interoperable middleware functionalities. Each node has at least five sensors and actuators, which communicate by one of the communication protocols. The simulation scripts use the ontology's equipment characteristics to simulate its behaviours. The three devices constantly monitor sensitive data for their operation and transmit relevant data to their respective broker or server whenever an update occurs.
The OPC UA device script is implemented using the open62541 library and connects an OPC UA client to its corresponding gateway's server. The client sends updated data from its sensors and actuators using write functions to specific server positions, storing all current data on the server and available to other devices when required. Moreover, it constantly queries for dependency data updates, as this information is directly related to the correct functioning of the equipment. The DDS and MQTT device's scripts follow a similar pattern as both are based on the publish-subscribe model. Initially, the broker's parameters are configured and as soon as the communication is established, the client subscribes to the topics related to sensors and actuators whose information is essential for the device's operation.

The MQTT client is based on the paho python MQTT library while the DDS was implemented using a ROS2 publisher and subscriber node. Both clients publish their data whenever modified, using the topic with their simulated device id.

The interoperability middleware was deployed on a gateway based on a raspberry pi 4 with 8GB of RAM and 32 GB SD memory card, running Ubuntu Server 20.04 LTS. The gateway includes the communication protocols brokers (DDS and MQTT) and server (OPC-UA), two bridging mechanisms for industrial communication protocols, a local database for storing the system data (InfluxDB), and a SCADA like (NodeRed dashboard) system to configure, monitor, and act during the simulation.

Figure 30: UC22 overview as given in D5.5

2.22.2 Ontology level and development during the project Ontologies developed/reused

The following tables show details of the demonstrators used or developed ontologies and tools.

Table 92: Ontologies and tools of UC22

No	Description	TLO (mark if self-developed)	MLO (mark if self-developed)	DO (mark if self-developed)	Tools (mark if self-developed)
1	A specialized ontology that incorporates concepts related to quantities, units, dimensions, and values. Its purpose is to provide a standardized framework for representing and managing these	---	---	QUDT Ontology	---

	aspects within system models.								
2	An ontology for describing sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators.	---		---		SSN Ontology		---	
3	It is an instantiation of the SSN ontology developed to represent Internet of Things (IoT) resources, entities, and services	---		---		IoT-Lite Ontology		---	
4	The ontology would likely define concepts such as position (location in space), orientation (direction or alignment), and pose (combination of position and orientation). It would also capture the relationships and dependencies between these concepts, enabling the representation and analysis of spatial information.	---		---		POS Ontology		---	

5	An ontology for defining essential concepts of robot and automation applications, such as behaviour, function, goal, and its tasks.	---		---		ROCO - Robotic Cloud Ontology		---	
6	An ontology has been developed for IoT applications, considering international standards and global ontologies such as IEEE 1872-201, SSN, QUDT, POS, and IoT-lite. The ontology includes classes and properties from these existing ontologies and extends them to incorporate IIoT-specific concepts that have not been previously addressed. This includes aspects such as the device's communication protocols, data structure, and other relevant details.	---		---		IIoTOnTo (Self-developed).		---	
7	Is an open-source software tool used for creating, editing, and managing	---		---		---		Protege	

	ontologies. Has been widely adopted in various research, academic, and industrial domains for ontology development, knowledge representation, and semantic modelling.								
8	An OPC UA (OPC Unified Architecture) server is a software application or component that implements the OPC UA standard and acts as a data provider or service provider in an OPC UA system. OPC UA is a communication protocol and data exchange standard designed for industrial automation and interoperability.	---		---		---		OPC-UA Server	
9	MQTT (Message Queuing Telemetry Transport) is a lightweight publish-subscribe communication protocol specifically designed for constrained devices and low-	---		---		---		MQTT	

	bandwidth, high-latency networks. It is widely used in Internet of Things (IoT) applications and scenarios where efficient and reliable messaging is required.								
10	An open-source, time series database designed for handling and analysing high volumes of time-stamped data. It is specifically optimized for storing, querying, and visualizing time series data, which is data that is generated and recorded over time.	---		---		---		Influx DB	

Table 93: self-developed ontologies and tools of UC22

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)
Ontology	IIoTOnTo	An ontology focused on IIoT that combines several models well disseminated in the literature, such as IoT-Lite and QUDT, with ontologies standardized by the IEEE (IEEE 1872- 2015 Standard Ontologies for Robotics and Automation) to develop one	To appear in the IFAC World Congress 2023 and IEEE ISIE Symposium 2023.

		specialized for IIoT applications, extending the ideas of the OntoCommons Project.	

2.22.3 Final implementation

The following table shows details of the demonstrator development steps and the progress achieved based on the finale survey.

Table 94: demonstrator development steps of UC22

No.	Development Step	Progress	Issues (if any)	Estimated final state at the end of OntoCommons in 10/2023
1	Study/Research of ontologies present in the literature that have classes and properties with similar concepts to IoT and IIoT applications.	Done	---	Complete
2	Development of a specific IIoT ontology using the Protégé software, based on well-established ontologies and international standard ontologies (IEEE).	Done	---	Complete
3	Case study definition	Done	---	Complete
4	Case study (defined in development step No. 3) description using the developed IIoT ontology.	Done	---	Complete
5	Development of the asset administrator shell (AAS) for each industrial asset presented in the	Done	---	Complete

	case study using the ontology description.			
6	Configure the interoperable middleware using the ontology-based and AAS-based configuration files developed in development steps 4 and 5.	Done	---	Complete
7	Configure and run the application using SCADA-like software.	Done	---	Complete
8	Monitor the data exchanged in the InfluxDB database, to check for possible problems and develop datasets for further use in Machine Learning and Artificial Intelligence failure prediction applications, for example.	Done	---	Complete

2.22.4 KPIs Assessment

In use case 22, improvements were achieved in the KPI FAIR and regarding TRL testing with physical devices is planned in the next year. Improvements were also targeted in the areas of "Number of gateways", "Number of communication protocols" and "Saving time for new devices integration". However, these could not be quantified in the last period of the project, as the work continues.

2.22.5 Evaluation of shall-requirements

The following table shows details of the demonstrators shall-requirements based on the finale survey.

Table 95: Shall requirements of UC22

UID	Title	Description	Priority	Comment	Status (Complete/ partly/discontinued/panned) at the end of OntoCommons in 10/2023
Use/application of ontologies					
UC22_RQ_U_01	Configuration of IIoT gateway.	The IIoT gateway shall be configured by the user using two ontology-based files (JSON and YAML files) and start the respective communication protocols servers and interoperability scripts.	**Shall**	---	
UC22_RQ_U_02	Simulation.	The use case interoperability shall be evaluated by running simulations with the IoT device's digital twins.	**Shall**	---	
UC22_RQ_U_03	Monitor real time data exchange.	All data exchanged between the devices can be monitored in real time by a SCADA system hosted by the IoT gateway.	**Shall**	---	
UC22_RQ_U_04	Data storage	The data exchanged by different IoT	**Shall**	---	

		devices shall be stored in a database (influx DB) to be used as a dataset for future machine learning applications.			
Development of ontologies					
UC22_RQ_D_01	Description of communication protocols	The ontology shall describe all communication protocols present in the use case, as well as all its configuration information (such as, MQTT url, port, and topics).	**Shall**	---	
UC22_RQ_D_02	Description of device data	The ontology shall describe the type of data exchanged by IoT devices and present the dependency data for each node.	**Shall**	---	
Maintaining/extension of ontologies					
UC22_RQ_M_01	Easy maintenance of ontology	The ontology shall be easy to maintain (e.g., adding lower-level terms, additional	**Shall**	---	

		relations, etc.) from non-ontology experts (e.g., SW engineers).			
Standardisation					
UC22_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards (e.g., ISO).	**Shall**	---	

2.22.6 TRL Assessment

In the overall view, the TRL is 3 and did not increase until the end of OntoCommons.

The project was only evaluated with simulations and lab experiments. It is expected that in the next year experiments with physical devices will be carried out. And also, to verify the middleware adaptability, new sensors/actuators/devices will be added to the system.

2.22.7 FAIR Assessment

The FAIR assessment was done via: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

The demonstrator has no applicable principles and has the approximately same maturity level for Findable and Accessible dimensions. We monitored the progress of the implementation of these dimensions as they are predominantly in the planning phase. The Interoperable dimension is remarkable as the reason for the development of the ontology used in this case study was exactly provide interoperability for systems with heterogenous devices and communication protocols. The Reusable aspect was not evaluated.

The case study was evaluated using the physical IIoT gateway and simulated devices. The three simulate devices (digital representation) emulate the tangible assets that are employed in the experiments. The simulations represent the active component of a digital twin's virtual representation of an asset. The gateway's communication bridges translate the process data from the three devices and store it in the OPC UA server. The SCADA like system collects data from devices via the OPC UA server and allows users to keep track of their current state. All experiment data is saved locally at the specified InfluxDB point.

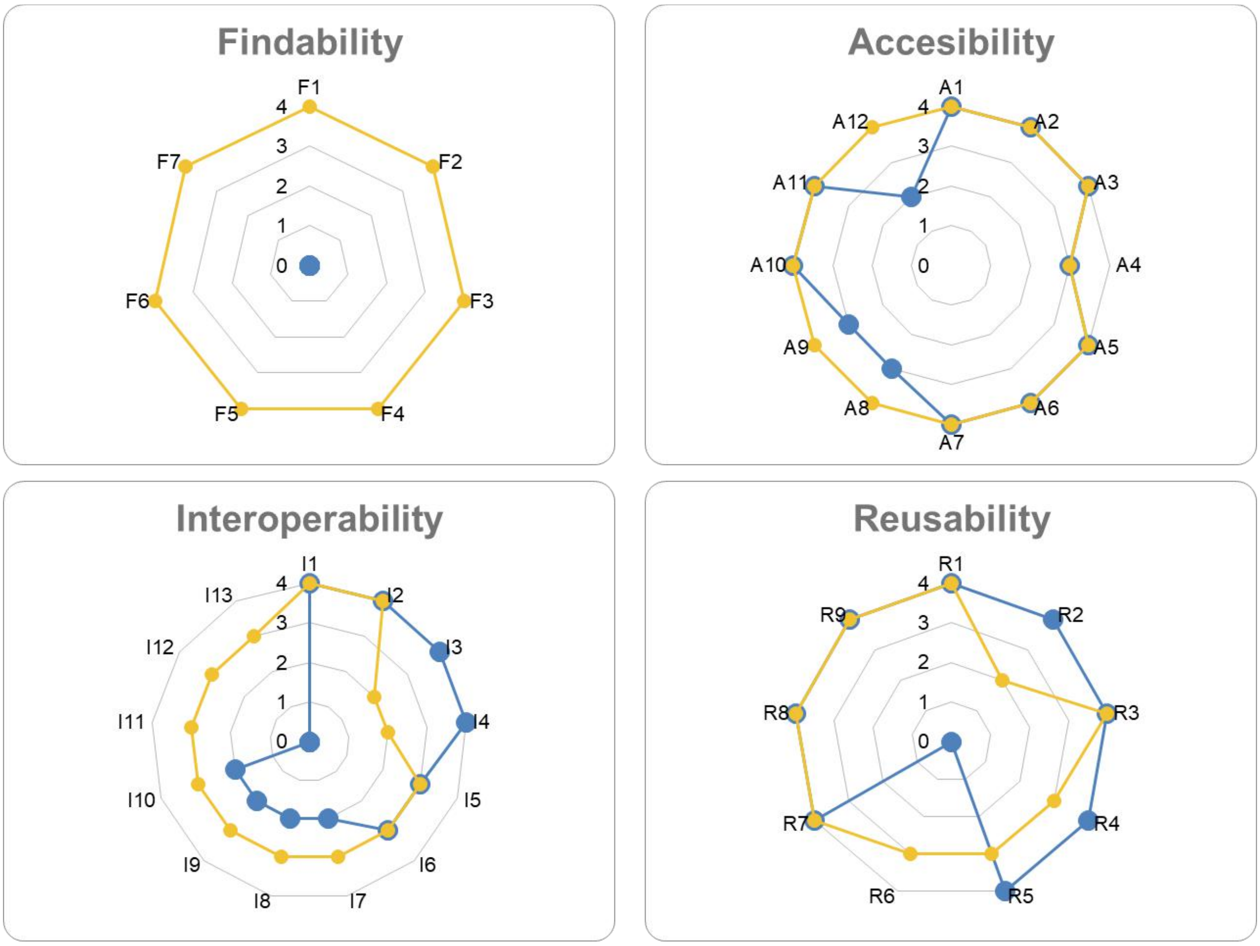
Findable: None of the principles in the Findable dimension have been implemented.

Accessible: All the principles in the Accessible dimension have been implemented and 2 of them have been fully developed during the project.

Interoperable: 12 of the 13 principles in the Interoperability dimension have been implemented and 3 of them have been fully developed during the project.

Reusable: 8 of the 9 principles in the Reusable dimension have been implemented and 6 of them have been fully developed during the project.

Table 96: FAIR results of the initial survey of UC22 in yellow, final results in blue



2.22.8 *Planned further developments*

The case study is finished, but it is planned to extend the study performed during its development to other domains, as well as to deploy the proposed ontology in real-world IIoT systems.

2.22.9 *Lessons learned*

Due to advances in microelectronics, information technology, and communication protocols, a larger number of devices are now connected and share data through the internet. These devices are typically developed by different companies and are based on different communication protocols and data structures, which often leads to interoperability problems. One way to mitigate these problems is by creating a standardized data structure that can be shared and understood by all devices. The use of ontologies is a powerful tool for creating such a standard pattern, and therefore should be continuously studied and improved to ensure an interoperable system for Industry 4.0 and Industrial Internet of Things (IIoT) applications.

Defining a new ontology base on nomenclature already used by other works in order not to create ambiguity. It was necessary to study different types of ontologies already disseminated in the literature and international standards to map similar concepts to different domains which could be included in IoT and IIoT application descriptions.

Another lesson learned is concerning the Protégé software. At first, it was challenging, due to the small amount of official technical documentation and to the existence of several tools to be used. One of the difficulties found was importing definitions, classes, and properties from other ontologies, many of which use different nomenclatures or use similar labels for different purposes. Causing consistency problems of the developed ontology.

2.22.10 Other comments

- A general Industry 4.0/IIoT oriented ontology based on international Standards (IEEE 1872-2015) and worldwide utilized ontologies. The developed ontology allows the description of different industrial systems to follow the exact specifications, reducing possible human errors.
- The representation of the industrial assets' most relevant information in the digital world using AAS. In this way, an asset's digital version is created (digital twin).
- Three types of communication protocols well-established and used in industrial applications were selected, MQTT, OPC-UA, and DDS. The authors developed different communication protocols to enable interoperable communication between devices based on the set protocols.
- A Supervisory Control and Data Acquisition (SCADA) like system for users/engineers to control the simulation and monitor devices' data using the Node-RED development tool.

3. Conclusions

3.1 General

The deliverable provides an overview of the final state of the 22 demonstrators and their development within the OntoCommons project. It is the result of the task T5.5 (Final validation, demonstration of use cases and agreement with wider stakeholders) in Workpackage 5.

Each of the demonstrators provided information on the final state, on the ontologies and tools used/developed, progress of the work in reference to planned activities, assessments of the final fulfilment of the requirements as specified in the previous deliverables D5.1-D5.5 as well as assessments of the improvements of use of FAIR principles, assessment of KPIs, TRL and lessons learned. The final assessment of the demonstrators will serve as input to the other WPs and to the OntoCommons Roadmap (see D1.16 and D1.17). Some of the demonstrators have different schedules than the OntoCommons project, and, therefore, progress and reporting on the demonstrator might differ from the surveys within OntoCommons.

The following tables Table 97 to Table 107 provide an overview of the final status of the 22 demonstrators.

Table 97: Overview of all use cases' results and finale validation, UC1 & UC2

	UC1	UC2
Name	IRIS - IndustRIal co-design Support	SeDIM: Semantic Data Integration for Manufacturing
Case Description	Assembly plant facility design process, logistics flow and logistic resource design.	Microchip manufacturing. Enable integration of heterogeneous factory-wide data for analytics of factory machines, processes and their monitoring and control.
Domain	Aerospace, Manufacturing	Manufacturing, Resources, Process plants, Industrial Facilities
Ontologies	BFO indirectly | IOF Core middle-level. | 2 domain-level: - QU4LITY; IOF-MBSE ontology	QMM-Core Ontology (self-developed) |as MLO and DLO | Data science ontology | Visualisation ontology | Statistical ontology
Tools	Protégé; MetaGraph 2.0; Neo4j	Ontology-based software system: SemML | ExeKGLib, a library for executable KG constructions
Shall-requirements	• Support industrial design process for assembly process of aircrafts • Apply ontologies for reasoning and decision making	• Wide range of requirements regarding ontologies, tools and standardization • W3C-compient ontologies with good alignment and compatibility with a wider ecosystems
TRL (start-→ end)	TRL 2 → TRL 5	TRL 5 → TRL 6
Lessons learned	• Discussions with domain experts are vital but challenging due to their practical knowledge exceeding documentation. • Domain experts use specialized language, requiring a common communication bridge. • Time constraints and vast knowledge require more efficient communication methods. • Welding standards are challenging to read due to inconsistencies and duplication.	---

OntoCommons - Ontology-driven data documentation for Industry Commons, has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 958371.

Partner	UIO (OntoCommons partner) and Airbus (3rd party)	BOSCH (OntoCommons partner)

Table 98: Overview of all use cases' results and finale validation, UC3 & UC4

	UC3	UC4
Name	Eng Demonstrator	Tribomat
Case Description	Comparison of industry standard material grades as listed in EN, ISO or ASTM standards through an ontology based reasoning engine.	The use case will shorten the time and the number/size of experiments required to identify the behaviour of a material or combination of them (e.g., metal, coating, lubricant) with respect to specific operation conditions.
Domain	Process industry, Material technology	Manufacturing at various sectors (e.g., Automotive, Aerospace, …); Processing Materials characterization
Ontologies	ISO 15926-14 as TLO and MLO | 3 self-developed DLO	EMMO as TLO | CHAMEO as MLO | TrobAin and aslf developed TribOnt as DLO
Tools	Document processors and templates	RSDR, Visual Paradigm, Linked Open Vocabulary, Protégé, OOÜS, Tool for Ontology Module Metrics, OnenLink Virtuoso, DBGraph, WIDOCO, GitHub, IndustryProtal
Shall-requirements	• Wide range of requirements regarding ontologies, tools and standardization • All shall-requirements complete or partly	• Requirements with focus on ontology development and maintanance • Requirementst on re-use of ontologies t fulfilled due to poor quality of the evaluated ontology
TRL (start--→ end)	TRL 3 → TRL 3-5 (future development)	TRL 3 → TRL 5
Lessons learned	• use of OTTR template expansion for building ontologies was beneficial	• OCES Methodology developed within the OntoCommons project was helpful for the ontology development process, but further methodologies/tools are needed to "put ontologies in production" and exploit them in real industrial applications. • Visual exploration of data via knowledge graphs was most promising compared to the use of predefined

		competency questions via REST web services
Partner	UIO (OntoCommons partner) and Aibel (3rd party)	Tekniker (OntoCommons partner)

Table 99: Overview of all use cases' results and finale validation, UC5 & UC6

	UC5	UC6
Name	EVMF - European Virtual Marketplace Framework	Ontology based yard management
Case Description	Facilitate platforms interoperability and services within an open European Virtual Marketplace Framework, involving tools and ontologies from the Allotrope Framework and NMBP materials modelling marketplace projects	Improve effectiveness and responsiveness of decision-making in logistics control systems based on data sharing built around data streams semantically described by dedicated PSS ontologies
Domain	Materials, Nanotechnologies, Biotechnology, Manufacturing and Processing	Equipment industry, Manufacturing
Ontologies	EMMO as TLO | EVMPO as MLO | different DLO (VISO, OSMI, SWO, OTRAS, EVMPO, MAEO	BFO as TLO | IOF as MLO | re-use of PSS Ontology and SC Ontology as well as self-developed application specific ontologies as DLO
Tools	Zontal Space platform for VIMMP, Owlready2, Python	Protégé and self-developed setup tool
Shall-requirements	• Requirements with focus on the use of ontologies and their maintenance • All shall-requirements fulfilled or discontinued	• Requirements mainly for Use/application of ontologies • All shall-requirements fulfilled
TRL (start-→ end)	TRL 3-4 → TRL 5	TRL 4-5 → TRL 5
Lessons learned	• Semantics and syntax both play important roles in finding the right balance between expressivity and usability in a solution • Friendly interfaces that are easy to navigate and understand are crucial for human users.	• No clear guidelines about the level of abstractions of the restrictions and rules in order to make them effective/useful for a yard/site configuration. Several iterations are needed to reach a good basic (yard independent) set of restrictions and rules. • Relation to mid- level ontology (and indirectly TLO) useful to generalise and

		keep entities open for diverse configurations but requires more time (especially when the middle level ontology is still not stable) • Selection of tool for rules definition is challenging in the phase when the initial set of rules is still not stable.
Partner	UKRI, GCL (OntoCommons partners)	ATB (OntoCommons partner) and OAS (3rd party)

Table 100: Overview of all use cases' results and finale validation, UC7 & UC8

	UC7	UC8
Name	Feedstock Quality Assurance	NanoMaterials Characterisation
Case Description	Evaluation and quality assurance of feedstock for further processing through measurement of different feedstocks, correlation with other feedstocks quality and correlation with quality of produced components	Nanomaterial risk assessment, evaluation of risk control efficiency and decision making. - Phase identification in multiphase materials for nanoindentation process
Domain	Materials, Materials Processing, Quality Control, Materials Characterisation	Nanosafety, Nanocomposites, Characterisation, Materials Design
Ontologies	BFO as TLO | MWBD as MLO |self-developed application specific ontology FeedMixOntology (FMO)	EMMO and BFO as TLO | no MLO | OYSTER, Additive Manufacturing Ontology, eNanoMapper as DLO
Tools	Protégé, InfoRapid KnowledgeBase Builder, Excel, Python, templates	3D Printer Software, Nanoindenter Software, Python, Protégé
Shall-requirements	• Requirements mainly for use/application of ontologies and standardisation • All shall-requirements fulfilled	• Shall-requirements on use/application of ontologies fulfilled, requirement on standardisation partly
TRL (start-→ end)	TRL 3 → TRL 4	TRL 4 → TRL 4-6 (different for ontologies or tools)
Lessons learned	• The implementation/development of DLO just with domain knowledge (e.g. material science) is difficult • Guidelines for the development are quite "technical" (written for ontology experts) • The re-use and adaption of an existing ontology was the best way	• Some challenges in connecting concepts from ontologies that are based on different upper ontologies (BFO/EMMO)

Partner	Fraunhofer (IFAM) (OntoCommons partner)	IRES (OntoCommons partner)

Table 101: Overview of all use cases' results and finale validation, UC9 & UC10

	UC9	UC10
Name	Ontology-based Maintenance	Cu/Al Data
Case Description	Standardize the terminology of the maintenance process, focusing in particular on the diagnosis of technical malfunctioning, and leveraging on knowledge extracted from service information flows and repair records	Enable effective data documentation and cross domain data reuse in the copper and aluminum industry
Domain	Equipment Industry; Maintenance of Large Manufacturing Machines	Materials Characterization
Ontologies	(So far mainly unstructured data → decision on ontologies will probably follow in the future) DOLCE as TLO | no MLO | no DLO	BFO as TLO | IOF as MLO | Self- developed domain ontology for billet procurement as DLO
Tools	Phone, email, apps for client report, third-party ad hoc search engine, early prototype use of Protégé	Protégé
Shall-requirements	• Requirements mainly on use/application of ontologies and development • All shall-requirements fulfilled or partly	• No shall-requirements defined by demonstrator
TRL (start-→ end)	TRL 1 → TRL 3-4 (different for ontologies or tools)	TRL 3 → TRL 4
Lessons learned	• Working in collaboration with a company is hard: they have precious little time to spare. It is a difficult issue to tackle, but it should be addressed, explicitly and in advance, in any future project requiring collaboration between academy and industry	• Establishing connections between ontologies is challenging due to limited automation, disconnected or poorly connected information systems, and diverse data formats and storage structures. • Achieving seamless integration and connection of ontologies is not currently feasible given these challenges.
Partner	CNR (OntoCommons partner) and Adige SpA (3rd party)	UIO (OntoCommons partner) and ElvalHalcor (3rd party)

Table 102: Overview of all use cases' results and finale validation, UC11 & UC12

	UC11	UC12
Name	Complex Equipments	Basajaun
Case Description	Describing and analysing the digital twin of products/industrial assets in manufacturing and energy industry across their lifecycle from design to service based on IT systems	Interoperability between different actors in the supply chain Value and supply chain for wooden building construction
Domain	Factories of the Future, Manufacturing	Manufacturing, Processing, Materials development
Ontologies	No TLO | Industrial Data Ontology, SOSA/SSN and QUDT as MLO | different self-developed domain ontologies DEXPI Ontology, CFIHOS Ontology	BFO as TLO | Reference ontology from IOF as MLO | self-developed forestry ontology with focus on harvesting and raw material logistics as DLO, custom made sawmill ontology with focus on log to board packages pipeline, custom made building component manufacturing ontology with alignment to IOF
Tools	Protégé for editing, Widoco for documentation, SIMPL CLI for release, SHACL for validation, R2RML and RML for mapping,	Self-developed applications, some libraries from rdf.js.org is used, legacy systems will be connected using an IDS connector as defined by IDSA (Industrial Data Space Association) using JSON-LD as a semantic enabling exchange format
Shall-requirements	• Requirements mainly on use/application of ontologies and standardisation • All shall-requirements partly	• All requirements mainly on tools • Requirements not yet finished since underlaying project is not finished
TRL (start-→ end)	TRL 5 → na	TRL 2-3 → TRL 5-7
Lessons learned	• Tools tailored to domain experts are needed for ontology modelling and data generation • Standardized methodology is needed for modelling product/artifact hierarchies. • Training materials and programming frameworks/SDKs are needed for modelling patterns and manipulating RDF-based data in the industrial domain.	• When discussing technical concepts with industrial partners, focus on explaining the benefits and direct problem-solving aspects of the suggested solutions • Providers of technology must be aware that practical applicability may require intermediate solutions based on current circumstances • Consider the perspectives of traditionalists and digitalization enthusiasts in the domain, being

		cautious when discussing the potential of applied ontologies
Partner	UIO (OntoCommons partner) and Siemens (3rd party)	Paramountric / Sweden

Table 103: Overview of all use cases' results and finale validation, UC13 & UC14

	UC13	**UC14**
Name	Life Cycle Sustainability Assessment of a Chemical Product	Architecture design and ontology definition - Aircraft
Case Description	Define the life cycle of the product, Collect and analyse information about inputs and outputs associated with the life cycle of the product, Calculate, integrate and interpret sustainability impacts	Architecture design and ontology definition for Onboard Maintenance System of Aircraft
Domain	Manufacturing, Life Cycle Assessment	Manufacturing, Aircraft and aerospace
Ontologies	No TLO | no MLO | ORIONT and BONSAI ontology as DLO, based on the eILCD format	BFO Ontology Framework EPFL, GOPPRRE ontology for architecture modelling
Tools	PowerPoint for visualization, Python and the Owlready2 package for transformation from excel into an ontology, Protégé	MetaGraph 2.0, Integrated with SysML/UML, Interaction with other BFO ontologies, Integrated and Generate Modelica models
Shall-requirements	• Only one shall-requirements mainly on ontology development defined and completed	• No final feedback, see deliverable D5.5 for last update
TRL (start-→ end)	TRL 1-2 (proof of concept)	TRL 5 → na
Lessons learned	• Further development and assistance from ontology experts are needed for a fully accessible and reusable domain ontology for Life Cycle Sustainability Assessment • Implementation of primary and secondary data with varying levels of detail is necessary, including addressing challenges with cost data confidentiality and availability • Social aspects will be qualitatively handled, and aggregating different types of data in LCSA poses	• TLOs (e.g., BFO) are too generic to support real engineering cases, requiring the generation of domain-specific ontologies • Ontologies are akin to special databases and can be efficiently applied in the development of the SOI (System of Interest) with software support • Exploring knowledge graphs can uncover new connections among ontologies, and verification and validation of ontologies help generate

	challenges that require further testing of normalization and weighting approaches	more accurate definitions for domain-specific ontologies
Partner	Orienting project / BASF	COMAC BATR / China

Table 104: Overview of all use cases' results and finale validation, UC15 & UC16

	UC15	**UC16**
Name	Monitoring human operators' safety	Food Knowledge Graph
Case Description	Monitoring human operators' safety and well-being via semantic data integration in an automotive manufacturing setting	Develop a proof-of-concept knowledge graph which is geared for additive or compound discovery in the sector of food processing or agri-science, using an ontology to link databases available from European institutions
Domain	Manufacturing. Assembly, Processing	Biotechnology
Ontologies	SSN/SOSA	AgroVoc and EuroVoc as TLO | no MLO | FOODON Ontology as DLO
Tools	CASPAR framework (In-house development)	MetaGraph 2.0, Protégé, self-developed tools DyPharm, DyMap and Dynacurrate AI
Shall-requirements	• No final feedback, see deliverable D5.5 for last update	• Wide range of requirements regarding ontologies, tools and standardization • All shall-requirements complete or partly
TRL (start-→ end)	TRL 3 → na	TRL 5 → TRL 8
Lessons learned	The application of semantic technologies in this scenario resulted in: • richer representation of the domain knowledge and of the respective provenance of the incoming information • better explainability of the derived outputs • deeper insights, e.g., discovery of underlying patterns "hidden" in the data	• Shifting from Foodon to Agrovoc has reinforced our belief in the value of our technologies for the use case • Continuous evolution of ontologies necessitates affordable tools to track changes, particularly at a large scale, which justifies the investment in ontology creation and use • Food-related ontologies exhibit less maturity compared to other life sciences ontologies, possibly due to the absence of international organization backing and license fees, as seen in large-scale clinical terminologies like SNOMED CT

Partner	CPSosaware Consortium / Italy	Dynaccurate SARL / Luxembourg

Table 105: Overview of all use cases' results and finale validation, UC17 & UC18

	UC17	UC18
Name	Siemens / iiRDS	IKEA Knowledge Graph
Case Description	Aims to create iiRDS (an ontology developed by the iiRDS consortium as metadata for technical documentation) package prototypes and evaluate the customer view and content delivery	IKEA Knowledge Graph sets as its goal to connect the data and make it usable throughout IKEA's services and systems.
Domain	Manufacturing, Technical Documentation	Materials modelling, Home-furnishing
Ontologies	No TLO | no MLO | iiRDS Ontology as DLO	In-house developed ontologies
Tools	Content management system (SIPS+) (customized Cosima system), iiRDS converter, Linguistic engine (CLAT, Congree); Delivery and content integration platform: c-rex	• Frontend for authoring and discussing modelling changes • Frontend for managing taxonomies, Visualisation of IKG. Visual editing • Suggest changes and review changes in all above mentioned tooling to enable governance
Shall-requirements	• Demonstrator finished, see deliverable D5.5 for last update	• Wide range of requirements regarding ontologies, tools and standardization • Most shall-requirements complete or discontinued • One shall-requirements regarding usage instructions only partly
TRL (start-→ end)	TRL 6 → TRL 6 (already at a high development level, when entering the OntoCommons project)	TRL 4 → TRL 9
Lessons learned	---	• At this point of the semantic web development, we can also rethink the current approach (R2RML, RML) and create new things that suit the current software development industry. Transparency through having everything in GitHub • Comparison between self-built data transformation process and RML showed:

		• Hard transformation, such as IRI lookup is possible without SPARQL massaging
		  ○ Performance of executing hundreds of files is 4 times faster
		  ○ More developer friendly
		  ○ Possibility for visual authoring which enable democratisation of data transformation definitions

Partner	Siemens AG / Germany	Inter IKEA Systems / Sweden

Table 106: Overview of all use cases' results and finale validation, UC19 & UC20

	UC19	UC20
Name	Materials Databases Integration using the Materials Design Ontology	Materials Characterisation Ontology
Case Description	The Materials Design Ontology is used for semantic and integrated access to the computational materials databases in the OPTIMADE consortium, dealing with the heterogeneity of the databases in terms of underlying data models and use of terminology. The developed ontology will be used in ontology-driven data access and data integration for application in the materials design domain	In NanoMECommons, the demonstrator is building an ontology of material characterisation to capture potentially any type of materials characterisation method and enable harmonisation. The starting point is a human readable metadata called CHADA and the work is to provide an EMMO compliant ontology.
Domain	Materials Development	
Ontologies	EMMO as TLO | PROV-O, CheBI and QUDT as MLO | Materials Design Ontology (MDO) as DLO	EMMO as TLO and MLO | self-developed CHaracterisation MEthodology Ontology (CHAMEO) as DLO
Tools	Protégé (ontology development), RepOSE (ontology debugging, completing, aligning), own ontology extension tool	Protégé, Miro board, Tables, CHADA document template, Open Innovation Environment based on https://github.com/simphony/osp-core
Shall-requirements	• One shall-requirement on semantic and integrated access, partly finished	• Shall-requirements regarding ontologies fulfilled • Requirement on maintenance of ontologies not fulfilled due to lack of tools

		• Requirement on visualisation possible with standard tools, but not part of this demonstrator
TRL (start-→ end)	TRL 3 → TRL 3	TRL 3 → TRL 3 (TRL improvement next part of underlaying project)
Lessons learned	• The prototype successfully answered all competency questions for MDO, while using only the APIs of the databases did not achieve the same result despite having the required data • In comparison experiments, the prototype outperformed several other systems in terms of the number of questions it could answer, although some other systems were faster. It is important to note that the prototype has not been optimized • Discussions among developers of domain and top-level ontologies, such as EMMO, are necessary to align ontological commitments. Meetings have been initiated to facilitate these discussions	• The approach for designing material characterization ontologies is based on modularization to enhance interoperability and knowledge sharing • Designing the CHAMEO ontology requires extensive effort to ensure comprehensiveness and generality while avoiding constraints that limit its applicability • The use of EMMO as a top-level ontology framework helps express different perspectives, although determining the required perspectives at the domain level can be challenging • Applying the domain ontology to specific cases involves lengthy interactions with domain experts, and Webprotege is the preferred tool due to its balance between usability and machine readability.
Partner	Linköping University / Sweden	Goldbeck Consulting Ltd / United Kingdom

Table 107: Overview of all use cases' results and finale validation, UC21 & UC22

	UC21	UC22
Name	Lubricant Design	Automated production of a nutrient solution for soilless culture application
Case Description	Develop and demonstrate (a) the technology of our platform and how it is possible to easily create user interfaces and (b) using domain ontologies it is possible to develop value-adding workflows. Case will show, how to develop a Designer for lubricants that fulfil both materials and use constraints.	Use of heterogeneous IIoT devices equipped with different sensors and actuators allows this to happen. These devices can use distinct communication protocols and data structuring, which increases interoperability problems. The demonstrator is developing an industry 4.0 oriented ontology, based on the IEEE 1872 international standard to mitigate these problems.

Domain	Materials Development, Materials Processing, Life Cycle Assessment	Biotechnology, Agriculture
Ontologies	Materials Design Ontology Various domain ontologies for engines, products and processes	No TLO | no MLO | QUDT Ontology, SSN Ontology, IoT-Lite Ontology, POS Ontology, ROCO - Robotic Cloud Ontology and self-developed IIoTOnTo as DLO
Tools	Neo4j, Protégé, GraphQL	Protégé, OPC-UA, Server, MQTT, Influx DB
Shall-requirements	• No final feedback, see deliverable D5.5 for last update	• Requirements mainly on use/application of ontologies and development • No information on final state provided by the demonstrator
TRL (start-→ end)	TRL 4 → na	TRL 4 → TRL 4 (TRL improvement next part of underlaying project)
Lessons learned	---	• The increasing number of connected devices in Industry 4.0 and IIoT leads to interoperability challenges due to different communication protocols and data structures • Creating a standardized data structure using ontologies can mitigate these interoperability problems and should be continuously studied and improved • When defining a new ontology, it is important to avoid ambiguity by leveraging existing nomenclature used in related works and international standards • The use of Protégé software initially posed challenges due to limited official technical documentation and the need to import definitions from other ontologies with inconsistent nomenclature, leading to consistency issues in the developed ontology.
Partner	Scienomics SAS / France	UFRGS / Brazil

3.2 Summary regarding ontologies

Within the project, there are many different approaches to designing, developing, using or reapplying ontologies. This depends strongly on the use of the ontology and the approach of the involved use case. In the following some examples are highlighted.

Development methodologies and ontology level

- Many demonstrators adopted in-house methodologies, supported by different tools (including the ones provided by OCES). Several demonstrators made direct use of LOT methodology (e.g., UC4, UC6) which was adapted in the context of OntoCommons. Most of the use cases use BFO as TLO followed by EMMO. For special applications use cases (e.g., UC16, biotechnology) use other TLO like AgroVoc and EuroVoc. Some of the use cases focus only on the domain level and don't use TLOs or MLOs (e.g., UC13, UC17).

Reuse and alignment of existing ontologies

- Some use cases, including UC2 and UC5, demonstrate the strategic reuse of existing domain-level ontologies. In UC6, existing DLOs (PSS and SCRO) are adapted to specific requirements. UC2 and UC5 showcase the importance of aligning such reused DLOs with overarching top-level ontologies for effective integration and interoperability.

Domain-specific use cases

- UC2, UC5 and UC11 exemplify the adoption of modular ontology development, crafting domain-specific DLOs. These modular DLOs promote reusability and facilitate interoperability among various components within the domain. Furthermore, UC10 introduces tailored DLOs for specific industrial domains like the copper tubes plant and foundry.

Integration of standards and core ontologies

- UC1 and UC11 exemplify the integration of established standards and core ontologies. For instance, UC1 employs ISO 15926-14 as a top-level ontology (TLO), extending it with domain-specific features. UC11 leverages standards like Industrial Data Ontology alongside bespoke ontologies to address billing, facility handling, and manufacturing control. These cases highlight the synergy between standardized and specialized ontologies.

Specialized use cases and development

- In UC9, DLOs aligned with DOLCE are developed to precisely represent complex concepts related to machine components, functions, and malfunctions. A comparable situation applies to the DLO development at UC18. Here the focus is on the furniture sector and consumer goods. These specialized use cases underscore the importance of ontology customization for nuanced domain contexts.

Research-led development and project contributions

- UC5 showcases the role of research-led development within projects like VIMMP and DOME 4.0. These projects contribute to the active development of domain ontologies, exemplifying collaboration and advancement within the ontology community. In cases where ontologies have been developed and/or updated, some have been already published (namely using the OCES tools to do this), others are in the process of doing so.

3.3 Summary regarding tools

Like the development and application of ontologies, the use or development of suitable tools is also highly dependent on the topic of the use case.

Ontology development

- Protégé is the most commonly used tool for ontology development. Some use cases consider it the best compromise at present, even if they criticize the low level of technical documentation (see chapter 3.7).

Data storage and data analysis tools

- If information is provided, data storage is done in standard databases with query-languages like Neo4j or Influx DB (e.g., UC21, UC22). Most use cases use existing tools for data integration and analysis like Python or Excel.

Information modelling and visualization

- Some of the use cases gave information tools for modelling and visualization. The most used is MetaGraph 2.0 (e.g., UC1, UC14, UC16). Other use cases use non-specialized tools like PowerPoint for the visualization probably due to its accessibility. Others use self-developed information modelling systems, further elaborated in literature, to improve visualization.

Content management and transformation

- Some use cases (e.g., UC18) use bought and self-developed tools for converting formats and to manage ontologies, taxonomies and other instances.

Templates

- Some use cases use templates to improve reusability, such as UC3, which uses OTTR templates to develop models.

3.4 TRL

The Technology Readiness Level is one of the major KPIs monitored by the project. Most of the use cases started at TRL of about 3-4 and are therefore on research or technology development level. Only one use case (UC13) is at TRL 1-2 (basic research and feasibility). Other use cases (e.g., UC2, UC17) started at a higher TRL of 5. Most use cases show an improvement of 1-2 levels. Therefore, most of the use cases are now in the range of TRL 4-5 (technology development). Three use cases reached higher levels of 7-9 (UC12, UC16, UC18). The evaluation of the TRL seems to be difficult for some use cases because there may be differences in the TRL between the ontologies used and, for example, the used or self-developed tools. Thus, the overall evaluation of the use case may not be easy to represent. Some of the use cases are being developed as part of other projects. The improvement of the TRL is thus in some cases only the subject of later developments (e.g., UC20, UC22).

3.5 FAIR

Improvement of use cases regarding the FAIR principles was one of the major impacts promised by the OntoCommons project. After analysing a large portion of demonstrators, we see significant improvements across four FAIR dimensions. This can be attributed to the fact that many demonstrators adopted ontology-based data documentation throughout the project. Using ontologies and semantic technologies already helped implementing many FAIR principles out-of-the-box, such as the ones about providing machine-understandable metadata. An interesting observation we made is that some demonstrators reported a regression on some of the FAIR principles. We believe that this is mainly because of two reasons. First, some of the principles were being considered, or in the implementation phase in the beginning of the project, but they were eliminated for some reason (e.g., the feature that was implementing a specific FAIR principles was not completed during the project). Second, the FAIR evaluation depended on the reporting of individuals, who may have different understanding of what a principle can mean. Many demonstrators have a greater understanding of FAIR principles compared to the beginning of the project, thanks to – among other things – comprehensive training provided by OntoCommons via different events. This may have caused that the maturity of some principles were wrongly estimated by the beginning of the project and reported at a lower level at the end of the project.

Overall, we can see that the application of semantic technologies at OntoCommons demonstrators improved the FAIRness of their (meta-)data to a significant extent.

3.6 Requirements

At the beginning of the project, the requirements of the initial use cases and, when they were added, those of the new use cases were defined by the use cases themselves. These were subdivided into different sections for specification and the respective urgency for implementation was defined by the use cases. Since this accurate definition of the requirements often resulted in many of them being specified, only the necessary shall-requirements are considered in the final validation.

For all use cases, that were able to give an update on their demonstrator, an improvement was indicated. Most of the use cases stated that the majority of the shall-requirements could be completely fulfilled. Since some use cases will continue to be developed after the end of OntoCommons, it was also indicated in these cases that the shall-requirements will be completely fulfilled or at least planned to be fulfilled until the end of the underlying project (e.g. UC2, UC11, UC12, UC18). Shall-requirements that could only be partially fulfilled by the end of OntoCommons often deal with topics such as improvement or interconnection to other systems and tools, use of ontology by non-expert (e.g. UC6), harmonisation (e.g. UC8), maintenance and standardization (e.g. UC22) or re-use of ontology (e.g. UC4). However, there were also shall-requirements that were not considered further because it turned out during the project that they were not relevant for the use case after all or even the orientation of the use case was adjusted (e.g. UC5, UC16, UC18, UC20).

3.7 Lessons Learned

Ontology Development and Challenges

- Use cases create tools for ontology tasks and complex knowledge transfer

- Insufficient standards regarding nomenclature, taxonomy, and consistency
- Lack of industry-wide standardization in ontology development methodologies and tools
- Challenges in selecting tools for rules definition
- Reuse of existing ontologies supports development of compatible components

Data Handling and Visualization

- Tools are needed for accessing data in legacy systems without duplication
- Importance of visual exploration for data retrieval and exploitation
- Need for end-user oriented tools for easy visualization and navigation among resources
- Use of ontologies for information retrieval from multiple databases via API
- Demand for tailored visualization tools for ontology development and exploration
- Self-developed data transformation processes can support demonstrators with special needs

FAIRness and Methodology

- Standardized FAIRness assessment needed
- Use of existing methodologies like OCES or LOT methodology and the OntoCommons tools support the development and maintenance of ontologies
- Importance of a common FAIRness certification process
- Need for tools and methodologies to support the assessment and improvement of FAIRness

Compatibility and Communication

- Tool selection challenges for rule definition
- New classes ensure ontology compatibility
- Communication balance between traditionalists and digitalization enthusiasts

Evolution and Interoperability

- Tools are essential for evolving ontologies
- There is less maturity in food-related ontologies compared to other life sciences ontologies
- Modular approach aids interoperability
- Extensive discussions needed for alignment of different ontologies - Need for comprehensive and generic concepts to accommodate future components and techniques

In summary, the text highlights the challenges and requirements of ontology development, tools, data access, visualization, methodology, standards, and communication within diverse use cases. It emphasizes the need for adaptable approaches, intuitive tools, and effective communication to bridge gaps between knowledge domains and support the evolving nature of ontologies.

3.8 Further benefits

The OntoCommons project has paved the way for significant advances in several domains like manufacturing, processing, characterisation and materials data management. It has fostered the development of strategies to eliminate data duplication while supporting seamless information sharing across the value chain. This project has also played a critical role in educating industry professionals about the nature and benefits of ontologies and breaking down the barriers to understanding semantic technology in the field.

Sophisticated use of generative and predictive AI has enabled complex connections to be made between different ontologies, providing a more coherent knowledge framework. Collaboration with experts in materials science has enriched the project's taxonomy and ontology development. In addition, OntoCommons has been a source of inspiration and education for participating employees, potentially triggering a culture shift within the company towards a more conscious approach to knowledge. This broad outlook underscores the profound impact of the OntoCommons project on the materials industry.

Building on the foundation established by the OntoCommons project, the outlook for the future is characterized by a commitment to expansion and innovation. Expansion will encompass a broader range of processing technologies, requiring the development of new ontologies tailored to these areas, while recognizing the importance of reusability in ontology development.

In addition, the integration of specific object properties and relationships into, for example, the EMMO and BFO frameworks will increase the semantic depth of the system. The road ahead also includes deeper integration of various Digital Lab Objects to enable seamless data exchange.

While the specific developments remain confidential, the direction is clear: a continued commitment to advance the state of materials data management. Characterization techniques (e.g., based on CHAMEO) will continue to evolve, and new sensors, actuators, and devices will be seamlessly integrated into the ecosystem.

The goal is to translate these advances into tangible value for business processes. The results will be presented to business process owners along with recommendations for expanding the use of semantic technologies. With these strategies, the future holds promising prospects for further improving knowledge management and data use in the materials industry.

3.9 Outlook

During the OntoCommons project, a lot of information from the industry, especially in the area of ontology and tool development, could be gathered through direct collaboration with the 22 participating demonstrators. This exchange gives a deep insight into the current industrial development and usage of ontologies and their application. Also, a more accurate picture of where the challenges, difficulties and problems are in the industrial implementation and what can be done to expand the industrial application of these digital and supporting tools could be captured.

The demonstrators, representing different areas and applications, have thus played a pioneering role in implementing the project's innovative approaches to data and knowledge management. After the completion of the OntoCommons project, the results and experiences gained can support and advance the participating demonstrators and the industry to which they are transferred in many areas. Implementing organizations can experience a significant boost in efficiency and innovation. By adopting the standardized knowledge management and data sharing practices developed through the project, they will be better able to streamline their processes, reduce redundancies, and accelerate innovation cycles. By continuing the cross-domain collaboration created in OntoCommons, more joint projects and initiatives that reach multiple sectors will become more common, leading to synergistic outcomes and holistic solutions to complex challenges. The demonstrators' best practices and tangible benefits of OntoCommons will serve as compelling examples for other organizations and sectors, leading more entities outside the project to adopt OntoCommons principles and technologies, resulting in broader, global impact.

The lessons learned in OntoCommons with the demonstrators also support that it is worthwhile to continue investing in research and development to improve systems and harness the power of AI, machine learning, and data analytics to gain deeper insights and drive continuous improvement. Likewise, the newly acquired ability to leverage standardized data and knowledge leads to being more agile in responding to market changes, seizing new opportunities, and maintaining leadership positions.

4. Annex I survey template

4.1 UCXXX (owner)

4.2 Brief description and visual representation

Check if the given information is still right. If not, what changed during OntoCommons? Add changes.

4.3 Ontology level and development during the project Ontologies developed/reused

Check if the given information is still right. If not, what changed during OntoCommons regarding used ontologies and/or tools. Mark, if the ontology is developed in-house or reused.

Table 108: ontologies and tools (input from D5.2)

No	Description	TLO (mark if self-developed)		MLO (mark if self-developed)		DO (mark if self-developed)		Tools (mark if self-developed)	
1									
2									
3									

Table 109: self-developed ontologies and tools

Ontology / tools (O/T)	Name	Description	Publishing link (if applicable)

4.4 Final implementation

Check if the given information from the last survey is still right. If not, what changed during OntoCommons regarding development steps?

Table 110: demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Your plans given in the last survey, just as a reminder, do not put further information in.	Estimated final state at the end of OntoCommons in 10/2023
1					
2					
3					
4					
5					
6					

4.5 KPIs assessment

What is your expectation for the end of OntoCommons in October 2023?

Table 111: Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated value at the end of OntoCommons in 10/2023

4.6 Evaluation of shall-requirements

What is your expectation regarding the fulfilment of the requirements of your use case at the end of OntoCommons in October 2023? Please feel free to add any further requirements for your use case.

Table 112: Shall requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP) at the end of OntoCommons in 10/2023
Use/application of ontologies					
Development of ontologies					

Maintaining/extension of ontologies					
Tools for ontology					

4.7 TRL assessment

How has the TRL evolved since the last survey (April 2022)? How are the TRLs expected to evolve until the end of the OntoCommons in October 2023?

4.8 FAIR assessment

How has FAIR been improved during OntoCommons? Please answer per dimension and fill out the survey under: https://ec.europa.eu/eusurvey/runner/OntoCommonsFAIRFinal

Findable:

Accessible:

Interoperable:

Reusable:

4.9 Assessment of further benefits

Which are further benefits of your use case beside KPIs?

4.10 Planned further developments

Are there any further developments planned or is the use case finished?

4.11 Lessons learned

What are the learned lessons from the use case? Where do you need any further support for the development of your use case?

4.12 Other comments

Do you have any further comments regarding your use case?

5. Annex II

5.1 TRL standard definitions used[9]

TRL	European Union
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

[9] https://en.wikipedia.org/wiki/Technology_readiness_level