ONTO COMMONS
ONTOLOGY-DRIVEN DATA DOCUMENTATION FOR INDUSTRY COMMONS

Report D3.9
"Report on the first focus workshop on domain ontologies"

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Report D3.9 "Report on the first focus workshop on domain ontologies"

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Glossary of terms and acronyms

Item	Description
MM	Materials and manufacturing
ESWC	European Semantic Web Conference
IOF	Industrial Ontologies Foundry
EMMO	European Materials & Modelling Ontology
EMMC	European Materials Modelling Council
TLO	Top-level Ontology

Keywords

Ontology; Data; Standardisation; Semantic landscape; Workshop; DORIC-MM

Disclaimer

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Executive Summary

The focused workshop was entitled *"Domain Ontologies for Research Data Management in Industry Commons of Materials and Manufacturing"* (DORIC-MM 2021) and was constituted of two main parts: a preparatory half-day event (kick-off) on the 15th of March 2021 and a full-day event on the 7th of June 2021, co-located with the 18th European Semantic Web Conference (ESWC). These activities had a strongly interactive character and aimed to gather inputs about the semantic landscape in the field of materials and manufacturing.

The March preparatory event was free and open, to attend it participants were only required to register as OntoCommons experts and answer a short survey. The June event was more academic: in line with ESWC, oral contributions for this event were invited or selected from submitted papers *(via* the OpenReview platform).

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1. Introduction

This document reports on the first OntoCommons Focused Workshop (FW) on Industrial domain ontologies. The aim of this activity was to support the Semantic Landscape Analysis in the materials and manufacturing (MM) domain, and it targeted all interested parties, including MM domain experts and developers of ontologies and semantic tools. The workshop was entitled "Domain Ontologies for Research Data Management in Industry Commons of Materials and Manufacturing" (DORIC-MM 2021) and comprised two on-line events: one on the 15th of March (kick-off) and one on the 7th of June (workshop). The first event was half-day long, open and free, and to attend it participants were only required to register on the project website and to answer a short survey. The kick-off consisted of a few brief presentations about community-building initiatives, followed by an interactive session and discussions, which were the core of the event. The 7th June event was a full-day workshop, co-located with the 18th European Semantic Web Conference (ESWC), and presentations were invited or selected from submitted papers. Having two events of different nature allowed us to have a varied audience, to connect to the wider European semantic web community and to attract contributions at different levels (e.g., survey answers and research papers). The 15th March event also permitted to gather the community and was the basis for further domain-specific expert meetings organized in May 2021. The material there gathered informed the preparation of the 7th June event and provided input for the semantic landscape analysis (see *report on existing domain ontologies in identified domains*).

The present document is structured as follows. In Section 2 we outline the main organizational aspects and point out relevant references, such as the event website, where presentations can be found. In Section 3 we detail the event agenda, summarize all the presentations and report on the attendance. In Section 4 we present and analyse the participants' input, and the modalities in which it was gathered. In Section 5 we summarize the workshop conclusions, and in Section 6 present our acknowledgements. The Appendixes contain further details: Appendix A the list of participants, and Appendix B, C and D give the topics addressed and extracts from the results obtained *via* a short survey embedded within registration, the interactive (Mentimeter) presentations and domain-specific discussions (on a visual collaborative board, MIRO), respectively. As the workshop was split into two events, the sections of this document often mirror this splitting.

2.Organization and references

2.1 Organizers

The OntoCommons Focused workshop, constituted by an event on the 15th March and one on the 7th June, has been organized by representatives of the OntoCommons Silvia Chiacchiera (STFC/UKRI, United Kingdom), Martin Thomas Horsch (HLRS, Germany), Joana Francisco Morgado (Fraunhofer IWM, Germany) and Gerhard Goldbeck (Goldbeck Consulting Ltd+EMMC ASBL, UK+Belgium). Beside the core group, close interactions have been kept with the participants of Task, "Domain-specific semantic Landscape Analysis". For the June event, in line with ESWC requirements, a *Programme*

Committee (PC) has also been formed, with both OntoCommons and external members, see next. While its main role was in connection to the June event, the PC has also been consulted for the March preparatory event.

2.2 Programme Committee

- Stefano Borgo (CNR, Italy)
- Welchy Leite Cavalcanti (Fraunhofer IFAM, Germany)
- Silvia Chiacchiera (STFC/UKRI, United Kingdom)
- Fabien Duchateau (University of Lyon 1, France)
- Iker Esnaola González (Tekniker, Spain)
- Anna Fensel (University of Innsbruck, Austria)
- Joana Francisco Morgado (Fraunhofer IWM, Germany)
- Gerhard Goldbeck (Goldbeck Consulting Ltd & EMMC ASBL, UK & Belgium)
- Martin Thomas Horsch (HLRS, Germany)
- Dimitrios Kyritsis (EPFL, Switzerland & UiO, Norway)
- María Poveda Villalón (Universidad Politécnica de Madrid, Spain)
- Umutcan Şimşek (University of Innsbruck, Austria)

2.3 Timeline highlights

- Proposal submitted to ESWC: November 2020
- Notification of acceptance from ESWC: December 2020
- Paper submission open: 25th January 2021
- Kick-off event: 15th March 2021
- Paper submission deadline: 26th March 2021
- Notification to paper authors and program sent to ESWC: 16th April 2021
- Camera-ready version of papers: 29th April 2021
- Event: 7th June 2021

2.4 Website, proceedings, and relevant references

The event website has been set up by Trust-IT in December 2020 and regularly updated when needed; it can be found at https://ontocommons.eu/doric-mm-2021. As of July, 2021, all presentations slides are available on the website, including the interactive Mentimeter presentations with the relative results.

Paper submission has been handled *via* OpenReview, at https://openreview.net/group?id=eswc-conferences.org/ESWC/2021/Workshop/DORIC-MM.

As a guidance to organize the MM domains we have used the DFG classification of disciplines, https://www.dfg.de/download/pdf/dfg_im_profil/gremien/fachkollegien/amtsperiode_2016_2019/fachsystematik_2016-2019_en_grafik.pdf.

The submitted papers will be collated in a proceedings volume and published (most likely in August 2021) with the STFC Conference series (as such, in particular, they will be assigned a PURL).

For a report on the Semantic Landscape Analysis we point the reader to the associated OntoCommons *report on existing domain ontologies in identified domains*[1].

3.Events agenda and participation

In this section we detail the agenda of the March and June events, summarize the respective presentations and papers, and, finally, report briefly on the participation.

As described in the Introduction, the 15th March DORIC-MM Kick-off was a half-day, open and free on-line event. It was highly interactive, and its aim was to gather input and opinions on the status of semantic technologies in the MM field from a variety of viewpoints. It served to gather the community and initiate discussions. Most participants were perspective participants of the June event too, but its nature allowed to attract a wider audience. In the first slot, OntoCommons and other community-building initiatives were introduced. Based on the survey embedded with registration, four DFG-based domains were identified as a suitable splitting for the parallel sessions of the second slot (see next). And, as shown in Figure 1, material from the survey (namely, the list of gathered ontologies) was used as input for the discussions. In the third and final slot, conclusions from each session were shared. At the end of the meeting, participants could express their interest in joining further expert meetings to take place in May.

The 7th June DORIC-MM workshop was a full-day on-line event co-located with ESWC 2021. Its agenda included keynotes, invited talks, paper contributions and discussions (panel and interactive). The aim of this event was to further develop the discussions initiated in March, also thanks to the specific examples provided by the contributed papers and presentations, to assess the status of the field and to propose actions to advance it. As already mentioned, the March event informed and supported the preparation of the June one. A further explicit connection between the two events was provided by the collaborative virtual board used in June, where all previous activities were summarized, and by a dedicated presentation in the afternoon session where the Organizers presented highlights from the March event. The panel as well as the audience comprised representatives from different domains, roles, from academia and industry. At variance with March, all sessions were plenary ones, and a partial topic splitting was done between the morning and afternoon sessions.

3.1 Kick-off of DORIC-MM, 15th March (14:30-17:30 CET)

The **Detailed Program** for the event was:

- **14:30-15:30: Initial plenary session. Introduction, interactive session. Input from the survey and recent events within the field of semantics applied to materials and manufacturing**
    - Welcome by the Organizers
    - "Introduction to OntoCommons and WP3 (Industrial domain ontologies)" [by Hedi Karray, ENIT, France– WP3 Leader and Project Technical Manager]
    - "Landscape analysis" [by Yann Le Franc, e-Science Data Factory, France]

[1] The *report on existing domain ontologies in identified domains* will appear on OntoCommons Zenodo channel.

  - "Introduction to the Industrial Ontologies Foundry" [Dimitris Kiritsis, EPFL, Switzerland & UiO, Norway]
  - "Input from the EMMC 2021 International Workshop" [Gerhard Goldbeck, Goldbeck Consulting Ltd & EMMC ASBL, UK & Belgium]
  - Interactive presentation [Silvia Chiacchiera, UKRI, UK]

- 15:30 – 16:30: Domain-specific interactive parallel sessions (*D1, D2, D3, D4*)
  - D1: Physics and Chemistry [Moderator: Gerhard Goldbeck]
  - D2: Mechanical and Industrial Engineering [Moderator: Hedi Karray]
  - D3: Thermal Engineering/Process Engineering [Moderator: Martin Thomas Horsch]
  - D4: Material Science and Engineering [Moderator: Yann le Franc]

- 16:45 – 17:30: Final plenary session - Joining, analyzing and wrapping up
  - 16:45 – 16:50: General intro and exchange
  - 16:50 – 17:10: Reports from each of the domain parallel sessions D1, D2, D3, D4
  - 17:10 – 17:25: Panel discussion
  - 17:25 – 17:30: Closing

During the event, interactions were made possible by the Mentimeter tool in the first slot, while in the parallel sessions a MIRO board was used. The Zoom chat was also available.

3.1.1 Presentations' summaries

To prioritize discussions, the presentations in this event were all very brief (5-10 minutes each) and all took place in the initial plenary slot: in this section we summarize them. The discussion slots of the event are instead described in Section 4 of this document.

Hedi Karray, leader of OntoCommons work package "Industrial domain ontologies" and project technical coordinator presented the OntoCommons project, its structure, and objectives. The OntoCommons Eco System (OCES) will consist of a hierarchy (top, middle, domain, and application levels) of networked ontologies, a set of tools and methodologies and a set of specifications. The project's multi-level approach to ontology harmonisation and an overview of WP3 were presented. This work-package's core objectives are to collect community input about domain ontologies (in the area of materials modelling, characterisation, and manufacturing), guide harmonisation and find agreements to improve intra- and cross-domain interoperability.

Yann Le Franc, leader of OntoCommons task on the "Semantic Landscape analysis", presented the strategy for this ongoing work and the analysis criteria (e.g., adherence to FAIR principles, domain criteria and ontology engineering criteria). The material is collected via a dedicated survey (https://ontocommons.eu/node/146), and an ontology catalogue will be created. Note: for an update on the task, we refer the reader to the associated OntoCommons *report on existing domain ontologies in identified domains*, that in the meantime has been finalized.

Dimitris Kiritsis, leader of OntoCommons work package "Cooperation", presented the Industrial Ontologies Foundry (IOF, https://www.industrialontologies.org/), an initiative he co-founded in 2016, and that will soon become a legal entity. IOF aims to develop ontologies that are relevant for industrial applications and manufacturing. It is structured in various working groups (WGs) and, similarly to OntoCommons, has a multi-level architecture (top, domain-independent, domain, sub-domain, and application levels). The Core WG focuses on core ontology terms that at the middle level can be used by many ontologies. For ontologies to be successful, global adoption and interoperability are needed: modularization and collaboration with other efforts are key. Note: we are glad to say that the IOF endorsed our DORIC-MM activities.

Gerhard Goldbeck, executive secretary of the EMMC ABSL association (https://emmc.eu/), presented the EMMC association, its role on the development and usage of the European Materials and Modelling Ontology (EMMO) and shared highlights from the recent EMMC International Workshop (EMMC2021). The EMMC is organized in Focus Areas, and in particular he presented outcome from the EMMC2021 sessions dedicated to Digitalisation and Interoperability: which ontology domains were discussed (chemistry, manufacturing resources, materials modelling software metadata, materials properties, REST-API integration, virtual materials marketplaces), the semantic types covered (application ontologies, metadata schema, semantic/relational databases, Knowledge Graphs, markup languages and object-oriented programming languages), what purpose ontologies are used for and the reported gaps (more input/feedback needed from users, standard silos, infrastructure gaps, uniformed APIs).

3.2 DORIC-MM Workshop, 7th June (full day)

The **Detailed program of the event** was:

- **Morning session (10:30-13:45 CEST, 7th June): Introduction, 1 keynote, 4 contributions (3 papers + 1 invited) on "Materials & modelling" and discussion.**
  - 10:30-10:40 Welcome and introduction
  - 10:40-11:05 [20+5 min] Hedi Karray, "Ontologies' Interoperability: concerns and perspectives"
  - 11:05-12:00 "Materials & modelling" session
    - 11:05-11.20 [10+5 min] M. Abd Nikooie Pour et al, "A First Step towards Extending the Materials Design Ontology"
    - 11:20-11:35 [10+5 min] M. T. Horsch et al, "Domain-specific metadata standardization in materials modelling"
    - 11:35-11:50 [10+5 min] F. Le Piane et al, "Introducing MAMBO: Materials And Molecules Basic Ontology"
    - 11:50-12:05 [10+5 min] J. Friis and E. Ghedini, "Domain-level ontologies and the methodology to connect them to a Top-level/Middle-level ontology"
  - 12:05-12:20 Break
  - 12:20-13:45 Discussion (Panel + all, interactively). Panel members: Alexander Behr (Dortmund Univ., Germany), Jesper Friis (SINTEF, Norway), David Leal (CAESAR Systems Ltd, UK), Heinz Preisig (NTNU, Norway). Moderator: Gerhard Goldbeck (Goldbeck Consulting Ltd & EMMC ASBL, UK & Belgium). Initial interactive presentation by Silvia Chiacchiera (UKRI, UK).
- **13:45-15:00 Lunch break**

- **Afternoon session (15:00-18.15 CEST, 7th June): Highlights from material gathered during the 15/03 preparatory event, 1 keynote, 5 contributions (3 papers + 2 invited) on "Industry & engineering" and discussion.**
  - 15:00-15:15 Highlights from the material gathered during the 15/03 preparatory event
  - 15:15-15:40 [20+5 min] Evgeny Kharlamov: "Industrial ontologies for manufacturing"
  - 15:40-16:55 "Industry & engineering" session
    - 15:40-15:55 [10+5 min] M. M. Vegetti et al, "SCONTO: A Modular Ontology for Supply Chain Representation"
    - 15:55-16:10 [10+5 min] S. Borgo, F. Compagno et al, "An overview of some ontological challenges in engineering maintenance"
    - 16:10-16:25 [10+5 min] I. Esnaola-Gonzalez and I. Fernandez, "Materials' Tribological Characterisation: an OntoCommons Use Case"
    - 16:25-16:40 [10+5 min] Johan Wilhelm Klüwer, "READI: Ontology-based requirements management for industry"
    - 16:40-16:55 [10+5 min] Maja Milicic Brandt, "Industrial Ontology Library at Siemens"
  - 16:55-17:05 Break
  - 17:05-18:05 Discussion (Panel+ all, interactively). Panel members: Mehwish Alam (KIT, Germany), Gianmaria Bullegas (Perpetual Labs Ltd, UK), David Cameron (Univ. of Oslo, Norway), Irlan Grangel-Gonzalez (Bosch, Germany), Johan Klüwer (DNV, Norway), Boonserm Kulvatunyou (NIST, Usa), Maja Milicic Brandt (Siemens AG, Germany), Robert Young (Loughborough Univ., UK). Moderator: Martin T. Horsch (HLRS, Germany).
  - 18:05-18:15 Wrapping up and closing

During the event, interactions were made possible via Zoom chat, on a MIRO board and via the Mentimeter tool.

3.2.1 Papers abstracts[2]

In this sub-section the abstracts of the papers presented are given. In the following one, we summarize the invited talks and keynotes. The discussion slots for the March event are addressed in Section 4.

Title: A First Step towards Extending the Materials Design Ontology

Authors: Mina Abd Nikooie Pour, Huanyu Li, Rickard Armiento, Patrick Lambrix

In brief: We show preliminary results regarding extending the Materials Design Ontology using a phrase-based topic model.

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[2] The material provided in this subsection was taken from OpenReview, and its authorship resides with the individual paper authors.

Abstract: Ontologies have been proposed as a means towards making data FAIR (Findable, Accessible, Interoperable, Reusable) and has recently attracted much interest in the materials science community. Ontologies for this domain are being developed and one such effort is the Materials Design Ontology. However, to obtain good results when using ontologies in semantically-enabled applications, the ontologies need to be of high quality. One of the quality aspects is that the ontologies should be as complete as possible. In this paper we show preliminary results regarding extending the Materials Design Ontology using a phrase-based topic model.

Title: Domain-specific metadata standardization in materials modelling

Authors: Martin Thomas Horsch, Joana Francisco Morgado, Gerhard Goldbeck, Dorothea Iglezakis, Natalia A. Konchakova, Björn Schembera

In brief: This work comments on the landscape of semantic assets in the field of materials modelling.

Abstract: Domain-specific metadata standards, including ontologies, markup languages, and technical interface specifications, are a necessary component of solutions for FAIR research data management with industrial applications. The Workshop on Domain Ontologies for Research Data Management in Industry Commons of Materials and Manufacturing (DORIC-MM 2021) discusses the state of the art, challenges, and perspectives for continuing innovation in this field. The present work comments on the landscape of semantic assets in the field of materials modelling, covering electronic, atomistic, mesoscopic, and continuum methods. Summaries are given of particularly promising lines of work, including the CAPE-OPEN interface standard, the XML schemas EngMeta, CML, and ThermoML, and the ontologies OntoCAPE, Metadata4Ing/Metadata4HPC, OSMO (the ontology version of MODA) and the VIMMP system of ontologies, and the domain-level modules of the European Materials and Modelling Ontology (EMMO). For future work, it is recommended to emphasize advancing in accordance with five principles: 1. Diversification of technologies; 2. Observation of practices; 3. Realistic objectives; 4. Incentives for providing citable data and software; 5. Co-design of simulation and data technology.

Title: Introducing MAMBO: Materials And Molecules Basic Ontology

Authors: Fabio Le Piane, Matteo Baldoni, Mauro Gaspari, Francesco Mercuri

In brief: MAMBO: Materials And Molecules Basic Ontology

Abstract: Recent advances in computational and experimental technologies applied to the design and development of novel materials have brought out the need for systematic, rational and efficient methods for the organization of knowledge in the field. In this work, we present the initial steps carried out in the development of MAMBO - an ontology focused on the organization of concepts and knowledge in the field of materials based on molecules and targeted to applications. Our approach is guided by the needs of the communities involved in the development of novel molecular materials with functional properties at the nanoscale. As such, MAMBO aims at bridging the gaps of ongoing efforts in the development of ontologies in the materials science domain. By extending current work in the field, the modular nature of MAMBO also allows straightforward extension of concepts and relations to neighbouring domains. Our work is expected to enable the systematic integration of computational and experimental data in specific domains of interest (nanomaterials,

molecular materials, organic and polymeric materials, supramolecular and bio-organic systems, etc.). Moreover, MAMBO can be applied to the development of data-driven integrated predictive frameworks for the design of novel materials with tailored functional properties.

Title: SCONTO: A Modular Ontology for Supply Chain Representation

Authors: Maria Marcela Vegetti, Alicia Böhm, Horacio Pascual Leone, Gabriela Patricia Henning

Abstract: Supply Chain Management (SCM) involves coordinating and integrating material, information and money flows, both within and across several companies. The integration of these flows is perceived differently by distinct communities, raising some semantics-related problems. In traditional industries as well as in the context of the recent Industry 4.0, smart manufacturing or cyber-physical systems initiatives, more efficient and effective integration of supply chain flows is required. This integration implies physical as well as application interoperability and a common understanding at the semantic level. For several years, ontologies have been considered the key technology to achieve semantic integration. So, this contribution introduces SCONTO, an ontology that formally describes a SC at various abstraction levels, by specifying its associated business processes based on the SCOR de facto standard as well as sharing a precise meaning of the information exchanged during communication among the many stakeholders involved in the SC. Moreover, SCONTO provides a foundation for the specification of information logistics processes and sets the grounds for measuring and evaluating a SC by stating different metrics and performance-related concepts.

Title: An overview of some ontological challenges in engineering maintenance

Authors: Stefano Borgo, Francesco Compagno, Nicola Guarino, Claudio Masolo, Emilio M. Sanfilippo

In brief: Addressing maintenance knowledge representation challenges via ontologies

Abstract: Maintenance is an important technical aspect that must be considered in engineering practices. In this paper we present a preliminary ontological investigation of questions such as "What is a component of an engineering system?" and "What happens when a component is replaced after a malfunctioning?", which are both fundamental from a maintenance modelling stance. We focus in particular on two inter-related problems, which we call the missing component and the replacement problems. We describe different approaches dealing with them. First, we start representing kinds of components and systems as temporally qualified first-order logic predicates, eventually reified. We then consider a four-dimensionalist (4D) perspective, mainly based on the ISO 15926. Lastly, we briefly mention a novel point of view based on possible worlds. By the end of the paper, we shortly compare the approaches by discussing their advantages and shortcomings.

Title: Materials' Tribological Characterisation: an OntoCommons Use Case

Authors: Iker Esnaola-Gonzalez, Izaskun Fernandez

In brief: Approach and Challenges for the OntoCommons Use Case 04

Abstract: This paper introduces an ontology-based approach for facilitating the access to the available information in different sources to help tribologists shortening the time, number and size of experiments required to identify the tribological characteristic of a material or combination of them (e.g., metal, coating, lubricant) with respect to specific operation conditions. More specifically, how the use of ontologies for mapping relevant tribological information sources, containing from experiment results to patents/scientific publications, enables the development of a holistic Se-mantic Federated Search service for tribology domain.

3.2.2 Keynotes and invited talks summaries

Title: Ontologies' Interoperability: concerns and perspectives

Speaker: Hedi Karray

Summary: The speaker took us back to the basic of the data exchange reminding the audience the fundamental purpose that is not simply sending and receiving information signals as understood by many but to exchange concepts and their underlying meanings. With an example of how some of the most commonplace exchange between a suitor and his interest may go awry for failing to express their true intentions and expectations in a rather successful communication, he emphasized the importance of capturing the subtle meaning and contextual background for every sort of information. He re-established this very purpose as the true intent of ontology that links the ancient philosophical pursuit to modern day adoption of ontology for achieving semantic disambiguation in information exchange. But then quickly reminded the audience that however ontology being a viable solution for interoperability, they are not themselves interoperable and introduced different levels at which such issues with interoperability appear. Some examples of ambiguity were introduced for each of the layers, that are syntactic, terminological, formatting, logical, semantic, and contextual. The speaker introduced how these alignment issues may be mitigated by stratification of ontologies by top, middle, domain, and application level, especially, choosing a suitable top-level ontology at the design time. However, ontologies may also be aligned by providing matching rules among concepts. Two cases of ontology alignments are elaborated using cases of PLC and ROMAIN, and POLARISCO and MEMOn, respectively. In the final few slides, the speaker introduced OntoCommons ecosystem which leverages these two types of alignment mechanisms to achieve intra-ontology and cross-ontology interoperability.

Title: Domain-level ontologies and the methodology to connect them to a Top-level/Middle-level ontology

Subtitle: The case of the CIF and crystallography domain ontology

Speaker: Jesper Friis and Emanuele Ghedini

Summary: The International Union of Crystallography (IUCr) has been working on standardizing crystallographic data for at least 30 years. The acronym CIF stands for both Crystallographic Information File and Framework, which is a system of dictionaries and rules. On the IUCr webpage (https://www.iucr.org/) one can see there are several dictionaries, the current presentation focuses on the "CIF Core" one. Such dictionaries are written in Dictionary Definition Language (DDL): they are machine readable, but not ontologized. The IUCr and EMMO communities have different but overlapping interests: the former is interested in ontologizing its standards, the latter to develop a widely endorsed formal description of atomistic structures. They came together under the umbrella of the EMMC and formed a task group, with the aim to create ontologies based on the CIF existing dictionaries and to create an EMMO domain ontology for crystallography. The approach is as follows: 1) ontologize the DDL as a small ontology (cif_top), then 2) use tools to generate from each CIF dictionary a TLO-independent module (e.g., cif_core), and finally 3) build on this to create an EMMO domain ontology (extracts of which were shown in the final part of the presentation). The advantages of this approach are that it builds on widely accepted community standards and, since the first two steps are independent of any TLO choice, it enables reusability.

Title: READI: Ontology-based requirements management for industry

Speaker: Johan Wilhelm Klüwer

Summary: DNV is an international classification society serving various sectors, such as maritime, energy, health, etc. READI (https://readi-jip.org/), which stands for REquirement Asset Digital lifecycle Information, is a joint industry project and involves all main oil and gas (O&G) industries.

Typically, in industry many (about 20) disciplines, most from the area of engineering, need to interoperate. Also, requirements have different sources and types: can be governmental, functional, come from standards etc. and all is encoded in a large number of documents. Hundreds of thousands of requirements need to be handled in each major project. As the current management of information is manual, not efficient and costly, ontologies are a way to improve this situation.

The speaker highlights other ongoing initiatives to digitalize the O&G sector using ontologies (DEXPI, CFIHOS, PCA, etc). And two important standards: ISO 15926, which is widely accepted (so its part 14 is used as an adaptation to OWL-DL and aligned with BFO) and ISO/IEC 81346. All of these are sources of knowledge that will be used in the READI project.

Ontology patterns are heavily used in READI too: in particular, OTTR (https://www.ottr.xyz/) provides a template language to be used at the domain-specialist level.

If "a" is an organization, and "A" and "B" are classes, a requirement is expressed as ""a" requires that every "A" is a "B"". Since OWL-DL lacks normative reasoning, to express these, READI uses the Reified Requirements Ontology (https://w3id.org/requirement-ontology/ontology/core). It can be used as a "carrier" for requirements. This allows to obtain quality checks (as identify duplicate and superfluous requirements). READI is developing a digital requirement service in a way that is independent of any particular software vendor. This is done combining various available technologies, such as: the OWL language, RDF endpoints and linked data.

Examples of the uptake of READI within the NOA and KRAFLA Norvegian projects are mentioned: ontologies will speed up preparation and reduce information loss. There is also considerable interest in the power industry, electrical grid, and there is a real push to share assets across companies. The hope is that what READI is developing will be used by other projects, contributing to transform the industry towards "intelligent data".

Title: Industrial Ontology Library at Siemens

Speaker: Maja Milicic Brandt

Summary: Siemens nowadays tackles three main areas: digital transformation of industry infrastructure and mobility, healthcare, and energy. For example, software for cars, trains, airplanes, smart grid, factories, smart buildings etc. The adoption of semantic technology within Siemens started in 2012, mainly with research projects, and then gradually moved into production phase. The need for a shared ontology library within the company was the most recent step.

Four examples of projects developing common and reusable semantic models are given: smart infrastructure building models, plant data model, product and plant lifecycle, and a project in the energy transmission domain (creating both ontologies and a tool to support domain experts to create ontologies). The motivations for such work are to: reduce modelling efforts, speed up data integration, enable product lifecycle integration, and enable a Siemens platform ecosystem. If industrial standards are made, interoperability with suppliers and customers can be achieved too.

Three basic pillars for building an ontology library are identified: content, guidelines, and community building within Siemens. Main learnings over time were: 1) we need a shared upper-level ontology, 2) we need to actively contribute to efforts outside of Siemens, 3) Ontology building takes time, 4) inference is needed (that is: more axiomatization needed, to switch the focus from representation to inference).

Expanding on the above: The upper ontology that is mostly used within Siemens is ISO 15926-part 14. It was easier (as compared to BFO, for example) to have it adopted within industry, since ISO-15926 was already well-known to some people. Contributions were made from Siemens to QUDT, READI, E-Class and Top Industrial Ontology ISO/TR 15926-14. Gist by Semantic Arts will be considered too to be aligned with ISO 15926-14. Data scientists and domain experts understand/know OWL and the domain, respectively, but not the other, and none of them initially understands upper ontologies. Typical issues when re-using ontologies: either what you need is not available in ontology forms, or there are multiple incompatible ones, and to contribute or even assess the value of what is available you need to build-up expertise, and it takes time. What can be done? Training, coaching, enabling domain experts to model the domain without informatic proficiency. SHACL constraints are being increasingly used, it would be useful to have them automatically generated.

Title: Industrial ontologies for manufacturing

Author: Evgeny Kharlamov

Summary: In the Semantic Web, ontologies map the physical world into a digital one. One can say digital twins have a similar role in Industry 4.0. Both ontologies and DTs involve modelling principles, languages, and a machine-understandable domain representation. However, in DT there is way more than conceptual modelling, also communication protocols, hardware etc. That said, modelling is still crucial for them too. Examples of applications are robotic arms and maritime vessels. In general, automation and automated factories all come with DTs. Industry4.0 was a vision and now is becoming a trend.

How to achieve it in practice? And where do ontologies enter? There are four levels of software, from those embedded into machines up to the management level software (in between, there are controllers of several machines, and controllers of the whole plant). The idea is to have such four levels integrated into a single system. Of course, this is an expensive endeavour, and many big players are investing in Industrial IoT strategies, AI etc, in different directions. Ontologies can enter to help the integration between the four layers.

In a sense, ontologies "live" inside controllers. Three main providers for controllers are BOSCH, Siemens and ABB. DTs can be seen as aspect models, where "aspect" is an industry-friendlier way to say "property"; it can also be a "container" of properties, in the sense you can batch together into one aspect few properties which are similar.

In Bosch, there are ontologies also to combine the various aspect models, and an AI layer is added on top. If we investigate how value is extracted from data, we see there is a physical level, then data, data integration (via KGs and ontologies), insight (via AI), and all this can be plugged into applications to extract value (Data -> knowledge -> insight -> value).

Some examples of semantic DTs are: oil platform at Aibel (for engineering and procurement), integration of geological data for visualization at Equinor, high level ontologies to interconnect various Semantic DTs at Bosch, remote diagnostic for turbines in Siemens, work by Festo and University of Oxford to model assembling/mounting of many parts.

In conclusion, several examples from industry show successful applications. However, more advanced DTS are needed, for example with quality evaluation and quality enforcement mechanisms, cost models (what's the most effective way to produce something?), uncertainty. Integration of DTs and AI is needed on a bigger scale. Teaching and tooling are needed too, to enable industry to use Semantic DTs. Standardization is needed both in modelling and in usage, and from many diverse perspectives (safety, etc).

3.3 Participation

For the 15th March kick-off we had 115 registered participants (see Appendix A) from 23 countries across the world; during the event, we started with a participation of about 90 people, and ended with about 70. The audience was indicatively composed as follows[3]: 33% Ontologist (e.g., philosopher, semantic web expert), 28% M&M Domain expert (e.g., materials scientist), 5% Implementer (e.g., database expert), 14% Application developer, 2% End user (e.g., manufacturer), 18% Other. From the domain side, the composition was[4]: 12% Physics and Chemistry, 38% Mechanical and Industrial Engineering, 15% Thermal Engineering/Process Engineering, 35% Material Science and Engineering.

For the 7th June event we had 76 registered participants from 17 countries across the world (see Appendix A); during the whole event, we had about 70 attendees at any time. The audience was

[3] As per Mentimeter question “In which role are you here today?”, which was answered by 57 participants.
[4] As per Mentimeter question “Which part of the semantic landscape are you more interested in?”, which was answered by 52 participants.

indicatively composed as follows[5]: 19% Ontologist (e.g., philosopher, semantic web expert), 30% M&M Domain expert (e.g., materials scientist), 11% Implementer (e.g., database expert), 22% Application developer, 4% End user (e.g., manufacturer), 15% Other.

Finally, we note that all OntoCommons beneficiaries and WPs were represented in this workshop.

[5] As per Mentimeter question "In which role are you here today?", which was answered by 27 participants in the morning session.

4.Participants input

4.1 How the input was gathered

Input was gathered *via* 1) a short survey in March embedded in the registration, 2) Mentimeter (https://www.mentimeter.com/) interactive presentations in both events, and 3) MIRO (www.miro.com) boards in both events. In Figure 1, we show a snapshot of the layout of the MIRO board used in the parallel sessions of the kick-off event (picture taken after the event). In the middle of the board, four panels were dedicated for each of the four domains: Physics and Chemistry (D1), Mechanical and Systems Engineering (D2), Thermal Engineering / Process Engineering (D3), and Material Science and Engineering (D4). Each of these panels provided the interactive platform for participants of one of the four parallel sessions based on the domains mentioned. At the left, existing domain ontologies were enlisted in a stack of virtual sticky notes for participants to refer to while interacting. A panel at the bottom provided space for participants to leave their contact details. The content of each panel generated during the workshop can be viewed in Figure 6 - Figure 9 in Appendix D.

Figure 1: The MIRO board used in the 15th March parallel sessions (snapshot after the event).

4.2 What was gathered

We recall that this activity was targeted to both ontologists and MM domain experts.

At March registration we asked participants about their relation to ontologies.

In the 15th March Mentimeter interactive session, we asked high level questions about standardization, semantic technologies, relevant initiatives, and strategies (in general and for the MM field).

The aim of each domain-specific parallel session was to provide one/two highlight points for: semantic landscape (SL), semantic gaps (SG), usage/implementation landscape (UL); usage/implementation gaps (UG).

In the 7th June Mentimeter interactive session, we asked questions about the level of adoption of semantic technologies, in particular, how to initiate novices to them, the development of domain ontologies, and ISO-like standardization.

In particular, on the whole, these activities allowed us to gather a list of names/acronyms of about 100 ontologies, which has been shared with the OntoCommons dedicated task to be combined with other sources and, if within scope, analysed in depth (see OntoCommons *report on existing domain ontologies in identified domains*).

In the following sections we give highlights from each source, further material is provided in the Appendix.

4.3 15th March event

4.3.1 Short survey

Here we give highlights about the survey embedded into the registration for the 15th March event. This survey was answered by 105 participants and its content was used to support the event organization and the semantic landscape analysis presented in OntoCommons *report on existing domain ontologies in identified domains*. In the Appendix B of the current document, we list all the questions, possible answers for multiple choice ones, and report the answers given by participants to the open questions about use cases and wishes (i.e., questions number 5, 6, and 9). For convenience we repeat the questions here:

Q5: If you have been working with ontologies before, could you give us a short description of the specific use-case(s) for which you used ontologies (max. 2-3 lines per use-case)?

Q6: If you are planning to work with ontologies, could you give us a short description of the specific use-case(s) you have in mind (max. 2-3 lines per use-case)?

Q9: If you had one free wish, what should be developed in the coming year within the ontology field?

Concerning use cases, we got 53+35 answers between the current and perspective ones. We categorize the provided answers for as “Mat”=Materials/Natural Sciences, “Man”=Manufacturing and Engineering ,”Gen”=General/cross domain. We find that among the current uses case (Q5), about

60% is in the Manufacturing domain, whereas in the perspective ones (Q6) the proportion is reduced to 50% due the presence of more numerous Materials/Natural Sciences ones.

Concerning the "wishes", we got 34 answers, which we categorize according to six categories: "F" = Top-level/Framework, "T" = Tool, "M" = Method/guideline, "S" = Specific ontology," C" = Cooperation/Sharing," E" = Examples/training. We find that the majority (about 40%) concern tools and is followed by (about 30%) specific ontologies, while all the other categories are less represented (roughly 10-15%).

4.3.2 Highlights from the Mentimeter presentation

In this section we give some highlights; the full list of questions can be found in Appendix C of the current document. Also, the full Mentimeter presentation and results can be found on the event website, at this address: https://ontocommons.eu/sites/default/files/DORIC-MM_kick-off_interactive_talk_with_results_SC.pdf .

- Question: "What are the main difficulties for standardization in general?" Result: "Conceptual: building a good framework" was the majority answer, closely followed by "Cultural/political: reaching an agreement".
- Question: "What are the main adverse factors for standardization of data documentation in M&M? Result: "Lack of long term and community vision" was the majority answer. The full result is shown below, in Figure 2.
- Question: "Do you know where to find ontologies for your field?" Result: Only 25% said "Yes". Clearly, there is an issue with findability.
- Question: "Do you have a clear understanding of how semantic technologies can support your work?" Result: 50% said "Yes", and 50% "Maybe" or "No". Clearly, to improve the uptake of semantic technologies, their benefits need to be further explained/demonstrated to MM domain experts.
- Question: "On which platforms do you publish your ontologies or look for existing ones?" The result is shown below, in Figure 3.

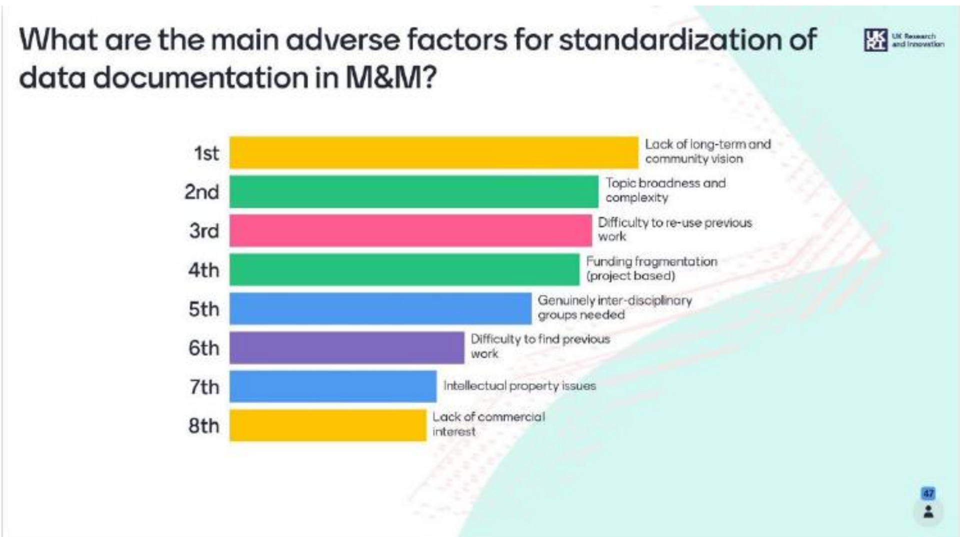

Figure 2: Snapshot from the March Mentimeter presentation, results for question Q9.

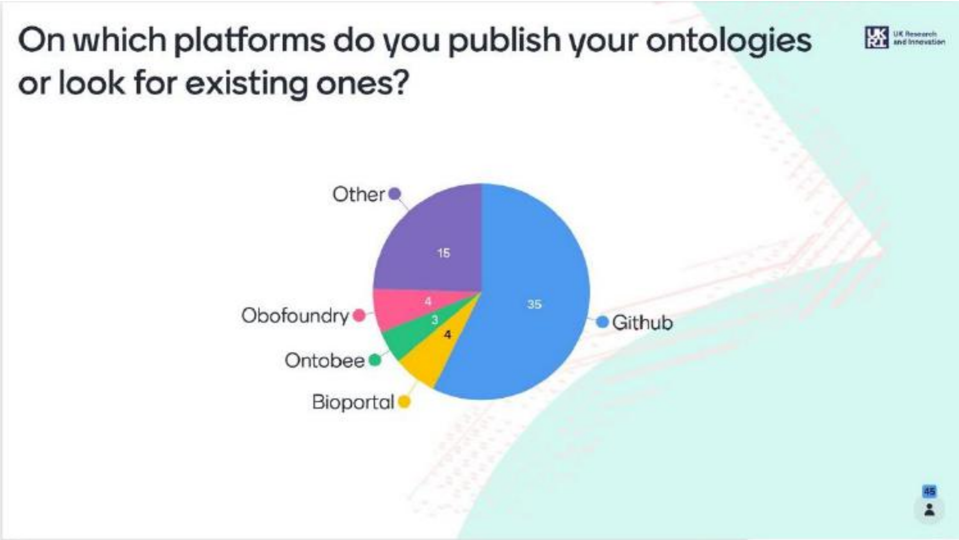

Figure 3: Snapshot from the March Mentimeter presentation, results for question Q15.

4.3.3 Highlights from the domain-specific parallel sessions and MIRO board

In this section we report the main conclusions of the four domain-specific parallel sessions of the 15th March. Snapshots of the corresponding Miro board panel are shown in the Appendix D.

D1 - Physics and Chemistry

- SL: TLO EMMO (European Materials and Modelling Ontology). Range of legacy and currently developed ontologies. Some vocabularies and metadata pre-standards
- SG: Use cases; Re-usability and interoperability/alignment; Lack of reasoner development, lack of true EU-wide standard vocabularies and metadata.
- UL: Domain standard tools, some re-inventing the wheel, OpenBabel in Chemistry etc many types of e.g., digital notebooks, python tools!
- UG: trust, demonstrators, tools that allow domain experts to easily map concepts to ontologies

Other:

- OpenBabel tool for mapping concepts to ontologies is desirable.

D2 - Mechanical and Industrial Engineering:

In brief:

- Lots of work has been done, but largely at a low Technology Readiness Level - TRL (i.e., research work), very little of this has direct economic commercial value.

- Need for a framework within which domain ontologies can be developed and extended, to be able to meet commercial needs.
- Following up on the importance of high expressivity (seen in the Mentimeter results), it would be nice to see work on Common-Logic, beside that on OWL.

Other points:

- Need for a repository for existing Ontologies
- A taxonomy of domains would help also in presenting reference domain ontologies.
- There is a gap between ontologies proposed by academia and the models that are used in Industry
- Need for a Common Development Framework
- Lack of a sustainability strategy.
- Issue of ontologies quality/trust, related to its adoption in businesses.
- Tools and methodologies to evaluate ontologies' quality and collaboration tools.

D3 - Thermal Engineering/Process Engineering

- SL: ISO15926 variants, ISO81346, (AAS Asset Administration Shell)
- SG: Alignment, modularity, reasoning, usability.
- UL: Supply-chain handovers: engineering-operations-maintenance
- UG: Digital twins, link to BIM around facilities.

Other points:

- Some sets of ontologies have been available over about twenty years and need to be consolidated. They include variants of ISO-15926 and OntoCape.
- Process and oil-and-gas industry have funded initiatives such as READI, DEXPI.
- Need for alignment, modularization, and agreement between overlapping initiatives.
- Need to make ontologies usable by domain experts.

D4 - Material Science and Engineering

- SL: Various ontologies adopted within the field. Link with "biology" ontologies
- SG: Lack for a common entry point to find ontologies. Lack of common vocabulary for linking experiments and modelling; standards designed to enable interoperability across different scales; model validation; molecular and nanomaterials (modelling and characterization)
- UL: Several Metadata standards used in the community; File formats for experimental data or simulation outputs incorporating metadata
- UG: Metadata standards for multiscale simulation workflows; Missing standard for mechanical testing; Missing standard for Crystallography; Difficulty linking metadata standards with ontologies (DICOM) [In fact, some file formats (e.g., DICOM, for images) include metadata fields already, and that causes an issue when connecting to ontologies.]

4.3.4 Highlights from the plenary panel discussion

Here we summarize the outcome of the final panel of the 15th March event:

- Different levels of standardization in the domains: while in some of our domains we have standards at the level of ISO, in others we are very far from that (e.g., a CWA).
- Standards are key, but very hard/impossible to be produced within the timescale of a typical EU project. Unless the project is really about just producing the standard, this typically needs extra funding and time to be realized after the project is over.
- *De facto* standards are also important, and for that it is needed to get commercial partners on board (could be manufacturers, software vendors).
- What is the incentive for large vendors, who might prefer their own proprietary standards? If industrial end-users push for this, it is possible to get large vendors on board too (see e.g., the case of Cape-Open).
- Importance of demonstrators.
- Meaningful data sharing is becoming more and more a clear need.
- Global semantic alignment is a requirement.
- Industry, Standardisation organisations, Universities, Supporters of data spaces are all relevant actors.

4.4 7th June event

In this section we report on participants input and on the outcome of discussions from the 7th June event (Note: for frontal presentations, please see Section 3 above).

4.4.1 Highlights from the Mentimeter presentation

- Question "Would you benefit from an improvement of data integration, sharing and format conversion in your field?" Result: almost unanimously "Yes, definitely".
- Question: "In your institute/company, semantic technologies … are heavily used/ start to be used/are not used at all yet?" Result: 70% answered they "start to be used".
- Question: "Do we need formal standards (as ISO ones)?" Result: 2/3 of the audience said "Yes".

Below we include two snapshots of the results to Q11 and Q12:

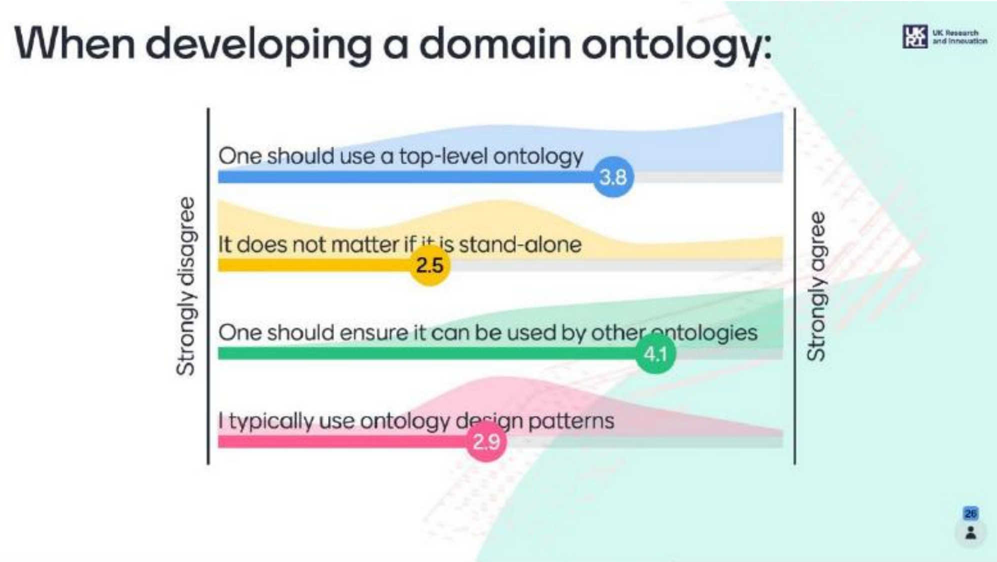

Figure 4: Snapshot from the 7th June Mentimeter presentation, results for Q11.

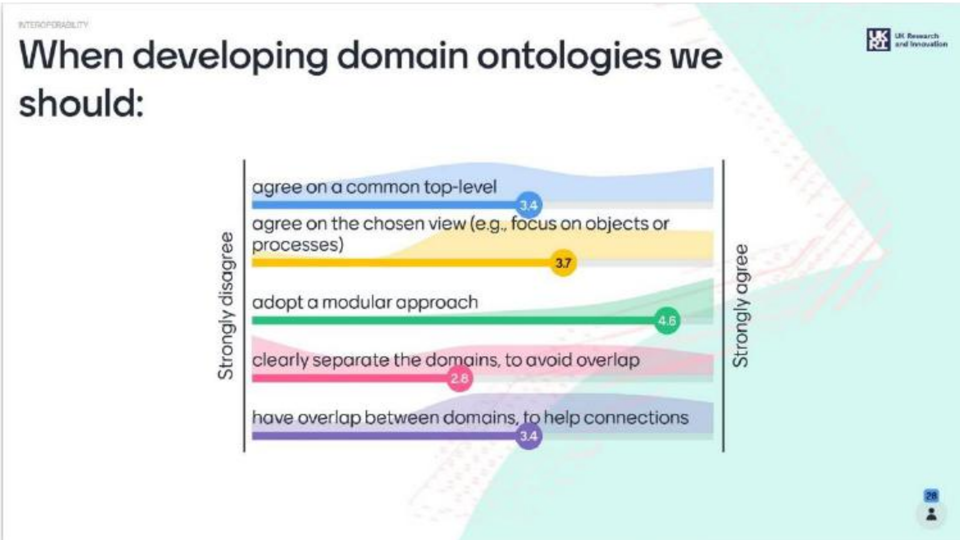

Figure 5: Snapshot from the 7th June Mentimeter presentation, results for Q12.

In the Appendix C we also report the recommendations we got from the audience in reply to the question Q9 ("What would you recommend as a first step to a M&M expert who would like to introduce semantic technologies in their work? ") and to Q15 ("How do we fund the process of taking valuable research results to the level of formal (ISO-like) standards?").

4.4.2 Highlights from the morning panel discussion

From the morning panel of the 7th June:

- **Examples of ongoing initiatives, the NDFI4cat in Germany and UK National Digital Twin project:**
  - Within the NDFI4Cat project they are scanning what is available concerning synthesis, catalysis, and design to build an architecture of ontologies in this field. They build a map of ontologies in the catalysis chain from molecular level to process-engineering

level. Later they will see how they can be combined; this will be problematic since their TLOs will be different.
  - The UK National Digital Twin project is looking into data models for national infrastructures to support planning and resilience (integrating, among others, geographic information, transport, water management, and electrical grid). There are ontologies in the various domains, but they need to be combined between them. And there are models to simulate parts of the infrastructure, and to get them work with each other is not obvious. ISO standards exist and are heavily used, so changes have implications.
- Example of OntoCape: Historically, OntoCape and Cape-Open (much earlier) were efforts to standardize models and interfaces. OntoCape probably was ahead of its time, so wasn't used properly (maybe because of limitations due to compute and storage capabilities at that time). The importance to re-use such types of works was highlighted. This also connects to the necessity of building common repositories (such as MatPortal).
- **International Vocabulary for Metrology (VIM)** is about properties, quantities, values, units, uncertainties: its terminology tends to be used in ontologies, but somehow inconsistently. FAIR metrology data, there is work to be done in this direction. There is an ongoing effort to ontologize the VIM within the EMMO mid-level to connect to the SI units.
- What does "property" mean? Used a lot, but not defined in VIM. There is a body of work that needs to be done on this. What does "behaviour" mean? Both are examples or commonly used, but tricky concepts.
- It feels like systems terminology, which is very generic, is missing in the EMMO.
- ISO standards are text documents. What is the work to take this into ontologies? Should it be done? Is it going on?
- **How to combine various views and domains? Dynamic visualization?**
  - It is a major problem, probably unsolved in engineering. For example, one could think in terms of dynamic visualization: it would be very good to have something like that for ontologies, where you are able to zoom in and out in detail as needed. Think of Google Maps: that is a type of visualization that might be valuable for an ontology ecosystem.
- **A system of (domain) ontologies**
  - A Unix-like philosophy could be used, as a periodic table of elements: many building blocks that can be combined, and there are rules to combine them. Different tiers of complexity are present and not all blocks need to be used at the same time.
  - Rather than TLO, the interface to TLO is what is more relevant from the point of view of developers of domain ontologies. In other words, we should "isolate" the domain ontologies from the TLOs different views.
- **What should be the next steps for an ecosystem of domain ontologies?**
  - Take some well-developed pieces of information and take them further and put it in the form of an ontology (e.g., as done in the EMMO-Crystallography). This allows cleaning out for inconsistencies, etc.
  - We really need to have both domain experts and ontologists to meet.

4.4.3 Highlights from the afternoon panel discussion

From the afternoon panel of the 7th June:

- **Bridging the gap between domain experts and ontologists (and examples):**
    - What methods could be used and how to hide the technical aspects from domain experts? Is collaborative interactive building a useful method?
    - One approach is *via* competency questions (i.e., what objectives do they have and what questions would they like to answer), to help domain experts to organize the knowledge in their domain. Experience is that guidance is needed to support business and domain experts, since the "competency question" approach does not necessarily come as natural.
    - In BAM they have been developing ontologies for materials characterization (>100 people in various teams, in each team there is an ontologist). There they have used a graphical collaborative tool, then later the input was transformed into ontologies. Examples, tutorials and very good documentation are needed. You need a TLO and a well-defined middle-level ontology.
    - From an academic perspective, another approach is to embed researchers in industry (e.g., one on the product design and one with the manufacturing engineers, and then trying to find mapping between the two).
    - Example of building the MMD ontology at Aibel (an ontology with 10.000 of classes was built). Templates must be simple, and ontology patterns can really work well. Web forms should be available to the domain experts. It was found that experienced domain experts with no semantic background could in this way contribute very effectively and quite independently to the ontology building.
    - It is important to show domain experts that ontologies are not only something theoretical, but can be used, to solve interoperability issues and to simplify certain tasks.
- **Role of industry**
    - We need to give industry some useful solutions. How do we make it a more cost-effective process (quicker, cheaper and more effective)?
    - Sharing and IP: In industry it seems there is an understanding that sharing ontologies with others would be beneficial for all.
    - Project like OC are important, but more involvement from industry is needed. Life sciences are much more ahead in standardization, maybe one important point is to choose a TLO.
- **Digital twins *vs* ontologies:** they are not exactly the same, digital twins needs to have some predictive capability. Digital Twins can be seen as having three components: a static asset model, measurements on what happens and simulations/ML to make predictions. All this works together to give you the best possible estimate of the state of the object.
- **Importance of numbers.** From the perspective of people involved with simulations and computational methods: How do we handle numbers in ontologies? We need to have a way to represent mathematical models ontologically. Other panellists expressed instead a different opinion, that adding numbers to OWL is not needed.
- **Visualization:** as already discussed in the morning panel, visualization is key.

- **ISO standards:** their cost is prohibitive for some users. Also, a drawback is that they are given as text.
- **Expressivity:**
  - Some panel members think that OWL might not be enough and wish for more expressive languages (e.g., Common Logic). In the past there were two commercial products (one from US, one from Germany) to work in CL, but the products do not exist anymore. They were far too costly for commercial usage; they no longer exist. From the modelling point of view this approach was much more suitable: it would be good if a tool was developed again in this direction. It was pointed out that NORMA is a free tool that supports CL.
  - Other panel members voice the opposite opinion: we should first tap on OWL before going to more expressive languages. It is much more difficult to work in FOL than in DL. Already using full OWL in manufacturing would be great.
  - Should we be considering graph grammar or programming in terms of Prolog (programming language)?

5.Conclusions

The OntoCommons Focused Workshop entitled "Domain Ontologies for Research Data Management in Industry Commons of Materials and Manufacturing (DORIC-MM)", aimed to support the semantic landscape analysis in the materials and manufacturing (MM) field. It has brought together ontologists and MM domain experts in two interactive on-line events, a half-day one in March and a full-day one June 2021, with 115 and 76 registered participants, respectively, and a wide representation of roles, domains, and countries, therefore achieving the participation targets. The June event was proudly co-located with the 18th European Semantic Web Conference (ESWC 2021), allowing to connect with the wider Semantic Web academic community. *Via* discussions and making use of different collaborative tools, on the whole this activity has notably allowed to gather: a list of relevant domain ontologies, which have entered the associated project *report on existing domain ontologies in identified domains*; a list of relevant initiatives; desiderata; example of use cases (as brief texts); ideas on semantic and usage landscape (what is there) and gaps (what is missing) in four domains (Namely: Physics and Chemistry, Mechanical and Industrial Engineering, Thermal and Process Engineering, Material Science); opinions and ideas about standardization, semantic technologies, and strategies (in general and for the MM field). Also, a large sub-set of the participants contributed to domain-focused expert meetings, whose outcomes are also detailed in the *report on existing domain ontologies in identified domains*.

Frontal presentations given in the March event have introduced community-building initiatives, such as OntoCommons itself, the IOF and the EMMC ABSL. In the June event, there was an introductory keynote on interoperability; three talks, by BOSCH, SIEMENS and DNV, presented the state-of-the art of semantic technology from an industrial perspective; a talk discussed how to build domain ontologies from widely accepted standards and how to connect to a TLO; moreover, six talks, based on workshop papers, have addressed, *via* specific examples, conceptual, technical, and cultural/political aspects, such as ontology design, ontology extension, technology uptake.

The panel discussions have pointed out that the level of standardization level is quite different in the various MM domains, and ways to fund the standardisation process have been proposed. Strategies have been suggested to bridge the gap between domain experts and ontologists, and examples of success stories in this line have been given. The role of industry was discussed from different perspectives. Opinions were gathered on the current practices and desirable ones when building a domain ontology and a system of domain ontologies (which can inform the development of the OntoCommons Ecosystem). Visualization was highlighted as an important aspect, and it was suggested the dynamic visualization techniques could be valuable to represent an ontology ecosystem such as the one OntoCommons is building.

6. Acknowledgements

We would like to warmly thank all the attendees of the 15th March and 7th June events for their impressive participation, all the speakers and panel members for their engagement and support also in the preparatory phases. Last, but not least, we would like to thank all colleagues who supported the event preparation and running.

7. Appendix A: Registered participant organisations

7.1 For the 15th March event

Table 1: List of registered participants for the 15th March event

	ORGANISATION
1	Politecnico di Milano
2	FUNDACIÓ EURECAT
3	UPM
4	TU Dortmund
5	Goldbeck Consulting
6	Nextworks
7	Fraunhofer IFAM
8	ENIT
9	PRé Sustainability
10	Technical University of Munich
11	University at Buffalo
12	Bundesanstalt für Materialforschung und -prüfung (BAM)
13	UKRI-STFC
14	UoI
15	Royal Society of Chemistry
16	5A SOLUTIONS
17	Germany
18	University of Oslo
19	Nanolayers Research Computing LTD
20	Salzburg Research
21	EPFL-UiO
22	ATB- Bremen
23	Ohio University
24	Fraunhofer
25	University of Ioannina
26	ENIT
27	ecoinvent Association
28	National Research Council (CNR)
29	Namkin

30	CNR-ISMN
31	Federal University of Rio Grande do Sul (UFRGS)
32	AIDIMME
33	Sevilla University
34	Nanolayers Research Computing Ltd.
35	ElvalHalcor
36	Consiglio Nazionale delle Ricerche (CNR)
37	ULB Darmstadt
38	Universidad Nacional del Litoral
39	Goldbeck Consulting Ltd
40	Perpetual Labs Ltd
41	ENIT
42	UKRI
43	University of Yaounde 1
44	Cambridge Nanomaterials Technology Ltd
45	SINTEF
46	Fraunhofer IWM
47	Universidade do Minho
48	Universidade do Minho
49	ISADEUS
50	suite5
51	Wayne State University
52	TOTAL
53	UFRGS
54	NOMAD Centre of Excellence
55	INGAR (CONICET/UTN)
56	Universidad Politécnica de Madrid
57	Universidad Politécnica de Madrid
58	Fraunhofer EMI
59	Innovation Centre for Process Data Technology
60	Industrial AI, University of South Australia
61	ISMN-CNR
62	Information Junction Ltd
63	University of Toronto
64	Politecnico di Milano-ABC department
65	Technische Universität Braunschweig, Institut für Technische Chemie
66	FIZ Karlsruhe - Leibniz Institute for Information Infrastructure, Karlsruhe Institute of Technology
67	University of Toronto
68	UKRI
69	Fraunhofer IFAM

70	Fraunhofer IFAM
71	The National Center for Nuclear Research
72	Industry Commons Foundation
73	Consejo Superior de Investigaciones Científicas (CISC)
74	Linkoping University
75	TU Wien
76	CNR
77	Toolboks
78	Ideaconsult Ltd
79	Infineon Technologies AG
80	Universitat Internacional de Catalunya
81	eScience Center
82	Université de Lorraine, CNRS, CRAN
83	Linköping University
84	Findwise ab
85	SINTEF
86	CAPE-OPEN LABORATORIES NETWORK
87	Swansea University
88	Onto
89	UCLouvain
90	Loughborough University
91	International Association for Ontology and its Applications
92	IRES
93	Loughborough University
94	Federal Institute for Materials Research and Testing (BAM)
95	VisuaLynk
96	NIST
97	Science and Technology Facilities Council, UK Research and Innovation (STFC/UKRI)
98	Politecnico di Milano
99	Laboratory for Applied Ontology ISTC-CNR
100	National Centre for Nuclear Research
101	politecnico di milano
102	IRES (Innovation in Research and Engineering Solutions)
103	ecoinvent
104	Austrian Center of Digital Production
105	SINTEF
106	UKRI
107	Fraunhofer IFAM
108	Salzburg Research
109	CNR

110	Fraunhofer IFAM
111	TIB
112	William & Valerie Sobel LLC
113	EPFL
114	Hosei University
115	National Institute of Standards and Technology

7.2 For the 7th June event

Table 2: List of registered participants for the 7th June event

	ORGANISATION
1	Tekniker
2	FUNDACIÓ EURECAT
3	TU Dortmund
4	Goldbeck Consulting
5	Fraunhofer Materials
6	Fundación TEKNIKER
7	ATB-Bremen
8	ENIT
9	Bundesanstalt für Materialforschung und -prüfung (BAM)
10	UKRI-STFC
11	UoI
12	Trust-IT
13	Goldbeck Consulting Limited
14	University of Oslo
15	CAESAR Systems Ltd
16	EPFL-UiO
17	Fraunhofer IWM
18	University of Bologna
19	Bosch Center for Artificial Intelligence
20	CNR-ISMN
21	Keysight
22	Laboratory of Applied Ontology
23	Consiglio Nazionale delle Ricerche (CNR)
24	SINTEF Digital
25	Universidad Nacional del Litoral
26	Goldbeck Consulting Ltd
27	Perpetual Labs Ltd
28	ENIT
29	Norwegian University of Science and Technology
30	Tekniker

31	Bosch
32	University of Yaounde 1
33	SINTEF
34	Fraunhofer IWM
35	University of Bristol
36	DNV
37	Bundesanstalt für Materialforschung und -prüfung (BAM)
38	TU Dortmund University, Equipment Design
39	National University of Ireland Galway
40	Perpetual Labs Ltd
41	UFRGS
42	NOMAD Centre of Excellence
43	Siemens AG
44	INGAR (CONICET/UTN)
45	parson AG
46	Fraunhofer EMI
47	UK Research and Innovation
48	TU Darmstadt
49	FIZ Karlsruhe - Leibniz Institute for Information Infrastructure, Karlsruhe Institute of Technology
50	Fraunhofer IFAM
51	UKRI STFC Daresbury Laboratory
52	Industry Commons Foundation
53	Linkoping University
54	TU Wien
55	Helmholtz-Zentrum Hereon
56	National Technical University of Athens
57	UKRI
58	Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University
59	Linköping University
60	Trust-IT
61	Loughborough University
62	IRES
63	Federal Institute for Materials Research and Testing (BAM)
64	NIST
65	Science and Technology Facilities Council, UK Research and Innovation (STFC/UKRI)
66	Laboratory for Applied Ontology ISTC-CNR
67	TIB – Leibniz Information Centre for Science and Technology and University Library
68	Austrian Center of Digital Production
69	University of Innsbruck
70	UKRI
71	University of Manchester

72	Leibniz-Institut für Kristallzüchtung (IKZ)
73	National University of Ireland, Galway
74	e-Science Data Factory
75	National Institute of Standards and Technology
76	CIATEQ, A.C. Posgrados

8. Appendix B: Extracts from the short survey

In this Appendix we provide the full list of questions asked in the short survey (Table 3) and the answers to selected ones (namely, questions number 5, 6 and 9, in Table 4, 5, and 6 respectively).

Table 3: Short survey

#	Question	Possible answers
1	Are you familiar with software engineering?	• Yes, I work on software engineering • I know about software engineering but I do not consider myself as an expert • I am not really familiar with software engineering
2	Are you familiar with ontology engineering?	• Yes, I work on ontology engineering • I know about ontology engineering but I do not consider myself as an expert • I am not really familiar with ontology engineering
3	How many ontologies have you (co-)developed?	• None • Less than 5 • Less than 10 • Too many
4	In which domain are you working or planning to work with ontologies?	• Chemistry • Physics • Mechanical and Industrial Engineering • Thermal Engineering/Process Engineering • Material Science and Engineering • Computer Science, Systems and Electrical Engineering • Construction Engineering and Architecture • Other – Please specify
5	If you have been working with ontologies before, could you give us a short description of the specific use-case(s) for which you used ontologies (max. 2-3 lines per use-case)?	(Open answer)
6	If you are planning to work with ontologies, could you give us a short description of the specific use-case(s) you have in mind (max. 2-3 lines per use-case)?	(Open answer)

7	In the context of your use-case for which purpose(s) would you use specific semantic tools and/or ontologies?	• Knowledge Management • Data Annotation (text, image,...) • Reasoning • Information retrieval • Other – Please specify
8	What has been your best experience using/developing/learning about domain ontologies in the last year?	(Open answer)
9	If you had one free wish, what should be developed in the coming year within the ontology field?	(Open answer)
10	Are top and middle level ontologies important to your domain ontology development?	• Yes • No • Maybe
11	If top and middle level ontologies are important to your domain ontology development, could you tell us which ones?	(Open answer)
12	Would you be ok to provide us more information about the ontologies you have developed or used to help us analyse the current landscape?	• Yes • No
13	Provide the list of names and associated URI of any ontologies you are using/encountered in your domain separated by a comma. If you do not know the URI, please at least provide the name of the ontology.	(Open answer)
14	Do you plan to attend the 7th June 2021 event too?	• Yes • No • Maybe • I do not know yet

To help the reader, we tag the provided answers for Q5 as "Mat"=Materials/Natural Sciences, " "Man"=Manufacturing and Engineering ,"Gen"=General/cross domain

Result: 34 Man, 10 Mat, 11 Gen (Note: some have two entries!)

Table 4: Answers to survey Q5

Answers to survey Q5: "If you have been working with ontologies before, could you give us a short description of the specific use-case(s) for which you used ontologies (max. 2-3 lines per use-case)? "		
#	Answer text	Tag
1	1. Knowledge sharing between production and product design i.e. design for manufacture in an aerospace business exploiting ontologies and PLM systems 2. Reference ontologies to support cross-disciplinary configuration services for global production networks. Interoperability across over 10 business and technical product development services tested with 4 distinct business scenarios targeted at improved market potential, time-to-market, cost and risk management. The core of this activity led to the development of ISO 20534: "Industrial automation systems and integration — Formal semantic models for the configuration of global production networks". 3. Some early activity towards ontologies to support RFID systems design.	Man
2	1) Integration of manufacturing process data from multiple sensors to facilitate anomaly detection and decision-making. 2) Integration of assembly process data to support simulation and trade-off between different assembly processes.	Man
3	Assembly design ontology	Man
4	building level ontologies with focus on occupants comfort, energy systems and building acoustics	Man
5	data integration; knowledge representation and reasoning for AI based systems	Gen
6	Developed my PhD thesis in ontologies harmonization in manufacturing domain	Man
7	Developed Process Industries ISO standard ontology (first ontology to be standardised by ISO) ISO 15926 for data sharing and integration within the industry. Wrote a book "Developing High Quality Data Models" that included an Top Level Ontology.	Man
8	Development of a core ontology for Geology as a hub for petroleum geology ontology network Ontology of figures representation in the context of petroleum exploration	Mat

9	Development of an ontology for product version management (VERONTO) Using an ontology network to interoperate product industrial data Standards Design of an ontology network to support the integration of planning and scheduling activities in batch process industries Development an ontology for comprehensive and consistent representation of product information.	Man
10	Development of domain specific ontologies for construction renovation scenarios	Man
11	Development of ontologies to facilitate the interoperability across different software tools - these ontologies include the description of a simulation workflow (inputs, outputs, pre-processing, post-processing, models) and also of the processes that are being modelled at various scales (electronic, mesoscopic and continuum). Development of ontology to describe mechanical testing methods (e.g.: Nanoindentation, fatigue test). Development of an ontology for cultural heritage preservation application to enable interoperability between a decision support system and modelling component.	Mat
12	development of ontology alignment tool; development of ontology alignment evaluation systems; development of ontology completion and debugging tool; development of ontologies, e.g., Materials Design Ontology (https://w3id.org/mdo), Animal Health Surveillance Ontology (https://bioportal.bioontology.org/ontologies/AHSO)	Gen, Mat
13	Digital Construction Ontologies (https://w3id.org/digitalconstruction/). The objective is to provide a framework for semantic interoperability for design and management tools used primarily in renovation projects of residential building, and eventually more broadly in the construction domain.	Man
14	Digital marketplaces for materials modelling: we wanted a framework to organize the knowledge needed on the platform (software, experts, etc). Aim: interoperability within the platform and to connect to external platforms and providers.	Mat
15	EMMO Top Level and Mid Level Ontology; Capturing nanomechanical characterisation; Representation of materials and manufacturing challenges; Marketplaces	Mat, Man
16	I developed a biomaterials ontology and currently investigating how to expand it. I am also creating computational tools consuming ontology for annotations.	Mat

17	I have been working with EMMO middle in general. The metrology and the connection to measurements has got a special attention together with ordering based on direct parthood. Some EMMO-based domain ontologies I have contributed to include: - The crystallography domain ontology, which is implemented as a formal language based on the CIF directory by IUCr. The initial use case here was to be able to provide a semantic interoperable description of (periodic) atomistic structures: MarketPlace SimASE app. - The battery interface ontology (BattINFO) developed in the BIG-MAP project. This ontology is highly modular in order to simplify later factorisation into a set of more generic domain ontologies, like electrochemistry and characterisation as well as batteries and battery interfaces. The aim is to provide a common representational language for connecting characterisation, modelling and AI for rapid development of new battery materials. The first use case will be facilitate the digital lab notebook developed in BIG-MAP. - The microstructure domain ontology, that focus on metallic microstructures. It tries to separate microstructure evolution from properties that can be calculated from a given microstructure state. It has also the ambition to allow to describe a microstructure either statistically (e.g. in terms of particle size distributions) and geometrically (in terms of a spatial 3D description) and to facilitate switching between these views. The aim is to facilitate seamless workflows involving characterisation, data processing and through-process and through-scale modelling. The initial use case is about connecting experimental grain orientations (EBSD and X-ray) with post-processing and virtualisation tools. The next step will be to compare with predicted grain orientation distribution functions using the Taylor or Alamel model. - The atomistic and electronic domain ontology. This has a major revision when the crystallography domain ontology was factored out and needs more attention. Same use case as for the crystallography domain ontology.	
18	In combination with search UI; For use in training models in RASA to create a virtual assistant Taxonomy/Ontology for content annotation	Gen
19	Integrating data from different sources.	Gen
20	integration of catalogue information in the furniture environment for cataloguing systems representation of furniture industrial assets such as machinery and processes for management platforms	Man
21	Integration of data from differenct actors in materials science and engineering with the focus on decentralized data spaces. Materials (product) and manufacturing data should be traceable within its life cycle in a distributed scenario.	Man, Mat

22	Integration of data from EHR to Integrate with Healthcare Insurance Business model according to Demographics of patient in the context of assigning the HealthCare Insurance Policy.	Gen
23	Integration of data sources associated with production planning and industrial scheduling	Man
24	Integration of several business data such as Configuration Management, Engineering, Procurement, Supply-Chain, Manufacturing Engineering, Manufacturing, Quality in order to answer to several business uses cases on complex industrial product for aerospace with final objectif of industrial performance improvement	Man
25	Integration of tools for manufacturing system modeling and analysis.	Man
26	manufacturing capability, supplier discovery	Man
27	Manufacturing equipment and systems decomposition Manufacturing process and execution information Topological information for manufactured parts Sensor data from equipment and relations to systems Machine capabilities	Man
28	Materials characterization data annotation.	Mat
29	ONTO-PDM : Ontology for Product Data Management ONTO-AGRI : Ontology for Agriculture Ontology for systems interoperability assessment	Man
30	Ontologies for development of the EPPN platform	Man
31	Ontology + rules for predictive maintenance	Man
32	Ontology of services Ontology of software Ontology of economic value Ontology of competition (in the business domain)	Gen
33	Ontology-based data governance and access for digital twins of petroleum and process facilities.	Man
34	Previously worked on a project to develop ontologies to support data integration in the domain of transportation/urban planning.	Man
35	process ontologie of tensile testing distinct use case of a steel sheet production	Man
36	process ontologies;	Man
37	Process planning use case for mechanical parts. Ontology to represent process and resource capabilities and use them to plan manufacturing of machined parts. Process planning and Scheduling ontology as reference ontology within IOF	Man

38	product feasibility based on ontology reasoning and machine learning algorithm for machine state identification semantic alignment of criticality analysis terms for a multi-plant company	Man
39	Product Lifecycle Management, Predictive Maintenance, Product Service Systems, Systems Engineering.	Man
40	Product service systems in manufacturing industry	Man
41	Providing decision support in WEEE remanufacturing using a domain ontology created in line with BFO Supporting decision making in selecting the right RFID tag to place on a product using a domain ontology created in line with BFO For knowledge management in tracking staff wearing PPE in specific manufacturing environments Tracking mobile assets in a complex manufacturing environment and ensuring that sufficient information is collected for trilateration algorithm	Man
42	Representation of knowledge in uranalysis to guide the analysis of urine samples by predicting particles that are likely to be observed and assessing the consistency of the findings. Representation of geological processes to help in abductive reasoning in petroleum exploration.	Mat
43	Retrieval of structured information from integrated computational/experimental data on molecular materials (molecular aggregates, molecular thin-films, etc.) Definition of complex workflows for the modelling of systems based on molecular materials	Mat
44	semantic data integration for supply chain management in the semiconductor domain	Man
45	semantic integration of manufacturing software applications natural language question answering	Man
46	structuring of experimental data for later use in data science applications	Gen
47	Teaching principles to novices for EMMO	Gen
48	text mining of scientific articles and integration of diverse pharmacological data	Gen
49	To support interoperability between computers and computers, computers and humans, and humans and humans	Gen
50	Use of Ontologies for Systems Engineering in the context of the development of avionics for a satellite	Man
51	Virtual Materials Marketplace (VIMMP) marketplace-level domain ontologies, use case known to OntoCommons. German national research data infrastructures (NFDI) for catalysis (NFDI4Cat) and for	Man

	the engineering science (NFDI4Ing). Interoperability aspects of the molecular model database (MolMod DB) of the Boltzmann-Zuse Society for Computational Molecular Engineering (BZS).	
52	We used ontologies to have a common data model representation of a domain. Also, we use them to interrelate the information of a certain domain (e.g. Water-nexus) to have a common vision of the interrelation of the variables. Specifically, I developed ontologies for the following domains: (I) Water distribution systems (ii) waste-water distribution systems (iii) Water-nexus (iv) Risk over the critical infrastructures Moreover, we supported the creation of SAREF4WATR.	Man
53	We've been working to design systems within our digital research platform in order to support centralized ontology development, but not specific use cases	Gen

To help the reader, we tag the provided answers for Q6 as "Mat"=Materials/Natural Sciences, " "Man"=Manufacturing and Engineering ,"Gen"=General/cross domain

Result: 17 Man, 13 Mat, 7 Gen (Note: some have two entries!)

Table 5: Answers to survey Q6

Answers to survey Q6: "If you are planning to work with ontologies, could you give us a short description of the specific use-case(s) you have in mind (max. 2-3 lines per use-case)?"		
#	**Answer text**	**Tag**
1	connecting data silos of a production plant to have a unified data model and facilitate data extraction. reconfiguration of production system based on rules defined in ontology and capabilities of the production system	Man
2	Create generic Ontology for small and medium industrial companies	Man
3	Current project focuses on the development of ontologies to support asset management activities for a municipal water service.	Man
4	data integration; knowledge representation and reasoning for AI based systems	Gen
5	development and integration of marketing ontology to extract and store information about marketing environment of companies	Gen
6	Development of domain specific ontologies for construction renovation scenarios	Man
7	Enrichment of furniture industrial models representation Implementation of furniture-related models through ontology representation	Man
8	environmental ontologies;	Mat

9	Environmental sciences	Mat
10	For the planning, we expect to apply ontology modelling to the following domains or use cases: (I) Industrial/Process symbiosis (ii) materials and resources sharing (iii) gene/genotype modelling	Man, Mat
11	From manufacturing domain in general towards inspection and metrology specific domain	Man
12	Future work includes further characterisation ontologies and an ontology to support data interoperability in the energy/battery domain	Mat
13	I have been involved in the OPTIMADE project which we started in 2016. We have created a common API between many manterials database (AFLOW, Materials Cloud, Materials Project, NOMAD, OQMD, ...). For the moment, it is mainly possible to query structures but we hope to be able to extend the API to more properties. We believe that an ontology would be an asset to this end. We have started discussions with people involved in EMMO and CIF2.	Mat
14	Integration of different sustainability assessment methods (such as life cycle assessment, social life cycle assessment, life cycle costing, criticality and circularity of resource use) in order to facilitate a joint assessment. See also the ORIENTING project website (orienting.eu).	Man
15	Integration of electronic, atomistic, mesoscopic and continuum data for materials engineering and process engineering	Mat, Man
16	Integration of industrial data and application Support for requirements edition Applications interoperability	Gen
17	Integration of materials characterization data with exposure measurements data from 3d printing process for data annotation and information retrieval.	Mat
18	Integration of ontologies related to renovation of buildings considering the semantic web and linked data principles to facilitate interoperability in the construction industry.	Man
19	Integration of particle emission measurements from the nano - enhanced filaments during 3D printing with nanoindentation data to identify relationships between nanomechanical properties and particle emissions for different materials (Ontocommons Demonstrator)	Mat
20	Integration of PLM data with ERP data in planning stage and then integration with MES data in manufacturing execution stage	Man
21	integration of textbook knowledge about materials science in a huge materials' ontology	Man

22	Interoperability between process engineering applications and plant design information	Mat
23	leverage upon reasoning capabilities of ontologies to extend and augment machine learning outputs for optimal maintenance and production management	Gen
24	Maintenance of industrial systems Supply chain and distributed manufacturing based on capabilities and capacity Model based enterprise for design and engineering to process execution and use phase	Man
25	Maintenance of manufacturing machines	Man
26	Management and access to FAIR data from experimental science Management and access to resources on Physical Sciences.	Mat
27	Novel applications combining data sets from two or more domains.	Gen
28	Ontologies on nanoMECommons project	Mat
29	Ontology-based data governance and access for digital twins of petroleum and process facilities.	Man
30	Teaching more novices about the usage of ontologies	Gen
31	The UK National Digital Twin programme is developing an ontology to enable a hub and spoke data sharing and integration environment to be developed for UK infrastructure to support use cases such as disaster response, regulatory support, and government policy development.	Man
32	use of machine learning to predict structural, electronic, optoelectronic, thermodynamic linear, and nonlinear optical properties and compare it with DFT methods.	Mat
33	Using ontologies for concept recognition tasks in multidisciplinary domains.	Gen
34	We plan to use ontology for data integration in the context of optimising the AM process for an Aerospace component.	Man
35	We will continue with more of the same, but also look at materials modelling ontology standardization	Mat

To help the reader, we tag the provided answers for Q9 as "F"=Top-level/Framework, "T"=Tool, "M"=Method/guideline, "S"=Specific ontology, "C"=Cooperation/Sharing ,"E"=Examples/training.

The answers are so distributed: 4 "F", 13 "T", 3 "M", 11 "S", 5 "C" and 3 "E" (Note: each answer was assigned one or two tags).

Table 6: Answers to survey Q9

Answers to survey Q9: "If you had one free wish, what should be developed in the coming year within the ontology field?"		
#	**Answer text**	**Tags**
1	A comprehensive framework for integration between top level ontologies.	F
2	A few nice tools for user-guided assisted annotation	T
3	A more graphical ontology editing environment (instead of or alongside Protege).	T
4	A standardized and widely accepted Top Level Ontology	F
5	A user friendly method or best practice to guide the ontology creation process. Protege is nice to use for an ontology engineer but there is a lack of software support to get domain expert involved in the ontology creation process. Additionally a standardized domain ontology for manufacturing and a repository where these ontology can be access and maintain would be good. Similar to this developed from ETSI https://mariapoveda.github.io/saref-ext/OnToology/SAREF4INMA/ontology/saref4inma.ttl/documentation/index-en.html	M, S
6	A well-founded ontology of measurement units	S
7	A domain ontology of the nanosafety that focuses on exposure assessment.	S
8	an easy-to-use visualization tool to develop new ontologies	T
9	An ontology-based tool to model knowledge graphs graphically and manually.	T
10	Better tools and patterns for domain areas of interest to guide ontological development. The ontology field is too fragmented and the exiting patterns insufficient to have a corpus of patterns for organizations to follow and form consensus.	T, M
11	Better tools for automatically visualising ontologies in a way that is easy to present parts of the ontology to others and within papers, without having to manually generate graphs from the command line or create pictures of the ontology.	T
12	Clear reference standard and responsive community	C
13	commercial tools that are more expressive that OWL i.e. based on Common Logic or something equivalent	T
14	contribution to standardization and common work	C
15	Create generic Ontology for small and medium industrial companies	S

16	Development of a set of ontologies to support the digital supply chain and to reach systems´ interoperability in supply chain environments	S
17	Development of improved tools to handle the development and visualization of ontologies. Development of guidelines/best practices together with tools that facilitate ontology alignment.	T, M
18	Easy to use tools supporting languages with more expressive than OWL.	T
19	Effective ways of moving discussions forward and keeping in focus.	C
20	I think ontologies could go: - Information/Knowledge exploration. - Creation of dynamic virtual "Things" - Cognitive reasoning and AI.	
21	materials science or machine learning applied to DFT	S
22	More extended and comprehensive industrial ontology	S
23	More free and available example of application to engineering and manufacturing	S, E
24	Multilingual (e.g. CLIF, OWL, RDFS) tools for ontology development.	T
25	New methodology and tools for harmonising ontologies based on different top-level ontologies.	T
26	OCES – OntoCommons Ecosystem	F
27	pattern for representing info about as-manufactured, as-designed, as-simulated, etc. such that they are linked and easily retrieved. Answer the question to whether this can be aligned with BFO and how.	S
28	Promotion of alignment thru co-operating and top-down approach to limit expansion and drive emergency of potential gaps.	F, C
29	shared repository of ontologies	C
30	Stability and accessibility - There should be stable tools to facilitate the work on ontologies and Linked Data. This field is full of unmaintained tools, perhaps developed in research projects. - All kinds of example ontologies and example datasets would be very useful	T, E
31	Support of ontologies to Systems engineering Support of ontologies to predictive maintenance Support of ontologies to Product-Service Systems	S
32	System engineering	S
33	Tools for easy development of ontologies using easy to use user interface.	T
34	Training materials so I can go out and teach industry	E

9. Appendix C: Mentimeter questions

In this Appendix we provide the full list of questions asked in the Mentimeter presentations and the answers to selected ones.

In the next table (Table 7) we report the questions asked in the 15th March Mentimeter session, for which all results are available on the event website:

(https://ontocommons.eu/sites/default/files/DORIC-MM_kick-off_interactive_talk_with_results_SC.pdf).

Table 7: Questions asked in 15th March Mentimeter session

#	Question	Possible answers
1	What do you see? (A map image was shown)	(Open answer)
2	What is your professional role?	(Open answer)
3	What are your main fields of expertise?	(Up to three open answers)
4	In which role are you here today?	• ONTOLOGIST (e.g., philosopher, semantic web expert) • M&M DOMAIN EXPERT (e.g., materials scientist) • IMPLEMENTER (e.g., database expert) • APPLICATION DEVELOPER • END USER (e.g., manufacturer) • OTHER
5	This role...	• ...represents well your current interests and job • ...constitutes your major professional facet
6	Which national and international initiatives (projects, communities, repositories) should OntoCommons be aware of?	(Open answer)
7	What standards (of any type) are relevant for your work?	(Open answer)
8	What are the main difficulties for standardization in general?	• Cultural/political: reaching wide agreement and adoption • Conceptual: building a good framework • Technical: using the framework
9	What are the main adverse factors for standardization of data documentation in M&M?	• Intellectual property issues • Lack of long-term and community vision • Funding fragmentation (project based) • Difficulty to re-use previous work • Difficulty to find previous work

		• Genuinely inter-disciplinary groups needed • Lack of commercial interest • Topic broadness and complexity
10	How do you value these aspects when choosing a framework/language?	• High expressivity • Low computational cost/weight • Ease to integrate with existing/legacy assets
11	Strategies and views for the M&M field:	• It was high time to look at the field as a whole • We should first create/strengthen smaller communities with more narrow focus • It is too ambitious to consider the whole field yet
12	What is a desirable and reasonable aim for the next future? To standardize all the knowledge...	• within your institute/company • that your institute/company needs (within it and to connect to the exterior) • within your field/application • that exists
13	Which part of the semantic landscape are you more interested in?	• Physics and Chemistry • Mechanical and Industrial Engineering • Thermal Engineering/Process Engineering • Material Science and Engineering
14	Do you know where to find ontologies for your field?	• Yes • Maybe • No
15	On which platforms do you publish your ontologies or look for existing ones?	• Github • Bioportal • Ontobee • Obofoundry • Other
16	Do you have a clear understanding of how semantic technologies can support your work?	• Yes • Maybe • No
17	What positive impact do you have/expect from semantic technologies?	(Open answer)
18	We used the DFG taxonomy of topics in the registration: did you find it appropriate?	• Yes • Partially • No
19	Would you suggest an alternative classification of M&M topics?	(Open answer)

And here (Table 8) we report the Mentimeter questions for the 7th June morning session, for which all results are available on the event website (https://ontocommons.eu/sites/default/files/DORIC-MM%202021_interactive_with_results.pdf) . Note that the first question is a warming up one, and the last one (Q16) was used in connection to the talk by F. Compagno, in the afternoon session. The following tables (Table 9 and Table 10) report the answers for questions Q9 and Q15.

Table 8: Mentimeter questions asked in 7th June morning session

#	Question	Possible answers
1	Which of these are you more likely to read in Summer 2021?	• Dante's "Inferno" (about Hell, 1321) • Zweig's "Magellan. Der Mann und seine Tat" (about the first globe circumnavigation, 1521) • Wittgenstein's "Tractatus Logico-Philosophicus" (about everything, 1921) • OntoCommons' report on the first focus workshop on domain ontologies (about this workshop, 2021)
2	In which role are you here today?	• ONTOLOGIST (e.g., philosopher, semantic web expert) • M&M DOMAIN EXPERT (e.g., materials scientist) • IMPLEMENTER (e.g., database expert) • APPLICATION DEVELOPER • END USER (e.g., manufacturer) • OTHER
3	What are your main fields of expertise?	(Up to three open answers)
4	Would you benefit from an improvement of data integration, sharing and format conversion in your field?	• Yes, definitely • Maybe • No • I don't know
5	In a nutshell, what is the data integration challenge you have?	(Open answer)
6	Your institute/company is	• Small (<10 people) • Medium (10-1000 people) • Large (>1000 people)
7	What funding type does your institute/company rely on?	• Mainly public funds • Mainly private funds • Both public and private funds

8	In your institute/company, semantic technologies ...	• are heavily used • start to be used • are not used at all yet
9	What would you recommend as a first step to a M&M expert who would like to introduce semantic technologies in their work?	(Open answer)
10	Why do we want formal ontologies? For...	• verifiable semantics across any multi-use systems • interoperability between software systems • effective cross-domain knowledge sharing
11	When developing a domain ontology:	• One should use a top-level ontology • It does not matter if it is stand-alone • One should ensure it can be used by other ontologies • I typically use ontology design patterns
12	When developing domain ontologies we should:	• agree on a common top-level • agree on the chosen view (e.g., focus on objects or processes) • adopt a modular approach • clearly separate the domains, to avoid overlap • have overlap between domains, to help connections
13	Do we need formal standards (as ISO ones)?	• Yes • Maybe • No
14	Assuming we need standards, how should these be structured?	• one standard (with lots of parts) • multiple standards (each with a particular industry focus) • some combination of these options • other
15	How do we fund the process of taking valuable research results to the level of formal (ISO-like) standards?	(Open answer)
16	At time t, a headlight bulb is installed in a certain car. At time t'>t the bulb is replaced with another. How many headlight bulbs are there?	(Open answer)

Table 9: Answers to Mentimeter Q9

Answers to Mentimeter Q9: "What would you recommend as a first step to a M&M expert who would like to introduce semantic technologies in their work?"	
#	**Answer text**
1	Allocate a budget!
2	clear objectives
3	Collaboration with experienced users
4	Conduct requirement analysis
5	Consider TLO from the start
6	Define a purpose (incl. few purposes) for the planned ontology
7	define clear objectives and deduce clear requirements - know what you want
8	Define the questions he/she wants to answer with the help of decision support systems.
9	demonstration of concrete incentives
10	Determine applications in which interrelations between data are crucial.
11	Explore a set of ontologies and find the common parts. Analyse the methods and what it "does".
12	Identify very well the objective
13	Institutionally backed standards
14	It's the metadata!
15	Look for shared definitions about what objects of your domain are (e.g. what's a molecule? what's a car?). It's a huge pre-formal-ontology barrier.
16	Provide a report about how data are generated
17	Provide basic training to process engineers on ontology development to begin teamwork with ontologists
18	Provide basic training to process engineers on ontology development to begin teamwork with ontologists
19	Show the application of their approach.
20	solving specific case studies for companied
21	start small
22	Think about your colleagues, join forces!
23	to participate in ontocommons

24	To recognize which are the data sources and sinks and recognize their meanings
25	Try to understand the meaning of his/her data.
26	Use existing ontologies
27	use existing tools
28	use only as much semantics as necessary to meet objective

Table 10: Answers to Mentimeter Q15

Answers to Mentimeter Q15: "How do we fund the process of taking valuable research results to the level of formal (ISO-like) standards?"	
#	**Answer text**
1	academic institutions should receive sufficient basic funding from governments to be able to do their job
2	Build it into larger projects. Sustainability is important
3	Demonstrating value to the industrial users
4	Demonstration may be publically funded. Individual implementation is private interest.
5	EU grants
6	Forming associations that seek EU funds
7	forming associations with membership fees and donations
8	Issue is to document the return of value. A classical bootstrap problem. Public funding to start with.
9	Needs EU funding and needs to be sustained.
10	Public driven with and private advisors, through EC funded associations.
11	Public funds + participation of experts from industry.
12	Sustained EU funding
13	To form associations involving industrial partners
14	Via associations and also projects for international economic development, since the interoperability they allow for is an Industry4.0 principle (since my vision as Industrial-Quality Engineering)
15	We highlight the need for data acquisition and join with colleagues doing characterisation of materials that are of particular interest (already today).

10. Appendix D: Extracts from the MIRO board

In this Appendix we provide snapshots of the MIRO board corresponding to the four domain-specific parallel sessions of the 15th March event.

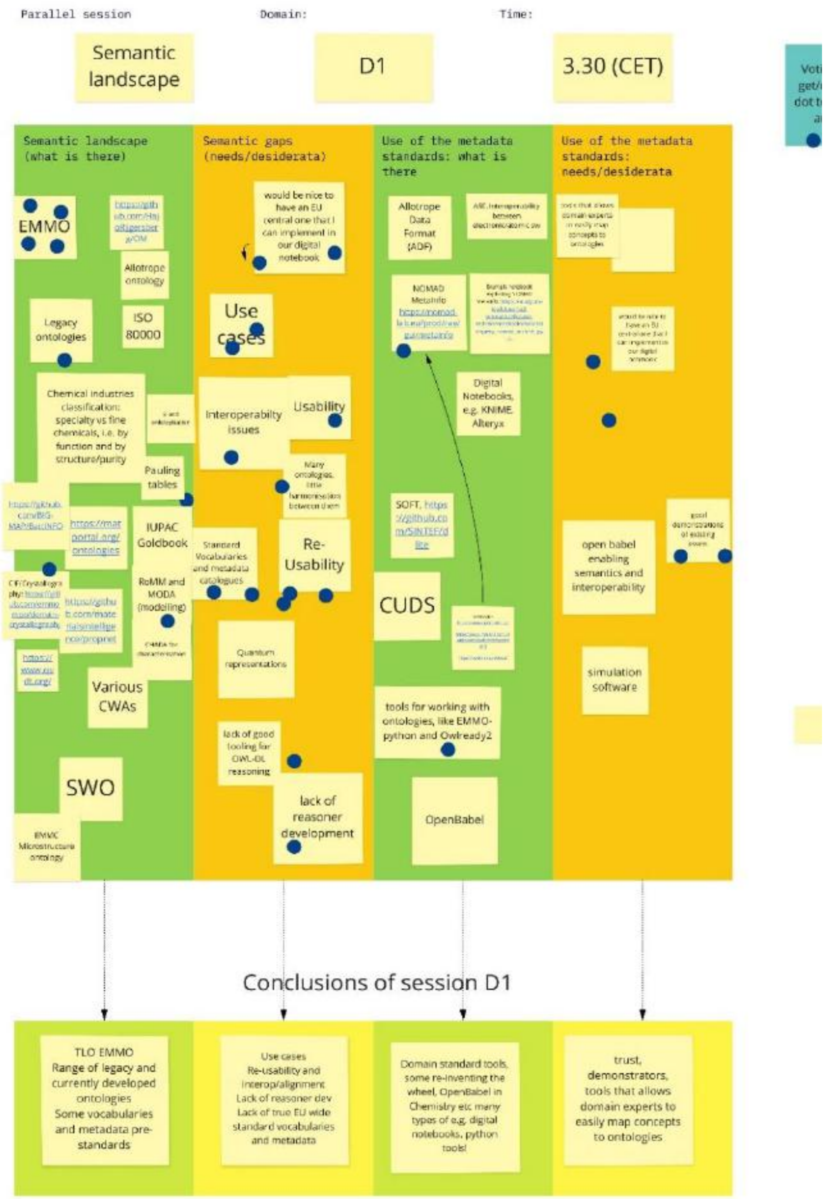

Figure 6: Snapshot of the MIRO board used during the 15th March event parallel session on the "Physics and Chemistry" domain, D1.

Figure 7: Snapshot of the MIRO board used during the 15th March event parallel session on the "Mechanical and Industrial Engineering" domain, D2.

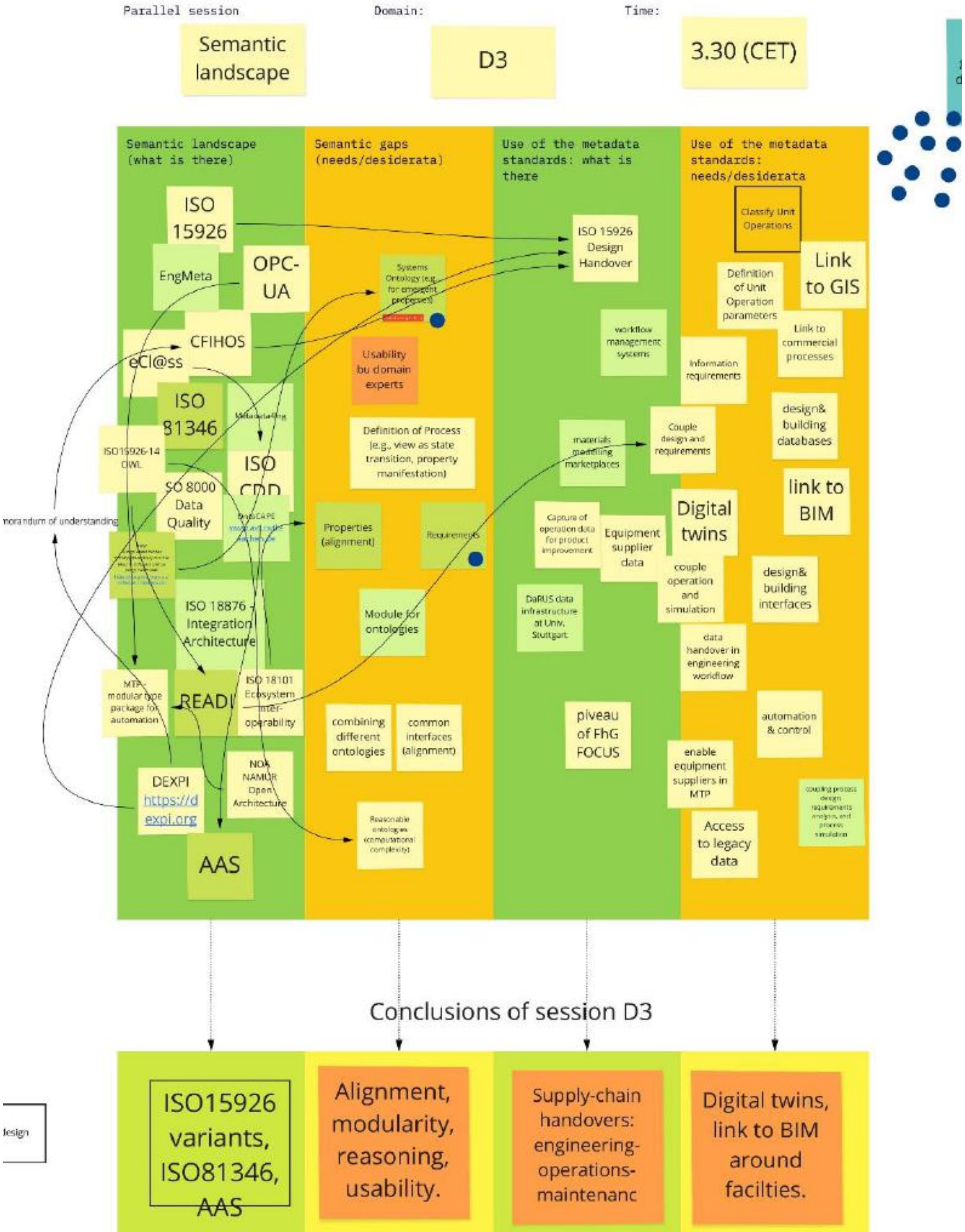

Figure 8: Snapshot of the MIRO board used during the 15th March event parallel session on the "Thermal Engineering/Process Engineering" domain, D3.

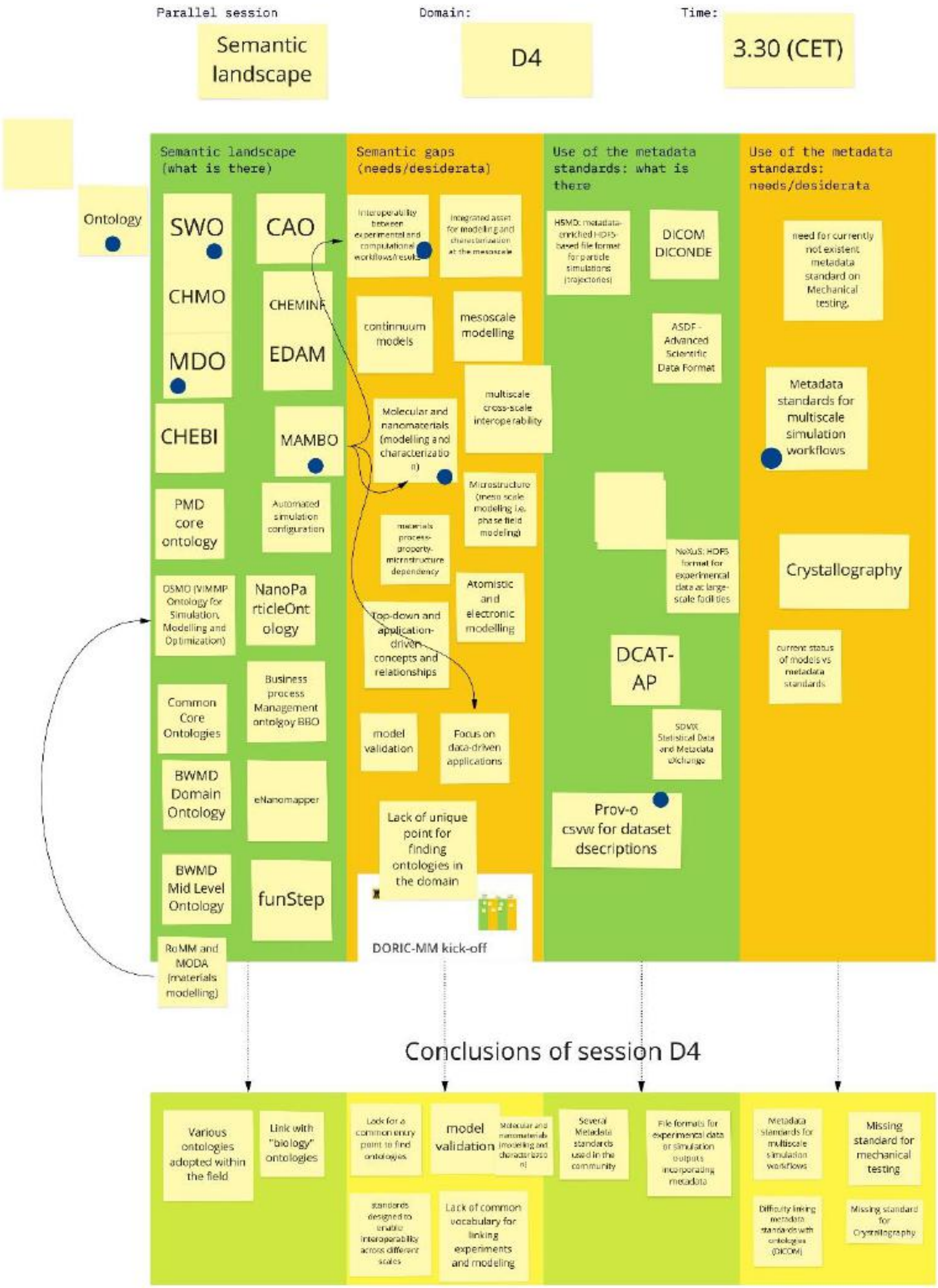

Figure 9: Snapshot of the MIRO board used during the 15th March event parallel session on the "Thermal Engineering/Process Engineering" domain, D4.