Deliverable D5.2 - "Cooperation Report with NMBP-39-2020-CSA (OntoCommons)"

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v0.2	11/12/2023	Evgeny Kharlamov (BOSCH)	Draft version
V0.3	12/12/2023	Willem van Dorp (UNR)	Adjust to newest template, add sections Lessons Learnt and Deviations from Annex 1
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V0.7	21/12/2023	Francesco Compagno	Added a “Cooperation Activities” section
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V0.91	11/01/2024	Silvia Chiacchiera (UKRI)	Small suggestions and additions, mostly in current Sec. 1.
V0.95	14/01/2024	Evgeny Kharlamov (Bosch)	Finalizing

Executive Summary

The interaction between OntoCommons and DOME 4.0 has worked according to expectation. Multiple meetings have been successfully organised, and all key information has been exchanged as expected and planned. The developments in OntoCommons have found their way to DOME 4.0, strengthening the DOME 4.0 platform. This document describes the collaboration between OntoCommons and DOME 4.0 partners, which resulted in multiple online and face to face meetings, development of a joint cooperation strategy, joint evaluation of the DOME 4.0 platform ontology, development of guidelines for ontology evaluation, multiple evaluation sessions, as well as joint workshops at the project and international level.

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1. Introduction

1.1. Objectives

This deliverable D5.2 reports on the DOME 4.0 cooperation activities with the OntoCommons project (NMBP-39-2020-CSA) and their results. The objectives were two-fold. Firstly, to describe and report on the interaction between the two projects. Secondly, to report on how the OntoCommons project's vision on the topics of ontology quality and standardization and their outcomes found their way to DOME 4.0.

1.2. Approach

There are two separate activities: the development of the guidelines and their application to DOME 4.0 ontologies. For the first one we refer to OntoCommons report D2.9.

Regarding the second activity, in terms of the guidelines jointly developed by the two projects specifically in the context of DOME 4.0 and OntoCommons collaboration: they were informed by the existing literature on ontology evaluation and standards and comprehensively address various aspects of ontology quality, encompassing functional, logical, structural, terminological, user-related, lifecycle, and FAIRNess requirements; they are also aligned with some relevant analogous previous methodologies. Importantly, the guidelines were designed to accommodate the diverse maturity levels of data metamodels among DOME 4.0 participating partners, offering concrete improvement suggestions tailored to each ontology's development stage. Subsequently, the guidelines were applied to evaluate the DOME 4.0 ecosystem ontology and those showcases of sufficient maturity, utilizing templates that were instantiated to generate corresponding reports.

After an appropriate literature review, due to the intricate nature of ontology standardization and quality, the necessity for these guidelines to address diverse facets of ontologies was evident. Additionally, due to the variety of maturity levels and characteristics of datamodels that one can find in the industry (and academia) in general and, in particular, among DOME 4.0 showcases (ranging from non-usage to fully developed ontologies; and from task-level to upper-level ontologies), it was clear that the guidelines would have to be contingent upon the specific type of ontology undergoing evaluation.

Therefore, a comprehensive list of quality considerations was developed, which can be broadly divided into parts related to Functional, Logical/Ontological, Structural/Topological, Terminological, User, Lifecycle, and FAIRNess requirements. The quality considerations are also assigned a relevance level depending on the type of ontology to be evaluated. Additionally, they are also aligned with some relevant analogous previous methodologies.

Subsequently, these guidelines were applied to assess the DOME 4.0 ecosystem ontology and DOME4.0 showcases, involving the instantiation of the OC-DOME Ontology Evaluation Template) during the evaluation process, yielding corresponding reports.

During the evaluation process every step of the evaluation template was filled out with a first version of evaluation, either by the experts that had developed the template, after having appropriately studied the evaluated ontology and having been briefed by the showcase personnel that developed the showcase ontology; or by the showcase personnel themselves. In both cases, such first versions were later reviewed

by additional personnel/experts. Finally, after having addressed any issues or comments raised during such actions, the reports were finalized.

Presently, only a minority of showcases have generated reports, mainly due to the heterogeneous ontology maturity levels among partners, which constitutes a primary challenge for this work. However, with the existence of a comprehensive set of guidelines (meaning, the guidelines reported in this document and those in the OntoCommons deliverable 2.9), it is planned to conduct evaluations as ontologies reach sufficient maturity.

As one main goal of the evaluation process was to provide tangible insights for enhancement, fostering increased standardization aligning with OntoCommon's overarching vision, intrinsic in each evaluation suggestions for improvement are present as well.

The jointly produced guidelines contributed also to the OntoCommons deliverable D2.9 "Recommendations and Guidelines for TLOs and MLOs" (developed also with the collaboration by CNR, and UNIBO, see the OntoCommons deliverable D2.9). Moreover, based on these collaboration activities, a special session "Ontology Standardization Meets Data Marketplaces" was organized during the workshop "2nd International Workshop on Semantic Industrial Information Modelling (SemIIM)"[1] co-located at ISWC 2023, in which part of the collaborative efforts were presented.

In Section 2 of the deliverable, we will focus on enumerating joint events and meetings, in Sections 3-4 we will focus on the evaluation document/guidelines: the methodology behind it, etc and how it was applied to DOME 4.0 use cases.

2. Cooperation Activities

Collaboration between OntoCommons and DOME 4.0 partners resulted in multiple online and face to face meetings, development of a joint cooperation strategy, joint evaluation of the DOME 4.0 platform ontology, development of guidelines for ontology evaluation, multiple evaluation sessions, joint workshops at the project and international level. Also, four partners (BOSCH, SINTEF, UNIBO and UKRI) and the DOME 4.0 subcontractor GCL participate with similar teams in both projects and this has greatly facilitated cooperation.

In terms of the cooperation development over time: the two projects had monthly meetings (that were active in several parts of the OntoCommons project) where the partners exchanged ideas, stream-lined the cooperation format. Then the partners met at multiple occasions virtually or face to face, where the most notable events are listed in Section 2.

[1] https://sites.google.com/view/semiim-2023/home

Besides multiple inspirational events and knowledge exchanges, the 2 projects jointly developed several tangible outcomes:

1. Scientific publications, for example, of a Bosch standardized welding ontology. As in Fig 1.
2. DOME 4.0 platform onto., its alignment to OntoCommons top level ontologies (See details in D3.2)
3. Milestone 5 has been accomplished
4. Multipage evaluation document/guidelines that was applied to DOME 4.0 use cases

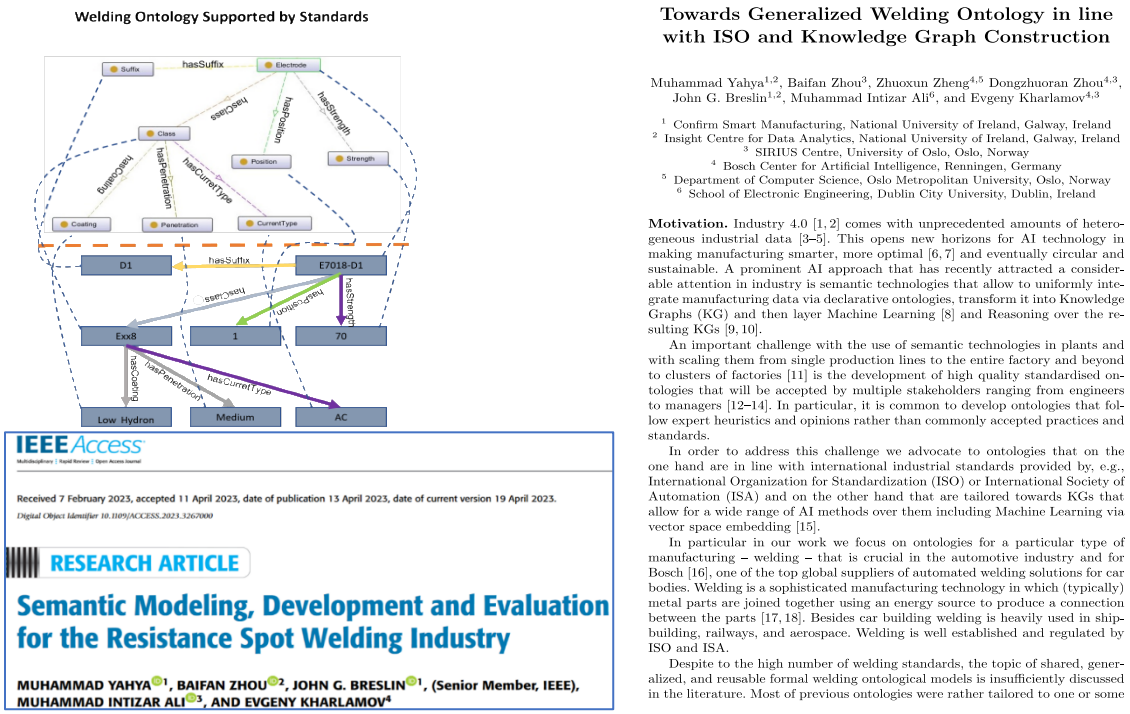

Figure 1: Top left – welding ontology, bottom left and right – joint DOME 4.0 and OntoCommons publication

In terms of the cooperation development over time: the two projects had monthly meetings (that were active in several parts of the OntoCommons project) where the partners exchanged ideas, stream-lined the cooperation format. Then the partners met at multiple occasions virtually or face to face, where the most notable events were:

- Online Workshop on Tools for Ontology Engineering, March 2021
- OntoCommons workshop "Industry Commons Marketplaces", on-line, 29th April 2021, organized by Fraunhofer IWM. [Event webpage, where presentations slides are available too: https://ontocommons.eu/news-events/events/ontocommons-workshop-industry-commons-marketplaces]
- DORIC-MM @ ESWC 2021 workshop that featured keynote speakers from both projects (Hedi Karray and Evgeny Kharlamov) and well as a panel, on-line, June 2021
- Joint workshop face-to-face at Galway during back-to-back projects meetings of DOME 4.0 and OntoCommons, Dec 2022

- Demo Workshop at Stuttgart organized by Bosch where both DOME 4.0 and OntoCommons demonstrators were presented, discussed, and evaluated, Nov 2022
- Joint SemIIM workshop at ESWC 2022
- DOME 4.0 Industrial Engagement Open Day and Hackathon, Bologna, Jan 2023
- Joint workshop at Berlin during the Data Market Places event organizer by Fraunhofer from OntoCommons, April 2023
- 4th EMMC International Workshop, Vienna, April 2023
- OntoCommons 2nd Global Workshop, Oslo, June 2023
- DOME 4.0 Industrial Engagement Open Day and Hackathon in Leuven, Oct 2023
- Joint SemIIM workshop at ISWC 2023, Nov 2023
- NeSyAI Tutorial at ISWC 2023, Nov 2023

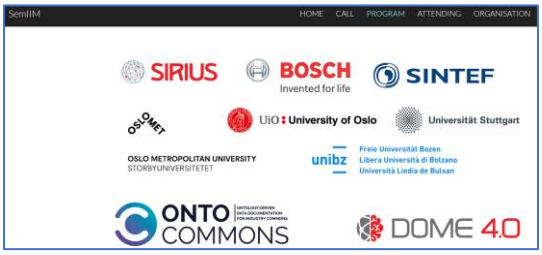

Figure 2: Screenshots from the SemIIM workshop's webpage; the workshop had a session and talks jointly organized by DOME 4.0 and OntoCOmmons

Note that the jointly produced guidelines that were mainly developed within T5.2 of DOME 4.0, contributed also to the OntoCommons deliverable D2.9 "Recommendations and Guidelines for TLOs and MLOs" (developed also with the collaboration of ENIT, CNR, and UNIBO, see the OntoCommons deliverable D2.9).

3. Guidelines for Ontology Evaluation: OC-DOME Ontology Evaluation Template

The guidelines development and evaluation was a considerable part of the DOME4.0 – OncoCommons cooperation, in particular we had:

- Online meetings among ontology-experts to develop the guidelines for ontology evaluations as well as offline work to created the guidelines.
- Online meetings between domain-experts belonging to the various DOME4.0's show-cases and the ontology-experts that developed the guidelines to explain and facilitate their application, as well as to conduct the actual evaluation and document it.
- Finally, we organized the session "Ontology Standardization Meets Data Marketplaces"of the Second International Workshop on Semantic Industrial Information Modelling (SemIIM, https://sites.google.com/view/semiim-2023/home), co-located with ISWC 2023.

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The section is organized as follows:

- in Section 3.1 we give a summary of our approach
- in Section 3.2 we discuss how to perform Ontology Evaluation that we conducted for Dome 4.0
- In Section 3.3 we give clarification on how to fill our OC-DOME Ontology Evaluation Template
- In Section 3.4 we introduce our OC-DOME Ontology Evaluation Template
- In Section 4.5 we discuss how our approach is related to other existing methodologies

3.1. Summary of Our Approach

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Subsequently, these guidelines were applied to assess the DOME 4.0 ecosystem ontology and DOME4.0 showcases, involving the instantiation of the OC-DOME Ontology Evaluation Template (referred from now on simply as “template”) during the evaluation process, yielding corresponding reports.

During the evaluation process every step of the evaluation template was filled out with a first version of evaluation, either by the experts that had developed the template, after having appropriately studied the

evaluated ontology and having been briefed by the showcase personnel that developed the showcase ontology; or by the showcase personnel themselves. In both cases, such first versions were later reviewed by the remaining personnel/experts. Finally, after having addressed any issues of comments raised during such actions, the reports were finalized.

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Notice that part of the material of this section can also be found in OntoCommons' deliverable D2.9, since the activities described in this document were a collaboration between the DOME and OntoCommons projects.

3.2. Introduction to Ontology Evaluation

Ontologies are formal, explicit specifications of a shared conceptualization[3]. That is, they are descriptions of the knowledge a community shares on some relevant domain, encoded in some formal language, and they try to represent explicitly as much of that knowledge as possible.

This definition is very general, and as such several software artifacts may be considered ontologies, but the term is usually linked to knowledge graphs, especially those using the standards of the W3C. Note that RDF and RDFS graphs, OWL ontologies, and SHACL graphs fall within this category.

Due to their nature, ontologies are notoriously difficult and time consuming to evaluate. The notion of ontology quality itself is object of discussion. At the very least, several different aspects are always considered to be part of the quality of an ontology. A high-quality, completely automated, and comprehensive evaluation of ontologies may not be possible.

[2] https://sites.google.com/view/semiim-2023/home

[3] https://jbiomedsem.biomedcentral.com/counter/pdf/10.1186/s13326-017-0172-7.pdf -- MIRO: guidelines for minimum information for the reporting of an ontology, Nicolas Matentzoglu , James Malone, Chris Mungall, and Robert Stevens

In order to facilitate and standardize ontology evaluation we supply a template, which lists a series of steps that should be carried out in order to evaluate comprehensively an ontology.

For each ontology, this template should be instantiated, and a corresponding report should be produced.

Since the literature on ontology evaluation is conspicuous, naturally, similar efforts were already present in the literature. Arguably, endeavours in this context that are most relevant to this document are the MIRO[4] (Minimum Information for Reporting of an Ontology) guidelines and the FOCA[5] methodology. In Section 3.5 the key steps of these methodologies are recalled, andan alignment is drawn between those and the template supplied in this document.

3.3. Clarifications on How to Fill OC-DOME Ontology Evaluation Template

Here, for each step in the OC-DOME template (that will be report in full in the next section), a corresponding clarification is supplied, which gives an indication on how to compile the step and/or on how to better develop or update the ontology in relation to the topic of the step.

- Introduction (In)1 – The full title of the ontology, expanding any eventual acronym.
- In2 – Where the ontology can be accessed at the moment. It is better if the ontology can be freely accessed at the address given by a resolvable URL (e.g. http://www.w3.org/2006/time, for the OWL Time Ontology), but if the ontology is not available in such a way, or not at all, indicate it here.
- In3 – What is the ontology purpose, that is why it was developed. For instance, an ontology may be developed with the high-level goal of bettering the management of knowledge and/or data of some company. In that case briefly explain why and how the ontology can achieve this. In other cases proceed analogously.
- In4 – Ontologies can range from very light-weight vocabularies to complex foundational ontologies. Refer to this table for basic ontologies types:

Basic types of ontologies [extracted from OntoCommons deliverable D2.9]	
Type	Description
Top Level Ontology (TLO)	A top-level ontology is an ontology (in the sense used in information science) which consists of very general concepts (e.g., the concepts of object, property, relation) that are common across all domains. In this document we also talk about “upper level ontologies”, for sake of simplicity, we use TLOs and upper level ontologies as synonymous terms
Middle Level Ontology (MLO)	Mid-level ontologies are primarily intended to extend and specialise the concepts of TLOs towards a set of specific disciplines with the aim of providing a core shared

[4] https://jbiomedsem.biomedcentral.com/counter/pdf/10.1186/s13326-017-0172-7.pdf -- MIRO: guidelines for minimum information for the reporting of an ontology, Nicolas Matentzoglu , James Malone, Chris Mungall, and Robert Stevens

[5] https://jbiomedsem.biomedcentral.com/counter/pdf/10.1186/s13326-017-0172-7.pdf -- MIRO: guidelines for minimum information for the reporting of an ontology, Nicolas Matentzoglu , James Malone, Chris Mungall, and Robert Stevens

	vocabulary for lower-level modules. A MLO will generally provide a higher level of detail than a TLO, extending the taxonomical structure of the ontology more along on the horizontal dimension (i.e., sibling classes under the same superclass).
Domain Ontology (DO)	Domain-level ontologies are further specialisations of MLOs, even closer to the application level. The vast majority of their concepts is related to a specific discipline/domain, with a few instrumental/pragmatic exceptions, and vertical connectors.
Application Ontology (AO)/Task Ontology	Application-level ontologies are further specialisations of DLOs, explicitly or implicitly hinged on a specific set of application cases. They usually include concepts related to a specific set of intended tasks rather than concepts related to a discipline per se.

- Functional requirement (Fu)1 – Has the ontology been developed to answer a certain set of requirements? A discussion of possible requirements can be found in [How to Write and Use the Ontology Requirements Specification Document, Mari Carmen Suárez-Figueroa, Asunción Gómez-Pérez, and Boris Villazón-Terrazas; a corresponding template is available at https://github.com/oeg-upm/LOT-resources]. A typical division between requirements is functional (what can the ontology do, usually interpreted as what queries or inferences does the ontology support) or non-functional (what are the `general' characteristics of the ontology, e.g. maintainability, multi-lingual support, etc.), but on a high-level this difference may not always be expressed. If the ontology is detailed in some research paper, a common costume is to list a series of requirements at the start of the paper. In addition, some ontology-development methodologies expressively asks for a list of requirements in input.
- Fu2 – Discuss here if the ontology satisfies the high level requirements specified in Fu1. This discussion is of high level, so no standard way to carry it out exists. One could, e.g., convert the high level requirements into narrower requirements, easier to check and formalize (e.g. SPARQL competency questions), check the satisfaction of those instead, and argue that therefore the ontology satisfy the high level requirements.
- Fu3,4 – Competency questions are questions that the ontology should be able to answer to. They are usually expressed first in natural language, then translated in a formal language. At first they were intended to be a set of questions that should be entailed, using logical inference, by the ontology [M. S. Fox and M. Gruninger, "Ontologies for enterprise integration," in CoopIS, 1994, pp. 82–89.], but then shifted to mean a set of questions that could be translated into SPARQL query language in order to check the ontology expressiveness. However, if interpreted in such a way, competency questions are more apt to enquire about asserted instance data only [Camila Bezerra, Fred Freitas, and Filipe Santana. 2013. Evaluating Ontologies with Competency Questions. In Proceedings of the 2013 IEEE/WIC/ACM International Joint Conferences on Web Intelligence (WI) and Intelligent Agent Technologies (IAT) - Volume 03 (WI-IAT '13). IEEE Computer Society, USA, 284–285. https://doi.org/10.1109/WI-IAT.2013.199]. Examples of competency questions can be find e.g. in [Potoniec J, Wiśniewski D, Ławrynowicz A, Keet CM. Dataset of ontology competency questions to SPARQL-OWL queries translations. Data Brief. 2020 Jan 7;29:105098. doi: 10.1016/j.dib.2019.105098. PMID: 31989008; PMCID: PMC6971340]. If some competency questions have been formulated for the ontology put them here.
- Fu5 – Discuss if reasoning is useful or not to answer the functional requirements given in competency questions. If the ontology is intended to be just a vocabulary for annotations, it is reasonable that it does not make use of axioms at all, but if the ontology wants to also model a

given (or many) domain(s) using some axioms, are these axioms useful in answering the competency questions?

- Fu6,7 – Sometimes competency questions can be used to evaluate just the expressiveness of an ontology, in the sense that the ontology is thought to have a good expressiveness if its signature (=its classes and properties) allows to formulate many/all questions from a given relevant list in a natural (=easy to read) way. If that is the case, then one may not even need to test the competency questions against data. On the other hand, if there is the expectation that the ontology should be queried to retrieve data, testing of actual query-answering capability may be critical.
- Structural requirement (S)1,2 – If the ontology has been serialized as a graph, e.g. an RDF or OWL graph, one can calculate many metrics based on the structure of the graph (e.g. the breadth, width, and breadth-to-width ratio of a taxonomy, the average number of subclasses for a given class, etc.). There are numerous aspects of ontology quality in general, and many of these have been linked to sets of these numerical metrics. However, there meaning carried by these scores is matter of debate. In any case, if scores have been calculated for some of such metrics, always discuss their meaning case by case, in the context of the ontology, and prefer relative comparisons (e.g. compare the scores calculated from the target ontology to those calculated from similar ontologies).
- S3 – Use OOPS! And discuss the ensuing evaluation.
- Ontological requirement (On)1 – The specific language the ontology is expressed in. If the ontology is written in OWL one can use e.g. profilechecker (https://github.com/stain/profilechecker) to check which dialect of OWL the ontology is written in.
- On2,3 – The appropriateness of a language for a given ontology is a complex matter. Some basic considerations that should at least taken into account are:
  - The fact that the language is well-known.
  - Expressivity vs computability tradeoff: the more things the ontology can express the more difficult reasoning and other tasks become, and vice-versa.
  - Close vs open world: open-world-assumption-languages (such as OWL) allow for continuous schema integration, but make data validation difficult. Vice-versa for closed-world-assumption-languages (such as SHACL). Some limited work exists already that helps with choosing among the different OWL profiles (see e.g. [C. Maria Keet, An Introduction to Ontology Engineering, p.99]).

  The mention of “unnatural constructs” can be interpreted as e.g. the presence of complex queries, for example, suppose that a relational database contains a table (‘sales’) with three columns and the primary key (‘id’, ‘seller’, ‘buyer’, ‘sale_date’). If we want to answer the competency question ‘who bought something from a given seller and at which date?’, the corresponding SQL query should look like this:
  SELECT buyer, sale_date FROM sales WHERE seller = <the given seller>
  while, if the databased is mapped to an ontology schema, a corresponding SPARQL query may, depending on the way the ontology schema is structured, look like this:
  SELECT ?buyer, ?sale_date WHERE {<the given seller> :wasSellerIn ?sale . ?sale :tookPlaceInDate ?sale_date . ?buyer :wasBuyerIn ?sale.}

Notice that due to RDF being a graph language we had to reify the ternary table. This may be considered an inconvenience, and the resulting query structure non-intuitive. Conversely, queries that relates many different tables in a relational database, or many different concepts in an ontology, will likely bring to a very confusing SQL query in the first case, while to a clear SPARQL query in the second case.

- On4 – Check if the ontology is consistent using an appropriate tool, such as Protegé with some reasoning engine. The ontology has to be consistent, moreover, the reasoning engine can reveal otherwise-unseen errors in the ontology: they may become evident if nonsensical inferences arise, then, by looking at the proof of the inference, one can correct them.
- On5 – If the ontology is a logical theory, can logical inference be used to some purpose? If not, why was the ontology developed as such?
- On6 – Discuss the axioms present in the ontology, if any. Unfortunately, this has to be done manually by some human expert, and there is no standard way.
- On7 – Alignment with an upper ontology can also be achieved indirectly, by aligning the ontology to an ontology itself aligned with an upper ontology. Alignment among ontologies, up to the level of upper ontologies, in one of the key parts of the EU project OntoCommons, since such an alignment propagates good ontological practices, maximize ontology reuse, and spares e.g. domain experts from having to model very abstract patterns, among other reasons. Alignment itself, in its most basic level, consists in stating meaningful equivalence and subsumption axioms between the classes and properties of the ontologies to be aligned. Some decision trees have been produced, that should help simplifying the work. For example, decision trees to align the classes of an ontology to DOLCE [C. Maria Keet, An Introduction to Ontology Engineering, p.129] and to
  BFO [Bernabé, C.H., Keet, C.M., Khan, Z.C., Mahlaza, Z. A method to improve alignments between domain and foundational ontologies, FOIS 2023] upper-level ontologies.
  Choosing which upper level ontology align to, or arguing why a given upper level ontology was chosen, is another complex activity. The difficulty may be lessened through the use of tools such as ONSET (http://www.meteck.org/files/onset/). In any case, since alignments between some of the most common top level ontologies are among the outputs of the OntoCommons project, in the future the choice of a top level ontology will be less problematic.
- On8 – The OntoClean methodology was developed to ensure good quality of taxonomies from an ontological point of view. Unfortunately it must be applied manually by an expert. However, if proper alignment with an upper ontology was carried out, then this step should become redundant.
- On9 – Same as On7 but for narrower-scope ontologies.
- On10 – One should always ensure, by e.g. carrying out a proper literature review, that all the ontologies that could have been reused have been reused. If some ontology describing a relevant domain already exists, but was not reused, explain why (e.g. the scope is too narrow, that ontology would not satisfy the requirements, etc.).
- On11,12 – Ontology quality is many-faced, coverage of the relevant domain is one of the most important aspects. Discuss if and why the ontology covers the relevant domain. One could e.g. refer to the requirements list and claim that, by covering all the requirements related to expressiveness (e.g. competency questions), the ontology covers the relevant domain. Another typical approach consists of comparing the ontology to a list of domain-terms and checking how

many of the terms are included in the ontology. The term list itself may be hand-crafted by domain experts or automatically extracted from a corpus of relevant literature.

- On13 – List any relevant standard that the ontology conforms to here.
- On14,15,16,17 – Good quality annotations are important and allow for automated extraction of good quality ontology documentation through tools such as WIDOCO (https://dgarijo.github.io/Widoco/). Adherence to the OntoCommons' annotation guidelines (see OntoCommons D2.9, Section 5.2-5.3) is encouraged, both for annotation related to the terms on an ontology and for the metadata annotating the ontology itself.
  Additionally, some naming convention should be specified and followed through. Again, adherence to OntoCommons' guidelines is encouraged (see OntoCommons D2.9, Section 5) The Evaluation of the annotations is another complex matter, one could argue e.g. that the annotation have good quality since they conform to some reasonable annotations guidelines or one could carry out an appropriate user study.
- Expert or user testing requirement (Ex) 1,2,3 – As part of the evaluation, the ontology should be evaluated by domain experts, ontology experts, and users (if the latter are different from the formers). There is no standard way to do this, but usually a questionnaire is supplied to the experts and the users. As an output of the OntoCommons project, it is being considered if and how to supply a standard way to carry out these steps.
- FAIRness requirement (Fa)1,2 – The ontology should be evaluated with respect to FAIRness principles. These five questions are just a remainder of some main aspects of FAIRness, but using any dedicated tool (such as FOOPS! - https://foops.linkeddata.es/about.html, Or O'FAIREe - https://github.com/agroportal/fairness, or FAIR-Checker - https://fair-checker.france-bioinformatique.fr/) will evaluate all of the FAIRness indicators, then one can just report the results here.
- Fa3,4,5 – These are just some key points related to the Accessibility (the "A" in FAIR) of the ontology: a full FAIRness evaluation given e.g. in the previous points will cover also these steps. These three steps highlight the need for an ontology to be openly shared (with a corresponding license). If the ontology contains sensitive data, please consider the possibility to share at least the schema. Additionally, long term accessibility of the ontology is another important aspect. If the ontology's developer are not able or willing to commit to long-term hosting of permanent URIs, then they may consider to use e.g. the W3C's Permanent Identifiers for the Web project (https://w3id.org/).
- Lifecycle requirement (Li)1,2 – The lifecycle of the ontology should be explicitly planned for. That is, some well-defined personnel should be tasked with long-term maintenance of the ontology.
- Conclusion (Co)1 – After having gone through all previous steps, have some critical issued appeared? If so, how one could adjust them in the future?
- Co2 – Summarize the key points of the evaluation.

3.4. OC-DOME Ontology Evaluation Template Body

The completion of steps marked with a * depends on the answers provided for previous steps, accordingly they may have to be left blank. Additionally, depending on the type of ontology considered (In4) some steps should be focused on more than others. This is indicated in the following table, where the cell contents indicate if the given step must/should/may be focused on depending on the ontology type:

Steps to focus on depending on the ontology type			
Step identifier	**TLO**	**DO**	**AO**
Title	MUST	MUST	MUST
Location	MUST	MUST	MUST
Purpose	MUST	MUST	MUST
Generality	MUST	MUST	MUST
High Level Requirements	MUST	MUST	MUST
Competency questions	MUST	MUST	MUST
Metric testing	MAY	SHOULD	SHOULD
Structural good-practices	MUST	MUST	MUST
Logical Properties	MUST	MUST	MUST
Ontological properties	MUST	SHALL	MAY
Concept coverage	MUST	MUST	MAY
Terminology	MUST	MUST	SHOULD
Users	MAY	MUST	MUST
Fairness	SHOULD	MUST	MUST
Ontology Lifecycle	MUST	MUST	MUST
Suggestions	MUST	MUST	MUST
Summary	MUST	MUST	MUST

We now give details on each of the step identifier and group them in 8 Groups:

1. Introduction
2. Functional Rers
3. Structural/topological testing
4. Logical, ontological, and terminogical aspects
5. Experts and users feedback
6. FAIRness resq
7. Ontology lifecycle reqs
8. Conclusion

Group 1

	Introduction	
#	Requirement	Description
In1	Title	The title of the ontology.
In2	Location	Where can the ontology (currently) be accessed.
In3	Purpose	Provide an overview of the purpose of the ontology in the context of the company's data and knowledge management.
In4	Ontology generality	Is the ontology an upper-level ontology, a middle-level or domain ontology, or an application/task ontology?

Group 2:

Functional requirements		
#	Requirement	Description
Fu1	High-level requirements	Is the ontology linked to a set of high-level requirements (for instance, business/domain experts' requirements or research questions)?
Fu2*		If so, does the ontology satisfy (all of) them?
Fu3	Competency questions	Is the ontology linked to a set of competency questions?
Fu4*		If so, how are the competency questions serialized (e.g. natural language, SPARQL, DL query)?
Fu5*		Is reasoning used to answer the competency questions (e.g., if R is a transitive relation, and the facts R(a,b) and R(b,c) are stated, when querying for x such that R(a,x), is c also returned)? Why yes or why not?
Fu6*		Were the competency questions executed against an ontology containing data?
Fu7*		If so, is there the expectation that there will be scalability issues when the queries will be run against data when in production?

Group 3:

Structural/topologic testing		
#	Requirement	Description
S1	Metric testing	Has the ontology been tested using a tool which extracts quantitative metrics about the ontology structure?
S2*		If so, are there any values that could indicate bad/good quality (for each, if any, indicate way it is so)?
S3	Structural good-practices	If the ontology is in the RDF language, what was the evaluation result using OOPS?

Group 4:

Logical, ontological, and terminological aspects		
#	Requirement	Description
On1	Logical properties	Which language is the ontology expressed in?
On2		Is this a good language for the goal of the ontology (e.g., is the open/closed-world assumption reasonable if employed?
On3		Does this language entail that some intended models are excluded from the ontology, or that some unnatural constructs have to be used?
On4		Is the ontology consistent?
On5		Does the ontology support particular reasoning tasks?
On6	Ontological properties	Do the axioms present in the ontology clearly and correctly model the target domain?
On7		Is the ontology aligned with an upper ontology?
On8		If not, why, and has the ontology's taxonomy been analysed using e.g. OntoClean or other Applied-Ontology-methodologies?
On9		Is the ontology aligned with some middle/domain-level or application/task-level ontology?

On10		Are there any (additional) pre-existing middle/domain-level or application/task-level ontologies that could have been reused?
On11	Concept coverage	Does the ontology cover the relevant concept of the domain?
On12		In which way was it tested?
On13		Does the ontology conform to, or is linked to, some pre-existing standards (if not explain why)?
On14	Terminology	Does the ontology conform to some guidelines for annotations?
On15		Are common terminological and naming conventions respected?
On16		Are the annotations clear and satisfactory for users?
On17		Is there any documentation describing the ontology?

Group 5:

	Experts' and users' feedback	
#	Requirement	Description
Ex1	Users	Has the ontology been evaluated by some ontology-experts?
Ex2		Has the ontology been evaluated by some domain-experts?
Ex3		Has the (application/task build using the) ontology been evaluated by prospective users?

Group 6

	FAIRness requirements	
#	Requirement	Description
Fa1	FAIRness	Has the ontology been evaluated with respect to FAIRness?
Fa2*		If so, how and with which result?
Fa3		In particular, is the ontology openly available?
Fa4*		If not, for what reason and could, at least the schema or a module of the schema being made available?
Fa5		Where is the ontology hosted and how will it be able to be accessed long term?

Group 7

	Ontology lifecycle requirements	
#	Requirement	Description
Li1	Ontology lifecycle	Is the ontology expected to evolve in the future?

Li2		Is there some staff in charge of maintaining and/or updating the ontology?

Group 8

	Conclusion	
#	Requirement	Description
Co1	Suggestions	Based on the evaluation findings, suggest improvements and potential enhancements.
Co2	Summary	Summarize the key takeaways from the evaluation.

3.5. Alignment with other Methodologies

In this section the FOCA questions and the MIRO properties are reported in full, and a cursory alignment between them and the template steps is shown and briefly discussed. As a brief holistic comparison, one can notice that

- MIRO (Minimum Information for Reporting an Ontology) consists in a list of *information items* (divided in sections from A to G) that have been developed to ensure higher quality and completeness of ontology reports, such as research papers describing a newly-developed ontology. As, such, they focus on how to completely describe an ontology and not on how to carry out an evaluation, indeed, MIRO's section "G. Quality Assurance" mandates to report how an ontology has been evaluated but does not mandate how to evaluate an ontology. The latter is, instead, the focus of this work. There is still a good deal of overlapping, however, which is detailed in the following table.
- On the other hand, the FOCA methodology is focused on ontology evaluation itself. Similarly to the OC-DOME Ontology Evaluation guidelines described in this document, following the FOCA methodology one starts by classifying the ontology to be evaluated in three types (task/domain/top-level), then proceeds to answer some questions each one linked to different aspects of ontology quality. The main difference with our guidelines are
    - that FOCA's questions are 13, focusing only on competency questions, and on some logical, ontological, and annotation-related aspects; while the OC-DOME template has 43 questions, which also span lifecycle- and FAIRness-related issues.
    - And that FOCA's answers consists of a single numerical value between 0 and 100, which are then aggregated in a single numerical value between 0 and 1, which functions as the "total quality" of an ontology; while the answers in the OC-DOME template are open-ended and no single number is offered as summary for the quality of the ontology

The full list of FOCA questions can be found at https://arxiv.org/pdf/1612.03353.pdf. The full list of MIRO guidelines can be found at https://github.com/owlcs/miro/blob/master/miro.md.

	Alignment with other methodologies		
ID of template step	ID of FOCA question	ID of MIRO property	Comment on the alignment (if needed)
In1		A.1	
In2		A.4	
In3		B.1, C.1	C.1 is split between scope/purpose, requirements, and CQs
In4		C.1	
Fu1	Q1	B.1, C.1, G.1, G.2	FOCA has only 2 questions related to functional requirements
Fu2	Q2	C.1, G.1, G.2	
Fu3	Q1	C.1, G.1, G.2	
Fu4	Q1	C.1, G.1, G.2	
Fu5	Q1	G.1, G.2	
Fu6	Q2	G.1, G.2	
Fu7	Q2, Q10	G.1, G.2	
S1		E.3	
S2		E.3	
S3			
On1		E.1	
On2			
On3			
On4	Q7, Q9	G.1	
On5	Q7, Q10		
On6		E.10	
On7	Q3	E.4, E.8	
On8	Q3	E.8	
On9	Q3	E.4	
On10	Q3	B.2	
On11	Q6		
On12	Q6		
On13			
On14	Q12, Q13	C.2, E.5, E.7, F.3	C.2 is entailed in On14 if the guidelines given above in Section **Error! Reference source not found.** for ontology metadata annotations are followed; same for F.3 Notice that E.7 title "Entity metadata policy" de facto is synonymous with "entity annotation policy"
On15	Q12, Q13	E.5	
On16	Q11, Q12, Q13		
On17	Q11, Q12, Q13		
Ex1			
Ex2		B.3	B.3 is implicit in Ex2, Ex3
Ex3		B.3	
Fa1		A.3, E.11	E.11 is implicit in Fa1
Fa2		A.3	

Fa3		A.3	
Fa4			
Fa5		A.4, E.11	
Li1		F.1	
Li2		F.1	
Co1			
Co2			
Remaining FOCA and MIRO items not aligned in the previous table			
ABSENT	Q4, Q5, Q8	A.2, A.5, A.6, C.3, D.1, D.2, D.3, E.2, E.6, E.9, F.2, G.3, G.4, G.5	Knowledge Acquisition of MIRO is not present in the template nor in FOCA's questions E.9 separates distinguishes properties and relationships from other ontological entities; This could look similar to FOCA's Q6 question, that also mentions properties, but the elucidation of Q6 mentions both classes and properties. The "Quality assurance" (and especially G.3-5) of MIRO is not present within the template, as the template is itself an evaluation. In particular, G.1 and G.2 are answered by the template itself, while G.3, G.4, G.5 are absent
PARTIAL	Q6, Q9, Q10, Q11	B.3, E.10	E.10 (using axiom templates) complliance is a possible method to On10 compliance

4. Ontology Evaluation Reports

We will now report on those showcases that had sufficient maturity in terms of ontology development to undergo evaluation. Please see details of what the use cases are about here: https://dome40.eu/dome-40-showcases

4.1. Introduction

After elaboration of the guidelines, the DOME 4.0 showcases' owners were reached out in order to start the evaluation process. However, many of those answered that the maturity of their data models is currently not at the level of having ontologised data. Therefore, only a minority of the showcases started the evaluation process, resulting in the reports attached below. Additionally, the DOME4.0 marketplace platform itself also underwent evaluation,producing a corresponding report.

4.2. Evaluation of SC1 – Evaluation of Chemical Kinetics Knowledge Graph (dating November 2023)

	Introduction	
#	Requirement	Description
In1	Title	The title of the ontology.
		OntoDerivation: Derived Information Framework ontology OntoAgent: Agent ontology OntoEMS: Environmental Measurement Station ontology OntoDispersion: Ontology for pollutant dispersion
In2	Location	Where can the ontology (currently) be accessed.
		OntoDerivation: TheWorldAvatar/JPS_Ontology/ontology/ontoderivation/OntoDerivation.owl at main · cambridge-cares/TheWorldAvatar (github.com) OntoAgent: TheWorldAvatar/JPS_Ontology/ontology/ontoagent/MSM.owl at main · cambridge-cares/TheWorldAvatar (github.com) OntoEMS: TheWorldAvatar/JPS_Ontology/ontology/ontoems/OntoEMS.owl at main · cambridge-cares/TheWorldAvatar (github.com) OntoDispersion: TheWorldAvatar/JPS_Ontology/ontology/ontodispersion at dev-aermod-vis · cambridge-cares/TheWorldAvatar (github.com)
In3	Purpose	Provide an overview of the purpose of the ontology in the context of the company's data and knowledge management.
		OntoDerivation: Stores metadata for derivations where some information is calculated from other pieces of information. OntoAgent: Provides core vocabulary for capturing service properties. OntoEMS: Represents environmental measurement stations, reported quantities, and associated reading time series. OntoDispersion: Represents data on pollutant dispersion simulations.
In4	Ontology generality	Is the ontology an upper-level ontology, a middle-level or domain ontology, or an application/task ontology?
		All the mentioned ontologies are predominantly application/task-oriented.

	Functional requirements	
#	Requirement	Description
Fu1	High-level requirements	Is the ontology linked to a set of high-level requirements (for instance, business/domain experts' requirements or research questions)?
		The ontologies are linked to high-level research project question on demonstrating cross-domain interoperability, however, these have not been linked syntactically. OntoAgent and OntoDerivation are designed to represent the processes of agent activity, simulation, and derivation within the knowledge graph.

		OntoEMS and OntoDispersion cater to the need to describe pertinent data such as weather, ship data, and emissions, specifically for the ship emission dispersion case study.
Fu2*		If so, does the ontology satisfy (all of) them?
		Yes, the ontologies satisfy the high-level requirements regarding a research project demonstrator.
Fu3	Competency questions	Is the ontology linked to a set of competency questions?
		The ontologies are indirectly tied to competency questions through SPARQL queries used in the showcases for data access across various domains.
Fu4*		If so, how are the competency questions serialized (e.g. natural language, SPARQL, DL query)?
		Competency questions are serialised in both natural language and SPARQL.
Fu5*		Is reasoning used to answer the competency questions (e.g., if R is a transitive relation, and the facts R(a,b) and R(b,c) are stated, when querying for x such that R(a,x), is c also returned)? Why yes or why not?
		No. Reasoning is not employed for the competency questions. The underlying data structures are straightforward, making complex reasoning unnecessary.
Fu6*		Were the competency questions executed against an ontology containing data?
		Yes, the competency questions have been executed using the ontologies in conjunction with real data (e.g. weather data) as part of the showcase.
Fu7*		If so, is there the expectations that there will be scalability issues when the queries will be run against data when in production?
		No scalability issues are anticipated when executing queries against real shipping data (around a dozen per day).

	Structural/topologic testing	
#	Requirement	Description
S1	Metric testing	Has the ontology been tested using a tool which extracts quantitative metric about the ontology structure?
		Yes, the ontology has been evaluated using the OntoMetrics.
S2*		If so, are there any values that could indicate bad/good quality (for each, if any, indicate way is so)?
		The Tangledness metric for OntoEMS stands at 0.121951, suggesting potential simplification in its structure. Conversely, OntoAgent has achieved a high relationship richness score of 0.928571, indicating its comprehensive relational architecture.
S3	Structural good-practices	If the ontology is in the RDF language, what was the evaluation results using OOPS?
		The four ontologies have been assessed using the OOPS! tool. The results can be easily reproduced by simply providing the tool with the address of the .owl files hosted on TheWorldAvatar GitHub. A summary of the main results is as follows: • It is found that many basic annotation properties are missing in the examined ontologies. For example, OntoAgent only have five rdfs:comment annotations that briefly describes the entities they referred to. Meanwhile, most entities lack any annotations, and their names are derived from the terminal part of their readable IRI. Ontoderivation, on the other hand, uses rdfs:label to translate the terminal part of their readable IRI from camel/pascal case to sentence case, but provides no comments or definitions. In contrast, OntoEMS and Ontodispersion use rdfs:comment to provide concise definitions for most of their entities, except for Ontodispersion's entity "hasOntoCityGMLCityObject," in which the rdfs:comment is used as a note to explain the developers' reasoning. • There are a few properties with multiple domain ranges defined. The tool considered this a critical pitfall because it entails that the various domains/ranges intersect (or that the property can not be instantiated, which would clearly be another design error). This happens with: ○ om-2:hasUnit – The domains are Measure and Forecast. It is not clear if these two classes can intersect or not, so the developers should analyse this point and eventually correct it. Looking at the axiomatisation and annotations of the classes, it could also be that one is meant to be a

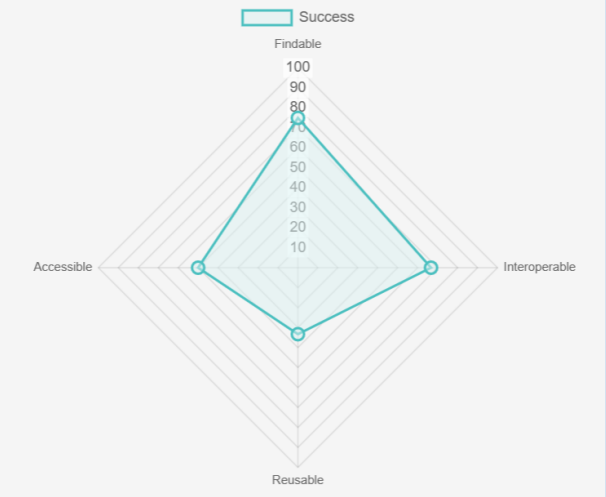
		subclass of the other (e.g. Measure subClassOf Forecast, as its stated axiomatisation is a strict specialisation of Forecast's), in that case, it would be sufficient to leave the more specific class only. ○ ontodispersion:hasPollutantID – The domains are Emission and DispersionOutput. It is still being determined whether these two classes can intersect, so the developers should analyse this point and eventually correct it. ○ ontodispersion:hasQuantity – The ranges are MassFlow, Density, Temperature. It is clear that the designer intended to write MassFlow or Density or Temperature, or possibly a cardinality constraint such as that each emission hasQuantity some Density, etc., and possibly hasQuantity only Density, etc. This should be corrected. • All four ontologies do not have disjointness axioms. This is considered an important pitfall by the tool, and, indeed, using disjointess axioms one could use reasoning to debug the ontology structure (for examples, design irregularities like the multiple ranges/domains of the previous point could entail contradictions), in addition to further constraint the classes meanings. For instance, ontoderivation:Finished and ontoderivation:InProgress look like classes that should be disjoint, but only the developers can say for sure (though, if those classes, as well as others analogous cases, are indeed not disjoint, that should be signalled explicitly, e.g. with some annotation). • The other identified pitfalls are either minor or result of conscious design decisions. In addition to the OOPS! Evaluation, opening OntoEMS with the Protegé editor reveals the punning of many classes. Further analysis shows that this is due to the following triples: rdfs:label rdf:type owl:DatatypeProperty ; rdfs:domain [rdf:type owl:Class ; owl:unionOf (ontoems:AirPollutantConcentration ontoems:ReportingStation)]. which states that rdfs:label is a data property with a precise domain; hence, all entities that are annotated with rdfs:label are necessarily considered individuals. Since some of these entities are also clearly outside of the stated domains (e.g. all the object properties with labels), this is clearly different from the result that the designers meant and should be corrected.

Logical, ontological, and terminological aspects		
#	Requirement	Description
On1	Logical properties	Which language is the ontology expressed in?
		The ontology is expressed in OWL. OWL is an apt choice for the goals of the ontology development and is suitable for CMCL's DOME 4.0 showcase. In particular, assuming that issues described in S3 are solved, all ontologies belong to the OWL DL profile (the one with most expressivity, but still decidable, albeit with high complexity) and Ontodispersion belongs also to OWL QL, as it has a very weak axiomatisation (checked using the tool "profilechecker").
On2		Is this a good language for the goal of the ontology (e.g., is the open/closed-world assumption reasonable if employed?
		Yes, since the ontologies are used to provide a schema for and to query appropriate data, without using reasoning algorithms
On3		Does this language entail that some intended models are excluded from the ontology, or that some unnatural construct have to be used?
		No, the chosen language does not exclude any intended models or necessitate using unnatural constructs.
On4		Is the ontology consistent?

		Yes, all 4 ontologies are consistent, after having checked with HermiT.
On5		Does the ontology support particular reasoning tasks?
		No
On6	Ontological properties	Do the axioms present in the ontology clearly and correctly model the target domain?
		Besides the possible errors outlined in S3, the correctness of the axioms correctness has been self-evaluated by domain experts that have developed and used the ontology.
On7		Is the ontology aligned with an upper ontology. If not, why,?
		No. The ontologies are not aligned with upper ontologies because it is outside the scope of the corresponding use case, with these ontologies being task-level ontologies. A manual review of the ontologies reveals that there could be at least one case where an entity from an upper-level ontology could have been reused. For example, instead of introducing OntoAgent:hasPart, the analogous property(ies) of the mereology module of the world avatar project, which the four ontologies of the showcase belong to, could have been reused. The developers should check if they can benefit from reusing more entities from higher-level ontologies of the world avatar. In addition, an alignment between the upper-level modules of the World Avatar project and well-known top-level ontologies could be beneficial, but it is well beyond the scope of the showcase.
On8		Has the ontology's taxonomy been analysed using e.g. OntoClean or other Applied-Ontology-methodologies?
		No. But as the ontologies are aligned with appropriate middle level ontologies, so, ideally, correct alignments would entail correct taxonomies, which do not need to be checked. The issue of quality of the taxonomy Is thus shifted to the quality of the alignments.
On9		Is the ontology aligned with some middle/domain-level or application/task-level ontology?
		Yes, several other ontologies have been reused/aligned with. For example, OntoEMS is aligned with the Thinkhome weather ontology, the M3-lite taxonomy, the Semanticscience Integrated Ontology, GeoSPARQL, and the Ontology of Units of Measure. The developers put effort into disambiguating synonymous terms (e.g. m3-lite:AirTemperature, OntoEMS:AirTemperature, and WeatherOntology:Temperature are declared as equivalent classes, though they are only subsumed by om-2:Temperature, which appears to be the correct alignment). Other points that deserve further analysis: • Whether it is appropriate to declare ShipType and Name as om-2:quantity (like speed, location, etc.) • A comment identifies PollutantID as a superclass of "pollutant identifier", but no entity with such a term exists in the ontology. More importantly, the OntoAgent ontology describes the minimal service model. The Dome4.0 marketplace ontology uses another ontology to describe the minimal service model (http://iserve.kmi.open.ac.uk/ns/msm#). There seems to be potential for alignment between the two ontologies (or use one of them in place of both).
On10		Are there any (additional) pre-existing middle/domain-level or application/task-level ontologies that could have been reused?
		Pre-existing task-level ontologies influenced OntoEMS and OntoDispersion developments but the developers made a conscious decision of using exactly the aforementioned 4 ontologies as they fit best their use case.
On11	Concept coverage	Does the ontology cover the relevant concept of the domain?
		Yes, the ontology covers the domain's relevant concepts.
On12		In which way was it tested?
		Testing has been limited to the functionality of the ontologies for demonstrating the showcase.
On13		Does the ontology conform to, or is linked to, some pre-existing standards (if not explain why)?
		No
On14	Terminology	Does the ontology conform to some guidelines for annotations (e.g. IOF annotation guidelines)?
		No, the ontology does not adhere to specific annotation guidelines like IOF.
On15		Are common terminological and naming conventions respected?
		Yes, established terminological and naming conventions have been followed.
On16		Are the annotations clear and satisfactory for users?

		External evaluations on the clarity of annotations have not been conducted yet.

	Expert' and users' feedback	
#	Requirement	Description
Ex1	Users	Has the ontology been evaluated by some ontology-experts?
		No
Ex2		Has the ontology been evaluated by some domain-experts?
		Yes and they found it satisfactory
Ex3		Has the (application/task build using the) ontology been evaluated by prospective users?
		No

	FAIRness requirements	
#	Requirement	Description
Fa1	FAIRness	Has the ontology been evaluated with respect to FAIRness?
		Yes
Fa2		If so, how and with which result?
		All ontologies have the same results from FAIR-Checker: 
Fa3		In particular, is the ontology openly available?
		Yes
Fa4		If not, for what reason and could, at least the schema or a module of the schema being made available?
Fa5		Where is the ontology hosted and how can be accessed?
		They are hosted on Github, see ln2

	Ontology lifecycle requirements

#	Requirement	Description
Li1	Ontology lifecycle	Is the ontology expected to evolve in the future?
		Yes, the ontology will be extended to include emissions from other sources in addition to those from ships.
Li2		Is there some staff in charge of maintaining and/or updating the ontology?
		Yes

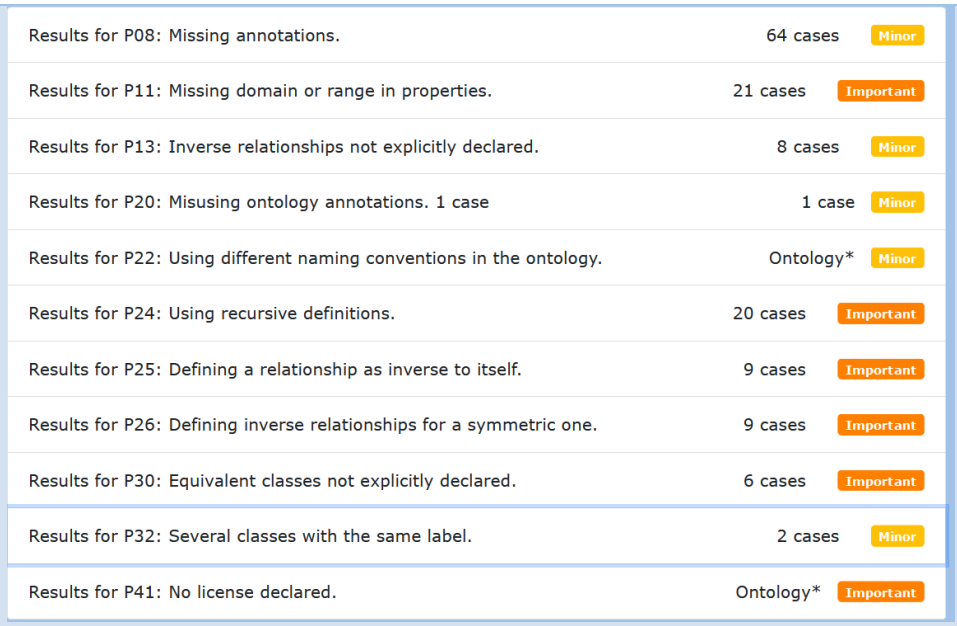
Conclusion		
#	Requirement	Description
Co1	Suggestions	Based on the evaluation findings, suggest improvements and potential enhancements.
		1. Ensure the ontologies adhere to standard guidelines and best practices. 2. Engage external domain experts for unbiased examination. 3. Intensify efforts to enhance the FAIRness of the ontologies. 4. Correct errors described in S3 and On9 5. Consider an alignment between OntoAgent and http://iserve.kmi.open.ac.uk/ns/msm#, which is used by the DOME4.0 marketplace ontology
Co2	Summary	Summarize the key takeaways from the evaluation.
		The developed ontologies effectively address the operational needs regarding the demonstration of the showcase. However, they remain highly application-specific and must fully adhere to ontology best practices. Based on the analysis of the ontology structure, of its annotations, and of its alignment with other ontologies there are some possible paths for improvement. Based on the FAIRness analysis, there is a notable need to incorporate metadata about provenances, licenses, external links, access protocols, and persistent IDs to enhance the FAIRness of the ontologies.

4.3. Evaluation of SC3 – Evaluation of the Plastic Simulation Ontology (dating November 2023)

Introduction		
#	Requirement	Description
In1	Title	The title of the ontology.
		Plastic Simualtion Ontology (plasticsim)
In2	Location	Where can the ontology (currently) be accessed.
		Currently the ontology is only available to Bosch researchers, but a publication is planned soon
In3	Purpose	Provide an overview of the purpose of the ontology in the context of the company's data and knowledge management.
		Find relevant data sources, to be used for plastic simulation, coming from various sources, such as different research labs and institutions.
In4	Ontology generality	Is the ontology an upper-level ontology, a middle-level or domain ontology, or an application/task ontology?
		The ontology is both a domain-level ontology, encompassing materials, material properties, and related software, in the context of innovative research in plastic simulation; and a task-level ontology, which should satisfy the purpose in the point In3.

	Functional requirements	
#	Requirement	Description
Fu1	High-level requirements	Is the ontology linked to a set of high-level requirements (for instance, business/domain experts' requirements or research questions)?
		The main requirement for the ontology is to facilitate recovering of relevant data sources to be used for plastic simulation. Moreover, an ontology requirements specification document was compiled, which contained a glossary of terms listed by domain experts, to be covered by the ontology.
Fu2*		If so, does the ontology satisfy (all of) them?
		The ontology has been developed in the context of DOME 4.0 project, and should be used to facilitate relevant dataset search in the DOME 4.0 marketplace. Since the marketplace is not fully operational yet, the task that the ontology should facilitate cannot yet be executed, so the confirmation of the satisfaction of this requirement should be postponed towards the end of the DOME 4.0 project.
Fu3	Competency questions	Is the ontology linked to a set of competency questions?
		Yes: a set of ten has been compiled by appropriate domain experts.
Fu3*		If so, how are the competency questions serialized (e.g. natural language, SPARQL, DL query)?
		The CQs are currently provided in natural language, and, currently, only part of them has been formalised in SPARQL. However, a complete formalisation of the CQs in SPARQL is planned.
Fu3*		Is reasoning used to answer the competency questions (e.g., if R is a transitive relation, and the facts R(a,b) and R(b,c) are stated, when querying for x such that R(a,x), is c also returned)? Why yes or why not?
		No.
Fu3*		Were the competency questions executed against an ontology containing data?
		Yes, the CQs that were translated in SPARQL were tested against mock data.
Fu3*		If so, is there the expectations that there will be scalability issues when the queries will be run against data when in production?
		No experiments were carried out, but scalability issues are not expected, since the databases receiving the queries should contain only limited amount of data (e.g. descriptions of material models, or data about material properties produced by some experiments, or metadata about appropriate datasets)

	Structural/topologic testing	
#	Requirement	Description
S1	Metric testing	Has the ontology been tested using a tool which extracts quantitative metric about the ontology structure?
		Yes: OntoMetrics
S2*		If so, are there any values that could indicate bad/good quality (for each, if any, indicate way is so)?
		After manual review of the metrics, no value stood out.
S3		If the ontology is in the RDF language, what was the evaluation results using OOPS?

	Structural good-practices	 However, most of the identified issues concern the ontology imported into the plastic simulation and not the plastic simulation itself. The issues that are relative to the plastic simulation itself are: - Some missing annotations, but this is only due to the fact that the annotation skos:prefLabel is used in place of rdfs:label to label entities. - The inverse relationship of one property was not explicitly declared. Such an inverse relationship was then declared. - Some issues with the naming conventions: this is only due to some entities containing hyphens (e.g. Visco-elasticModel) and they were left untouched. - Absence of a licence declaration: this is the main issue identified by OOPS! with the ontology. An appropriate licence will be added to the ontology after receiving internal approval from the company.

	Logical, ontological, and terminological aspects	
#	Requirement	Description
On1	Logical properties	Which language is the ontology expressed in?
		OWL 2 DL, checked using the tool profilechecker https://github.com/stain/profilechecker
On2		Is this a good language for the goal of the ontology (e.g., is the open/closed-world assumption reasonable if employed?
		Yes, it is a reasonable language to use, since the strong expressivity of OWL 2 DL may be used for the conceptual modelling of the domain. Dropping the expressivity of the ontology also in non-feasible since the ontology makes use of the DUL ontology
On3		Does this language entail that some intended models are excluded from the ontology, or that some unnatural construct have to be used?
		No
On4		Is the ontology consistent?
		Yes
On5		Does the ontology support particular reasoning tasks?
		No
On6	Ontological properties	Do the axioms present in the ontology clearly and correctly model the target domain?
		Yes: The ontology exploits some logical axioms to describe the domain the domain more accurately, which have been reviewed by ontology experts during development.
On7		Is the ontology aligned with an upper ontology. If not, why?

		Yes: the ontology is aligned to the upper ontology DOLCE, in particular to its OWL serialisation called DUL (DOLCE-ultra-lite). The alignment has been reviewed by an ontology expert and has been found satisfactory. Notice in particular that - the distinction between certain domain entities (Material vs Material Family/Type) has been interpreted as the difference between first and second order entities, and has been modelled by interpreting the latter as Concepts subclasses and the former as non-Concepts subclasses i.e. Material Family is a subclass of dul:Concept, while Material is a subclass of dul:Substance - the distinction between certain domain entities (e.g. Material Property vs Material Parameter, …) has been interpreted as the difference between rigid classes and roles; and has been modelled again using dul:Concept for the roles (e.g. Material Parameter is a subclass of Parameter, which is itself a subclass of Concept, while Material Property is a subclass of Quality).
On8		Has the ontology's taxonomy been analysed using e.g. OntoClean or other Applied-Ontology-methodologies?
		Since the ontology is aligned with DOLCE upper ontology it should automatically respect OntoClean's constraints. Additionally, a review from an ontology expert find no violation of OntoClean's constraints
On9		Is the ontology aligned with some middle/domain-level or application/task-level ontology?
		No
On10		Are there any (additional) pre-existing middle/domain-level or application/task-level ontologies that could have been reused?
		No: a review of the related literature was carried out, and no other suitable ontology was found. This is likely due to the domain being very specific and innovative.
On11	Concept coverage	Does the ontology cover the relevant concept of the domain?
		Yes
On12		In which way was it tested?
		The ontology covers the glossary of terms selected by domain experts mentioned in step Fu2
On13		Does the ontology conform to, or is linked to, some pre-existing standards (if not explain why)?
		No
On14	Terminology	Does the ontology conform to some guidelines for annotations (e.g. IOF annotation guidelines)?
		The annotation schema is as follows: Every entity has exactly one English skos:prefLabel and skos:definition, and optional English skos:altLabel and rdfs:comment annotations.
On15		Are common terminological and naming conventions respected?
		Yes: The IRI of the entities are constructed using a namespace prefixed to a readable string, which is written in PascalCase for classes and in camelCase for properties, while the skos:prefLabel annotations use Title Case.
On16		Are the annotations clear and satisfactory for users?
		The annotation have been evaluated and revised by ontology and domain experts and have been found satisfactory.

	Expert' and users' feedback	
#	Requirement	Description
Ex1	Users	Has the ontology been evaluated by some ontology-experts?
		Yes, ontology experts were involved in the evaluation of the ontology and found it satisfactory.
Ex2		Has the ontology been evaluated by some domain-experts?

		No: the ontology has been developed with the help of domain experts, but they have not evaluated the ontology. An evaluation by their part, with the role of users, is planned when the DOME4.0 marketplace will be fully operational.
Ex3		Has the (application/task build using the) ontology been evaluated by prospective users?
		The users of the ontology would be the same as the domain experts.

	FAIRness requirements	
#	Requirement	Description
Fa1	FAIRness	Has the ontology been evaluated with respect to FAIRness?
		No, since critical steps are currently yet to be carried out, such as (deciding if and how) to publish the ontology and supply it with a proper license.
Fa2		If so, how and with which result?
Fa3		In particular, is the ontology openly available?
		No
Fa4		If not, for what reason and could, at least the schema or a module of the schema being made available?
		The decision to openly release the ontology must go through an appropriate internal process
Fa5		Where is the ontology hosted and how can be accessed?
		n./a.

	Ontology lifecycle requirements	
#	Requirement	Description
Li1	Ontology lifecycle	Is the ontology expected to evolve in the future?
		Yes, in particular, - an eventual expansion of the ontology to express more formalized competency questions - an appropriate adjustment of the ontology to make it usable in the context of the DOME4.0 data.
Li2		Is there some staff in charge of maintaining and/or updating the ontology?
		No, this should be something explicitly planned.

	Conclusion	
#	Requirement	Description
Co1	Suggestions	Based on the evaluation findings, suggest improvements and potential enhancements.
		There are some important steps that should be taken in order to improve the ontology, the main ones are: 1) Decide if/how to release the ontology and with what license

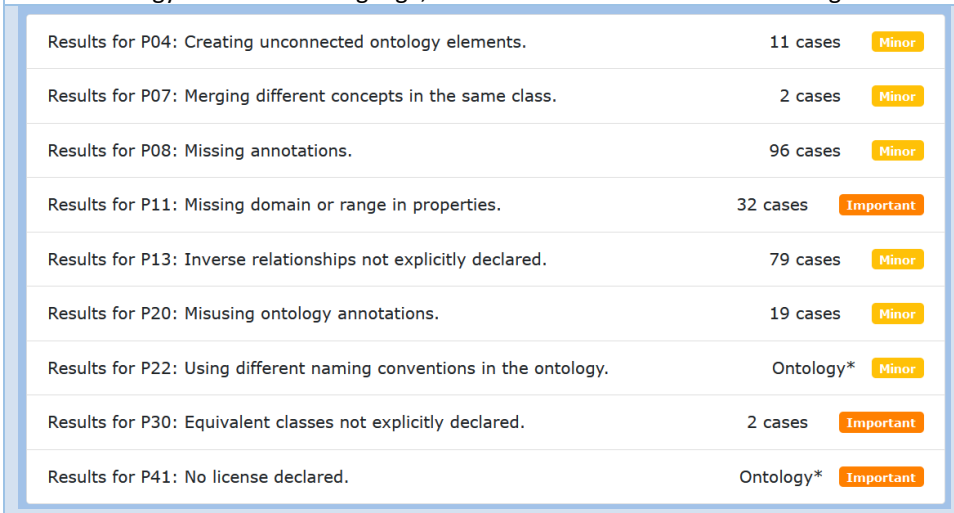
		2) After step 1 evaluate the ontology FAIRness score 3) Make domain experts test the ontology in the context of the DOME4.0 data marketplace
Co2	Summary	Summarize the key takeaways from the evaluation.
		The evaluation briefly summarized the main characteristics of the plastic simulation ontology, as well as direction for improvement, especially in the context of FAIRness.

4.4. Evaluation of SC7 – Evaluation of Ontologies for Intelligent Manufacturing (dating Oct 2023)

	Introduction	
#	Requirement	Description
In1	Title	The title of the ontology.
		Resistance Spot Welding Ontology (RSWO)
In2	Location	Where can the ontology (currently) be accessed.
		On GitHub, either at https://github.com/nsai-uio/RSWO (mentioned within an annotation in the ontology itself), or at https://github.com/MuhammadYahta/RSWO-UO (difference unclear). Additionally, a documentation webpage was generated using the WIDOCO tool, and is available at https://nsai-uio.github.io/RSWO/OnToology/rswo.owl/documentation/index-en.html, while an in-depth description of the ontology is provided in a research paper that is openly available at https://www.researchgate.net/publication/370010145_Semantic_Modeling_Development_and_Evaluation_for_the_Resistance_Spot_Welding_Industry
In3	Purpose	Provide an overview of the purpose of the ontology in the context of the company's data and knowledge management.
		The purposes of the RSW ontology are: 1) Model the Resistance Spot Welding (RSW) domain by formally describing relevant operations, machines and machine parts, and software systems. 2) Annotate the large volumes and varieties of data generated by I4.0 factories. In order to integrate data sources, enhance interoperability, and unify knowledge related to the RSW domain in general and also in the specific setting of Bosch's RSW operations.
In4	Ontology generality	Is the ontology an upper-level ontology, a middle-level or domain ontology, or an application/task ontology?
		The ontology lies on the borderline between a domain ontology and a task ontology, given its purposes

	Functional requirements	
#	Requirement	Description
Fu1	High-level requirements	Is the ontology linked to a set of high-level requirements (for instance, business/domain experts' requirements or research questions)?
		1) The ontology should model the RSW domain 2) The ontology should facilitate several data inspection- and diagnostic-related tasks that are carried out by domain experts.
Fu2*		If so, does the ontology satisfy (all of) them?
		Yes: the ontology both models the RSW domain and the data inspection and diagnostic tasks have been listed as competency questions (CQs)
Fu3	Competency questions	Is the ontology linked to a set of competency questions?
		Yes: a set of ten CQs is provided in the research paper describing the ontology

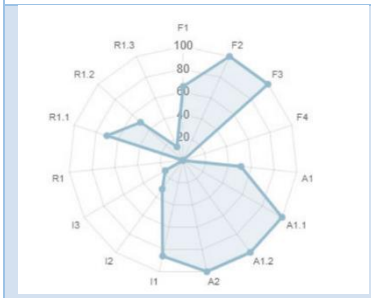
Fu3*		If so, how are the competency questions serialized (e.g. natural language, SPARQL, DL query)?
		The CQs are provided first in natural language and then formalized in SPARQL query language
Fu3*		Is reasoning used to answer the competency questions (e.g., if R is a transitive relation, and the facts R(a,b) and R(b,c) are stated, when querying for x such that R(a,x), is c also returned)? Why yes or why not?
		No: there is no need for inference of new data starting from already existing data.
Fu3*		Were the competency questions executed against an ontology containing data?
		Yes
Fu3*		If so, is there the expectations that there will be scalability issues when the queries will be run against data when in production?
		There is no expectation in either way since until now the ontology has been used to manually annotate only a few data for sake of example

	Structural/topologic testing	
#	Requirement	Description
S1	Metric testing	Has the ontology been tested using a tool which extracts quantitative metric about the ontology structure?
		Yes: OntoMetrics
S2*		If so, are there any values that could indicate bad/good quality (for each, if any, indicate way is so)?
		The discussion of the metrics obtained by OntoMetrics that is present in the paper must be redone: meaningless metrics are discussed, such as Average population (which depends on how much data was fed into the ABox of the ontology and as such is not meaningful in this context); while other aspect should have been addressed, such as the almost complete lack of axioms (except for subclass-of axioms and domain and range axioms).
S3	Structural good-practices	If the ontology is in the RDF language, what was the evaluation results using OOPS?
		
		However, except for the absence of a licence declaration (The license is actually present in the ontology, after having contacted the OOPS! developers they explained how to modify the license syntax appropriately to make the tool detect it) and for some missing annotations (cfr. “Terminology” steps), they either have minor importance or are the result of conscious design choices.

	Logical, ontological, and terminological aspects	
#	Requirement	Description
On1	Logical properties	Which language is the ontology expressed in?
		OWL 2 DL, checked using the tool profilechecker https://github.com/stain/profilechecker
On2		Is this a good language for the goal of the ontology (e.g., is the open/closed-world assumption reasonable if employed?
		Yes, it is a reasonable language to use, since the strong expressivity of OWL 2 DL may be used for the conceptual modelling of the domain. However, since dropping to OWL 2 EL would just require removing cardinality restrictions (of which only one is used) and inverse properties (which are used several times, but arguably could be disposed of), one could consider doing so. Especially if difficulties in reasoning tasks are encountered in the future.
On3		Does this language entail that some intended models are excluded from the ontology, or that some unnatural construct have to be used?
		No
On4		Is the ontology consistent?
		Yes
On5		Does the ontology support particular reasoning tasks?
		No
On6	Ontological properties	Do the axioms present in the ontology clearly and correctly model the target domain?
		Yes: The ontology exploits some logical axioms to describe the domain the domain more accurately. These axioms are also described in the corresponding paper. Additionally, these axioms have been reviewed by several ontology experts appositely formed on the RSW domain, and have been found correct and satisfactory from the point of view of modelling the target domain, though some have had to be modified with respect to their original version in the paper (an updated version of the ontology is currently available within Bosch).
On7		Is the ontology aligned with an upper ontology. If not, why,?
		Yes: while the original version of the ontology was not aligned to any upper ontology, the ontology has later been aligned to the upper ontology DOLCE, in particular to its OWL serialisation called DUL (DOLCE-ultra-lite). The alignment has been reviewed by an ontology expert and has been found satisfactory. The only possible issues that have been located concern the representation of certain entities as rigid classes (e.g. Material) instead of roles (e.g. Resource), but role modelling is a complex topic and further discussion on this has been delegated for future work.
On8		Has the ontology's taxonomy been analysed using e.g. OntoClean or other Applied-Ontology-methodologies?
		Since the ontology is aligned with DOLCE upper ontology it should automatically respect OntoClean's constraints. Additionally, a review from an ontology expert find no violation of OntoClean's constraints, except for possible some concerning roles (see On7)
On9		Is the ontology aligned with some middle/domain-level or application/task-level ontology?
		Yes: RGOM, SOSA, OM, DC, SWO, and Time. Precise references to these ontologies can be found in the research paper describing the paper. However, during the evaluation procedure the alignments present in the first version of the ontology were reviewed by some ontology experts and some errors were found,

		which were later corrected. The subsequent version contains reviewed and corrected alignments.
On10		Are there any (additional) pre-existing middle/domain-level or application/task-level ontologies that could have been reused?
		No: an in-depth review of the related literature was carried out, which revealed that there are indeed other ontologies which describe domains intersecting with the RSW domain, but they were discarded for different reasons: an in-depth description of these is present in the research paper.
On11	Concept coverage	Does the ontology cover the relevant concept of the domain?
		Yes
On12		In which way was it tested?
		Through domain expert evaluation, conformance to international standards, and comparison to similar ontologies.
On13		Does the ontology conform to, or is linked to, some pre-existing standards (if not explain why)?
		Yes: ISO-14327 and ISO-14373
On14	Terminology	Does the ontology conform to some guidelines for annotations (e.g. IOF annotation guidelines)?
		No
On15		Are common terminological and naming conventions respected?
		Yes
On16		Are the annotations clear and satisfactory for users?
		The annotation have been evaluated by several ontology experts, along different aspects such as sufficiency and unambiguity, and have been found satisfactory. However, there are several imperfections that would be better to correct. For example, the ontology is ridden with spelling errors, but this is a minor issue to correct. More importantly, the annotations are lacking, as they typically are one rdfs:label and one rdfs:comment which both repeat the URI of the entity. The repetition of the URI with rdfs:label is common occurrence (though it is redundant in mono-lingual ontologies that use readable URIs, like RSWO) while the repetition of rdfs:label with rdfs:comment is not. Moreover, there is an almost-complete lack of other annotations, such as definitions, (meaningful) comments, notes, and examples. This should be redone following some pre-determined annotations guidelines.

	Expert' and users' feedback	
#	Requirement	Description
Ex1	Users	Has the ontology been evaluated by some ontology-experts?
		Yes, several ontology experts were involved in the evaluation of the ontology and found it satisfactory.
Ex2		Has the ontology been evaluated by some domain-experts?
		Yes, several domain experts were involved in the evaluation of the ontology and found it satisfactory.
Ex3		Has the (application/task build using the) ontology been evaluated by prospective users?
		The users of the ontology would be the same as the domain experts

	FAIRness requirements	
#	Requirement	Description
Fa1	FAIRness	Has the ontology been evaluated with respect to FAIRness?
		Yes: the ontology has been evaluated using the tool FOOPS!
Fa2		If so, how and with which result?
		 In addition, these results show that RSWO has relatively high scores compared to the ontologies hosted on the industry portal
Fa3		In particular, is the ontology openly available?
		Yes
Fa4		If not, for what reason and could, at least the schema or a module of the schema being made available?
Fa5		Where is the ontology hosted and how can be accessed?
		The ontology is hosted on GitHub: https://github.com/nsai-uio/RSWO and can be freely accessed. An updated version of the ontology that was modified during the compilation of this document is internally available to Bosch. Though it should be made clear which is the last-updated version of the ontology, since several versions are present in different locations (see the first page)

	Ontology lifecycle requirements	
#	Requirement	Description
Li1	Ontology lifecycle	Is the ontology expected to evolve in the future?
		Yes, for instance alignment with a top-level ontology is planned
Li2		Is there some staff in charge of maintaining and/or updating the ontology?
		No, this should be something explicitly planned.

	Conclusion	
#	Requirement	Description
Co1	Suggestions	Based on the evaluation findings, suggest improvements and potential enhancements.
		There are some important steps that should be taken in order to improve the ontology, the main ones are: 4) Provide annotation guidelines and extend the current annotations, better if such guidelines could be used for other Bosch's ontologies 5) Implement and correct/rethink the axioms of the ontology 6) Discuss if Inference can be fruitfully used when handling data or if it is something only for highlighting modelling errors on a schema-level 7) Moreover, correct the alignments with pre-existing ontologies and add alignment with top-level ontologies
Co2	Summary	Summarize the key takeaways from the evaluation.
		The evaluation showed some key characteristics of the RSW ontology, such as the usefulness of alignment with a top-level ontology, while RSWO already extensively reuses appropriate pre-existing domain-level ontologies. This shows the goodness of RSWO, especially with respect to concurrent similar ontologies, to model the target domain.

4.5. Evaluation of the DOME 4.0 Ecosystem Ontology (dating November 2022)

	Introduction	
#	Requirement	Description
In1	Title	The title of the ontology.
		DOME 4.0 Ecosystem ontology
In2	Location	Where can the ontology (currently) be accessed.
		https://dome40.eu/deliverables . See the two entries for D3.2 that correspond to the documentation (https://dome40.eu/sites/default/files/2022-11/DOME%204.0%20D3.2%20Ecosystem%20information%20model%20ontology%2030.11.2022%20PU.pdf) and ontology source (https://drive.google.com/drive/folders/11FvsCIfm2qZ5RcjKo-pSaohyWWWVzIJs?usp=share_link). The ontology source is also available in a DOME 4.0 GitHub repository (currently, private, accessible by DOME 4.0 partners).
In3	Purpose	Provide an overview of the purpose of the ontology in the context of the company's data and knowledge management.
		DOME 4.0 Ecosystem ontology includes key concepts that are needed on the DOME 4.0 platform both on the user-facing and technical sides, and connects to EVMPO (mid-level ontology) and to the EMMO (top-level ontology). The aim of the Ecosystem Ontology is to provide a light formal vocabulary to support the integration of multiple web-based sources of data and services, in the area of materials and manufacturing. This ontology is used by core components of the DOME 4.0 platform, as the front-end user interface (e.g., the available filtering options and fields for registration), the semantic broker and connectors to other platforms. (Taken from: DOME 4.0 D3.2)
In4	Ontology generality	Is the ontology an upper-level ontology, a middle-level or domain ontology, or an application/task ontology?
		Application ontology

	Functional requirements	
#	Reqs	Description
Fu1	High-level requirements	Is the ontology linked to a set of high-level requirements (for instance, business/domain experts' requirements or research questions)?
		Within the development process, a set of main questions has been identified, such as: ● Q1: What types of products can be used as filters on DOME 4.0? ● Q2: What standard identifiers are available on DOME 4.0? ● Q3: What file formats are available on DOME 4.0? ● Q4: What topics are available on DOME 4.0? ● Q5: What are the properties of an offering on DOME 4.0? (Extract of the questions. Source: internal DOME 4.0 development document.)
Fu2*		If so, does the ontology satisfy (all of) them?
		Yes, by construction. About future extensions, cf. point "Li1"
Fu3	Competency questions	Is the ontology linked to a set of competency questions?
		As mentioned in point "Fu1" above, some were formulated as part of the development process. Moreover, there are queries (in SPARQL) that are actually used internally by the platform broker, e.g., to filter data providers by topic. This is what happens behind the scenes when a user enables a "filter" option.
Fu4*		If so, how are the competency questions serialized (e.g. natural language, SPARQL, DL query)?
		Natural language (cf. "Fu1") and SPARQL (cf. "Fu3").
Fu5*		Is reasoning used to answer the competency questions (e.g., if R is a transitive relation, and the facts R(a,b) and R(b,c) are stated, when querying for x such that R(a,x), is c also returned)? Why yes or why not?
		It can be used. However, for questions such as filtering on topics, explicit assertions about data providers more than the inferences are needed as of now.
Fu6*		Were the competency questions executed against an ontology containing data?
		"Data" in the sense of instances are contained in the "platforms.ttl" file (scenario/ directory, cf. D3.2 source files). It contains real data providers connected to DOME 4.0 and realistic example platforms and subscriptions, to exemplify the usage of the model.
Fu7*		If so, is there the expectation that there will be scalability issues when the queries will be run against data when in production?
		Not at present

	Structural/topologic testing	
#	Reqst	Description
S1	Metric testing	Has the ontology been tested using a tool which extracts quantitative metrics about the ontology structure?
		The Ontology has been tested with the current (22-09-2023) version of Ontometrics: Base metrics Axioms: 780 Logical axioms count: 278 Class count: 54 Total classes count: 54 Object property count: 31 Total object properties count: 31 Data property count: 23 Total data properties count: 23 Properties count: 54 Individual count: 75 Total individuals count: 75 DL expressivity: ALCROF(D) Class axioms SubClassOf axioms count: 46 Equivalent classes axioms count: 13 Disjoint classes axioms count: 0

GCICount: 3
HiddenGCICount: 12

Object property axioms
SubObjectPropertyOf axioms count: 8
Equivalent object properties axioms count: 0
Inverse object properties axioms count: 0
Disjoint object properties axioms count: 0
Functional object properties axioms count: 0
Inverse functional object properties axioms count: 0
Transitive object property axioms count: 0
Symmetric object property axioms count: 0
Asymmetric object property axioms count: 0
Reflexive object property axioms count: 0
Irreflexive object property axioms count: 0
Object property domain axioms count: 30
Object property range axioms count: 30
SubPropertyChainOf axioms count: 5

Data property axioms
SubDataPropertyOf axioms count: 4
Equivalent data properties axioms count: 0
Disjoint data properties axioms count: 0
Functional data property axioms count: 11
Data property domain axioms count: 22
Data Property range axioms count: 22

Individual axioms
Class assertion axioms count: 85
Object property assertion axioms count: 0
Data property assertion axioms count: 0
Negative object property assertion axioms count: 0
Negative data property assertion axioms count: 0
Same individuals axioms count: 0
Different individuals axioms count: 0

Annotation axioms
Annotation axioms count: 25
Annotation assertion axioms count: 310
Annotation property domain axioms count: 0
Annotation property range axioms count: 0

Schema metrics
Attribute richness: 0.425926
Inheritance richness: 0.851852
Relationship richness: 0.488889
Attribute class ratio: 0.0
Equivalence ratio: 0.240741
Axiom/class ratio: 14.444444
Inverse relations ratio: 0.0
Class/relation ratio: 0.6

Knowledgebase metrics
Average population: 1.388889
Class richness: 0.222222

Graph metrics
Absolute root cardinality: 14
Absolute leaf cardinality: 38
Absolute sibling cardinality: 54
Absolute depth: 132
Average depth: 2.275862
Maximal depth: 5
Absolute breadth: 58
Average breadth: 3.222222

Maximal breadth: 14
Ratio of leaf fan-outness: 0.703704
Ratio of sibling fan-outness: 1.0
Tangledness: 0.055556
Total number of paths: 58
Average number of paths: 11.6

S2*

If so, are there any values that could indicate bad/good quality (for each, if any, indicate way it is so)?

No metric value that could be a sign of bad quality stands out.

In particular, the graph metrics reveal a reasonable taxonomy; the knowledgebase metrics just highlight that some classes are instantiated, those individuals are mainly instances of skos:concept, so care should be taken to harmonize the skos-based part of the schema with the owl-based one (this is elaborated further in On3-5)

From the schema metrics one can notice that about one quarter of classes are defined (this is due to the numerous equivalence axioms consisting in alignments and extensional definitions of the classes), and there is a reasonable number of axioms. These aspects both reasonably indicate a well-axiomatized ontology.

From the base metrics one can notice 3 general concept inclusion, which within the ontology appear as the most complex axioms (as they are in the shape of "(property1 some class1) subclass of (property2 value individual1)"), and even those appear correct during review.

S3 Structural good-practices

If the ontology is in the RDF language, what was the evaluation result using OOPS?

Analysis of the ontology using OOPS! does identify some pitfall:

Results for P04: Creating unconnected ontology elements.	4 cases	Minor
Results for P07: Merging different concepts in the same class. 1 case	1 case	Minor
Results for P08: Missing annotations.	76 cases	Minor
Results for P11: Missing domain or range in properties.	2 cases	Important
Results for P13: Inverse relationships not explicitly declared.	31 cases	Minor
Results for P22: Using different naming conventions in the ontology.	Ontology*	Minor
Results for P30: Equivalent classes not explicitly declared.	2 cases	Important
Results for P41: No license declared.	Ontology*	Important

However, after manual review of each pitfall, all are either justified in the ontology or are not significant enough to warrant any action, except for the absence of a license (The license is actually present in the ontology, after having contacted the OOPS! developers they explained how to modify the license syntax appropriately to make the tool detect it) and for some missing annotations (cfr. "Terminology" steps).
In addition, OOPS! does not identify automatically all of the pitfalls in its catalog, precisely the following pitfalls
P01 Creating polysemous elements;
P14 Misusing "owl:allValuesFrom"
P15 Using "some not" in place of "not some"
P16 Using a primitive class in place of a defined one
P17 Overspecializing a hierarchy
P18 Overspecializing the domain or range
P23 Duplicating a datatype already provided by the implementation language
are not checked.
P14, and P15 are easily checked as the corresponding owl constructs are not used in the ontology; while P23 is also not breached since no datatype is introduced over xsd.
After manual review of all the properties in the ontology, their domain and range seem appropriate, so that P18 is not breached.
Likewise, for P01 no polysemous element appears present.
P16 and P17 also require manual review, of the ontology classes this time. The hierarchy appears to have the right level of granularity; additionally, many classes are present that are defined using OWL constructs, and it appears that those defined classes are precisely those that are reasonably to define in such a way.

	Logical, ontological, and terminological aspects	
#	Reqs	Description
On1	Logical properties	Which language is the ontology expressed in?
		The ontology is written in OWL, precisely in the DL profile (this was verified with the profilechecker tool). In addition it also contains a skos vocabulary.
On2		Is this a good language for the goal of the ontology (e.g., is the open/closed-world assumption reasonable if employed?
		Yes: the owl language is used to provide a schema for the platform, and this not only leverages an established W3C standard for modelling, but also allows for harmonization with an ecosystem of ontologies written in logical languages, coherently with DOME 4.0 goals. While skos is used to align it to standard vocabularies of relevant concepts.
On3		Does this language entail that some intended models are excluded from the ontology, or that some unnatural constructs have to be used?
		No reification is needed. The only noticeable thing in this context is that the use of both owl and skos entails that one has to decide on how to harmonize those two languages. There is no standard way to do it. In this ontology, the authors opted for duplication of classes and skos-concepts/skos-concept-schemas individuals. Then classes and skos individuals were woven together by use of reasonable axioms (e.g. extensional definition axioms such as "http_method equivalent {CONNECT , DELETE , GET , […]}" (other axioms with the same functions are mentioned in On5). However, some possible minor inconsistency in the harmonization process between skos and owl may be constituted by 1) the fact that some classes are associated to a single skos concept (e.g. Consumer & CONSUMER), while some other classes are associated to skos concept schemas (e.g. Product Type has as instances exactly all the items of LIST_OF_PRODUCT_TYPES) 2) Sometime the class to a skos entity is labelled as a type (e.g. product type, sometimes not, e.g. Consumer) 3) More importantly, the association of LIST_OF_DATA_ACTIONS with the class Action seems inconsistent with the remaining owl/skos associations, due to the alignment with emmo, but this is elaborated further in On7
On4		Is the ontology consistent?
		Yes
On5		Does the ontology support particular reasoning tasks?
		The ontology supports some reasoning tasks, mainly: -the general concepts inclusions (e.g. " has_service some get_type_service SubClassOf has_platform_type value DATA_PROVIDER") allow to infer that certain individuals have some given object property values (e.g. a service that provides a "get" method is a data provider) -the equivalence axioms such as "connect_type_service equivalent (has_oper_has_meth value GET)" allow for classification of individuals in the correct classes assuming that they have the correct data properties, and they also establish a correspondence between the skos, concepts and the owl classes
On6	Ontological properties	Do the axioms present in the ontology clearly and correctly model the target domain?
		Yes: - part the axioms are inspired by the minimal service model, which correctly represents the domain in question - others correctly merge skos vocabularies with owl classes - others allow for meaningful classification of domain individuals (e.g. if the platform is such and such it is of that type, etc.)
On7		Is the ontology aligned with an upper ontology?
		A module of alignment to the EMMO (version 1.0.0-beta4) has been developed (ADE, Alignment of DOME 4.0 and EMMO), it is available in a separate directory ("alignment/") in the ontology source. Also, classes from the EVMPO (European Virtual MarketPlace Ontology) mid-level ontology are used. This shows that the ontology complies with the critically-important requirement of reusing and harmonizing itself with appropriate ontologies. After reviewing the alignments, they appear correct, with only two possible inconsistencies: 1-An equivalence axiom is possibly missing between dome-core:Product and evmpo:product (and same thing for Agent) 2- the individuals instantiating the annotation class are "classificators"/"concepts" instances (e.g. the "GET"-method is an instance of "annotation"-class, that is, "GET" is the method itself not any of the individual get request that are carried out in some time interval). Coherently, the alignment with EMMO considers them ('File format', 'Product type', 'Standard identifier', and 'Topic') as "coded" instances – in particular, as signs that stand for things.

		However, the instances of the dome-core:Action class (“UPLOAD”, “ SEARCH_WITH_WILD_CARD”, etc.) which are skos:concepts also do not appear as things that occur in a specific time interval, but they are classified as emmo:intentional-process, and in EMMO a process is "A whole that is identified according to a criteria based on its temporal evolution that is satisfied throughout its time extension." Therefore, one would deduce that “ SEARCH_WITH_WILD_CARD” etc. should have a temporal extension, but that is probably not what is intended. More likely, it is meant that the individual "SEARCH_WITH_WILD_CARD" is a type of action that a user can carry out when interacting on the platform. So that one should distinguish between “Action”, subclass of emmo:intentionalProcess and an “ActionType” class, possibly subclass of “annotation” (Note that this is analogous to the distinction between platform and platform type already present in the ontology).
On8		If not, why, and has the ontology’s taxonomy been analysed using e.g. OntoClean or other Applied-Ontology-methodologies?
		N.A.
On9		Is the ontology aligned with some middle/domain-level or application/task-level ontology?
		Yes, see EVMPO mentioned above. Other ontologies and non-formal knowledge sources are also reused, including: DCAT, EuroSciVoc, FAIRsharing Data formats catalogue, Minimal Service Model (MSM), Review of Materials Modelling (RoMM). For details, see DOME 4.0 Deliverable D3.2.
On10		Are there any (additional) pre-existing middle/domain-level or application/task-level ontologies that could have been reused?
		During the development phase, a set of possibly relevant ontologies and models were identified. They are listed in DOME 4.0 D3.2, Appendix 1 / Table 1. Some of these were directly re-used, others indirectly informed the development phase.
On11	Concept coverage	Does the ontology cover the relevant concept of the domain?
		Yes: from DOME 3.2 deliverable, the ontology “contains both concepts that are relevant from the user perspective (e.g., categories for filters in the UI) as well as concepts that are needed from the technical side (e.g., the URL at which a certain web-service is provided)”, those concepts have been selected by domain experts during the ontology development, and are sufficient to enable the tasks that the ontology supports.
On12		In which way was it tested?
		The ontology is currently used within components of the platform, see point “In3” above. This provides a way of testing it.
On13		Does the ontology conform to, or is linked to, some pre-existing standards (if not explain why)?
		“Standard identifiers” are used, such as: CAS number, EC number, SMILES and IUPAC InChi to identify chemical substances. “Standard API specification” are listed, meant as one that is followed by multiple platforms; currently two relevant ones were identified (IDS and OPTIMADE).
On14	Terminology	Does the ontology conform to some guidelines for annotations?
		Currently no, but such an evolution is expected soon, as per DOME 4.0 deliverable 3.2 “OntoCommons is finalising in these weeks the technical specifications detailing what annotations will be required by the OCES, together with a well-defined set of bridge concepts.” For now the annotations used are one rdfs:label for each class and one or more optional elucidating rdfs:comment for each class. Data and object property do not have labels, but they always have at least one comment instead.
On15		Are common terminological and naming conventions respected?
		Yes: the IRIs are human readable ending with an expression in snake case, and each and every class (but not the object properties and the data properties) is annotated with a rdfs:comment in sentence case. One may automatically add analogous comments for object and data properties, but It is not important.
On16		Are the annotations clear and satisfactory for users?
		The annotations are sufficient to the developers that are using the ontology, as the terms in question are well-known and taken from standard vocabularies.
On17		Is there any documentation describing the ontology?
		Yes: the DOME4.0 deliverable 3.2

	Expert’ and users’ feedback	
#	Requirement	Description
Ex1	Users	Has the ontology been evaluated by some ontology-experts?
		Yes, in the internal DOME 4.0 review process before submission of D3.2.
Ex2		Has the ontology been evaluated by some domain-experts?

	"Task 3.2 work has been carried out in close connection with the DOME 4.0 platform developers, considering the broad scope of the project showcases and in consultation with the exploitation work-package for the business-related concepts." (cf. DOME 4.0 D3.2)
Ex3	Has the (application/task build using the) ontology been evaluated by prospective users?
	The DOME 4.0 platform developers (that use the ontology within certain components, and in this sense are "users") have provided feedback and contributed to the ontology development. End-users mostly see the ontology indirectly, from GUI dropdowns: testing in this sense is done internally, by the project partners.

	FAIRness requirements	
#	Requirement	Description
Fa1	FAIRness	Has the ontology been evaluated with respect to FAIRness?
		The ontology cannot currently be evaluated using an automated FAIRness assessment tool, since its URI is currently not resolvable
Fa2*		If so, how and with which result?
		n.a.
Fa3		In particular, is the ontology openly available?
		Yes, the ontology is openly available as it is part of the DOME4.0 project deliverable 3.2
Fa4*		If not, for what reason and could, at least the schema or a module of the schema being made available?
		n.a.
Fa5		Where is the ontology hosted and how will it be able to be accessed long term?
		at https://drive.google.com/drive/folders/1ZowhIGqFmBt_p9TMpjPj215D7NH9MuoP while in the future it should be hosted on a permanent location yet to be determined

	Ontology lifecycle requirements	
#	Requirement	Description
Li1	Ontology lifecycle	Is the ontology expected to evolve in the future?
		"As any semantic asset, also the Ecosystem Ontology needs to be a "live" entity: while the bulk of its content will not change, whenever necessary, additions will be made in coordination with the platform developers and following best practices for metadata governance" (from DOME 4.0 D3.2)
Li2		Is there some staff in charge of maintaining and/or updating the ontology?
		Currently, this is done as part of the DOME 4.0 project.

	Conclusion	
#	Requirement	Description
Co1	Suggestions	Based on the evaluation findings, suggest improvements and potential enhancements.
		The ontology can be improved by making the skos-owl alignment more consistent (see On3, 5) and by revising a small part of the alignment with emmo (see On7). Other ways of improvement are better annotations and making the ontology's URL resolvable, but those have been explicitly planned already.
Co2	Summary	Summarize the key takeaways from the evaluation.
		The ontology has clearly been well developed under every quality aspect analyzed in this document. An important lesson coming from this evaluation work is that standard guidelines on how to harmonize skos schemas and owl schemas would be useful (of course, work on this topic exists already, but it was not sufficient to completely alleviate the difficulties that the developer encountered).

5. Conclusions

This document detailed the efforts carried out in the first 3 years of DOME 4.0 on collaboration with the OntoCommons project. In particular, we gave the list of joint activities (Section 2) and deep dived into the projecting the OntoCommons vision on ontology quality and standardization on the DOME4.0 project (Sections 3-4), including the ontology evaluation reports obtained from the DOME4.0 showcases.

In conclusion, the report shows that there have been many interactions between OntoCommons and DOME 4.0. The interactions were the result from a significant amount of joint meetings, as well as four partners being represened in both consortiums.

Regarding the ontologies, there were two separate activities: the development of the guidelines and their application to DOME 4.0 ontologies. For the first one we refer to OntoCommons report D2.9.

Regarding the second activity, in terms of the guidelines jointly developed by the two projects specifically in the context of DOME 4.0 and OntoCommons collaboration: they were informed by the existing literature on ontology evaluation and standards and comprehensively address various aspects of ontology quality, encompassing functional, logical, structural, terminological, user-related, lifecycle, and FAIRNess requirements; they are also aligned with some relevant analogous previous methodologies. Importantly, the guidelines were designed to accommodate the diverse maturity levels of data metamodels among DOME 4.0 participating partners, offering concrete improvement suggestions tailored to each ontology's development stage. Subsequently, the guidelines were applied to comprehensively evaluate the DOME 4.0 ecosystem ontology and those showcases of sufficient maturity, utilizing templates that were instantiated to generate corresponding reports.

6. Lessons learnt

An important lesson that we learned is that the culture of ontology development and use in industry still has a good room for improvement, e.g., in DOME 4.0 there are ontologies that are advanced while some are at the initial level of maturity. The activities described in this deliverable highlighted the difficulty of cooperating with cross-sectoral industrial partners, the low maturity of data semantisation, on average, among industrial partners and the significant amount of effort and time that is required to develop strategies to enable semantic interoperability. Additionally, as a result of this collaborative effort, it has become clear that a shared set of standardized guidelines for ontology quality and evaluation is very useful for fostering ontology standardization and pushing for a higher average quality of semantic artifacts.
The activities described in this deliverable highlighted the difficulty of cooperating with cross-sectoral industrial partners, the low maturity of data semantisation, on average, among industrial partners and the significant amount of effort and time that is required to develop strategies to enable semantic interoperability.

7. Deviations from Annex 1

As notified to the project officer, the report was delayed by 2 months (submission in M38 instead of in M36). Other than that, there are no deviations from Annex 1.

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Project partners:

#	Type	Partner	Partner full name
1	SME	CMCL	Computational Modelling Cambridge Limited
2	Research	FHG	Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V.
3	Research	INTRA	Intrasoft International SA
4	University	UNIBO	Alma Mater Studiorum – Universita di Bologna
5	University	EPFL	Ecole Polytechnique Federale de Lausanne
6	Research	UKRI	United Kingdom Research and Innovation
7	Large Industry	SISW	Siemens Industry Software NV
8	Large Industry	BOSCH	Robert Bosch GmbH
9	SME	UNR	Uniresearch B.V.
10	Research	SINTEF	SINTEF AS
11	SME	CNT	Cambridge Nanomaterials Technology LTD
12	University	UCL	University College London

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