



Report D1.12

“Ontology-based digital marketplaces for Industry Commons v1”

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"Ontology-based digital marketplaces for Industry Commons v1"

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Glossary of terms

Item	Description
DOME 4.0	Digital Open Marketplace Ecosystem 4.0
VIMMP	Virtual Materials MarketPlace
HW	Horizontal Workshop
FW	Focused Workshop
TLO	Top-Level Ontology
MLO	Mid-Level Ontology
TRO	Top Reference Ontology
OCES	Ontology Commons EcoSystem

Keywords

Ontology; Data; Standardisation; Digital marketplaces; Industry Commons

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Executive Summary

This document reports on the status of the cooperation between OntoCommons and the digital marketplaces, combining and summarizing outcomes from regular meetings with the marketplace projects (DOME 4.0, MARKET4.0, MarketPlace, and VIMMP), and from dedicated OntoCommons workshop activities (namely, focused workshop FW1.1- Industry Commons Marketplaces and the Ontology-based digital marketplaces for Industry Commons session in the first horizontal OntoCommons workshop). Input from other recent events in this area is included too.

Table of Contents

Table of Contents	5
List of Figures.....	5
List of Tables	5
1. Introduction.....	6
2. Cooperation events.....	7
2.1. Events this document focuses upon.....	7
2.2. Other events providing input	7
2.3. Related OntoCommons deliverables.....	7
3. Collaboration Topics.....	8
3.1. Marketplaces Knowledge Graph (KG)	8
3.2. Marketplaces Ontology Framework	9
3.3. Common API for Marketplaces.....	9
3.4. Demonstrators	10
3.5. Summary of identified difficulties and suggestions	10
3.6. Federated Data Spaces.....	11
4. Conclusions.....	13
Appendix: OntoCommons FW1.1 - Industry Commons Marketplaces.....	14
A.1. Workshop motivation, aim and agenda.....	14
A.2. Workshop minutes (extract).....	18

List of Figures

Figure 1. Snapshot of the discussion board for Group 1 - Marketplaces KG in OntoCommons FW1.1.....	24
Figure 2. Snapshot of the discussion board of Group 3 - Common API in OntoCommons FW1.1	30
Figure 3. Snapshot of the discussion board for Group 4 - Demonstrators in OntoCommons FW1.1	32

List of Tables

Table 1. Marketplace ontologies (gathered in FW1.1 and updated where appropriate at time of writing)	25
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1. Introduction

Within its general aim of supporting the adoption of ontology-based standardised documentation for Industry Commons, one of OntoCommons' specific objectives is to support the adoption of such technology and results by the *digital marketplace* projects. All the activities in this line fall under Task 1.5, "Ontology-based digital-marketplaces cooperation" that runs over the whole project duration. The present document summarises the status of the cooperation at the time of writing (M18), and a similar one will be produced at the end of the project (M36). The digital marketplace projects involved in the collaboration up till now, with their timelines and grant agreement (GA) numbers, are:

- Digital Open Marketplace Ecosystem 4.0 (DOME 4.0)¹ [Dec 2020 – Nov 2024, GA 953163]
- MARKET4.0² [Nov 2018 – Apr 2022, GA 822064]
- MarketPlace³ [Jan 2018 – Dec 2022, GA 760173]
- Virtual Materials MarketPlace (VIMMP)⁴ [Jan 2018 – Jun 2022, GA 760907]
- WeldGalaxy⁵ [Oct 2018 – Mar 2022, GA 822106]⁶.

MarketPlace and VIMMP focus on materials modelling, MARKET4.0 and WeldGalaxy on equipment for manufacturing, and the more recent DOME 4.0 on industrial data⁷. These projects are at different stages of development, as the timelines above clearly show, and their uptake of semantic technologies is also varied (cf. Appendix). On the other side, the OntoCommons EcoSystem is being developed, and a series of major deliverables about the project results are either recent (D4.3 "Review of tool support for ontology management and ontology-based data documentation") or in-progress at the time of writing (e.g., D2.4 "TRO Beta Release" and D2.5 on "MLOs Beta releases"). The present document is structured as follows: in Section 2 we list the collaboration events, in Section 3 we give

¹ <https://dome40.eu/>

² <http://market40.eu/>

³ <https://www.the-marketplace-project.eu/>

⁴ <https://www.vimmp.eu/>

⁵ <https://www.weldgalaxy.eu/>

⁶ The WeldGalaxy project, which in the meantime has finished, was also involved in the initial meetings.

⁷ MarketPlace and VIMMP belong to the call NMBP-25-2017 ("Next generation system integrating tangible and intangible materials model components to support innovation in industry"), whereas MARKET4.0 and WeldGalaxy belong to DT-NMBP-20-2018 ["A digital 'plug and produce' online equipment platform for manufacturing" (IA)] and DOME 4.0 to DT-NMBP-40-2020 ["Creating an open market place for industrial data" (RIA)].

highlights from the discussions, then draw our conclusions in Section 4. In the Appendix, we include the report of OntoCommons FW 1.1, which, in particular, contains a list of ontologies used/developed within the marketplaces.

2. Cooperation events

In this section we list the events that have contributed to the content of this document and point the reader to other relevant OntoCommons deliverables.

2.1. Events this document focuses upon

- OntoCommons Focused workshop FW1.1- *Industry Commons Marketplaces*, on-line, 29th April 2021, organized by Fraunhofer IWM. [Event webpage, where presentations slides are available too: <https://ontocommons.eu/news-events/events/ontocommons-workshop-industry-commons-marketplaces>.]
- *Ontology-based digital marketplaces for Industry Commons* session in the first horizontal OntoCommons workshop (HW), on-line, 3rd November 2021. [Event webpage, where presentations videos are available too: <https://ontocommons.eu/news-events/events/global-workshop-ontology-commons-addressing-challenges-industry-50-transition>]
- Monthly meetings (September, October, November 2021) in preparation for OntoCommons HW, on-line, organized by GCL.
- Monthly OntoCommons – DOME 4.0 coordination meetings (from March 2022 on), on-line, organized by BOSCH.

2.2. Other events providing input

- 3rd *EMMC International workshop 2021*, 2-4 March 2021, on-line [Event webpage: <https://emmc.eu/emmc-2021/>] In particular, the Digital Marketplaces session
- OntoTrans 1st open workshop - *Innovation 5.0: Open Translation Environment for materials and manufacturing value chains*, 15-16 March 2022, on-line [Event webpage, where presentations are available too: <https://ontotrans.eu/ontotrans-1st-open-workshop/>]

2.3. Related OntoCommons deliverables

- D6.5 - "Report on the outcomes on the first OntoCommons Horizontal Workshop" (to appear on Zenodo)

3. Collaboration Topics

As a result of the cooperation events, the following key topics for collaboration have emerged. We report here on the status of the interactions and outcomes so far, as well as elaborate on future actions.

The topics represent specific requirements and tangible developments that help to facilitate an Industry Commons ecosystem founded on ontology-based data documentation.

The topics are:

- Marketplaces Knowledge Graph
- Marketplaces Ontology Framework
- Common API for Marketplaces
- Demonstrators

The status of collaborations regarding the topics is based on the FW1.1 (April 2021) discussions and further interactions between projects, also widening the range of involved projects to Open Innovation Environments (OIE) (OYSTER, NanoMECommons), Open Translation Environment (OntoTrans), and Open Innovation Platforms (e.g. OpenModel).

3.1. Marketplaces Knowledge Graph (KG)

While the definition of KG is not unique, it is generally accepted it is “a knowledge base that uses a graph-structured data model or topology to integrate data”⁸. And while a KG could make use of ontology, that is not necessary: in this sense, KGs can be less demanding, and the possibility of creating a Marketplace KG to integrate information across digital marketplaces has been discussed. As an example, the NanoMine KG⁹ for nanocomposites materials science was mentioned.

Utilisation of KG approach is one of DOME 4.0 developments which has been reported e.g., in the OntoTrans 1st Open Workshop [<https://ontotrans.eu/ontotrans-1st-open-workshop/>].

In the direction of KG and lightweight approaches, Wikidata-based developments have also been mentioned (for example, see plenary talk by P. Murray-Rust in the HW): these could provide a means of collaboration with a worldwide community, and could be leveraged for certain steps, such as terminology gathering.

⁸ https://en.wikipedia.org/wiki/Knowledge_graph

⁹ McCusker, J.P., Keshan, N., Rashid, S., Deagen, M., Brinson, C., McGuinness, D.L. (2020). NanoMine: A Knowledge Graph for Nanocomposite Materials Science. In: J. Z. Pan, *et al.* The Semantic Web – ISWC 2020. ISWC 2020. Lecture Notes in Computer Science, vol 12507. Springer, Cham. https://doi.org/10.1007/978-3-030-62466-8_10
<https://www.ontocommons.eu/>

3.2. Marketplaces Ontology Framework

Some of the digital marketplaces are already using ontologies, even if at different levels: the assets used/developed by MarketPlace and VIMMP are listed in Table 1. Marketplace ontologies (gathered in FW1.1 and updated where appropriate at time of writing) in the Appendix¹⁰, where is also shown that when a TLO is used, it is the EMMO. MARKET4.0 has not been developing and using ontologies but is interested in adoption of ontologies as listed in Table 1. Marketplace ontologies (gathered in FW1.1 and updated where appropriate at time of writing). Participants agreed that to interoperate with other platforms and initiatives, it will be very beneficial to have a TRO integrating different TLOs.

Collaborative ontology development within the EMMO framework is continuously ongoing under the EMMC governance umbrella, using the EMMO GitHub repository: <https://github.com/emmo-repo/>. Recent developments which are relevant to marketplaces interoperability include the set of OIE ontologies (also in use in MarketPlace) and the MarketPlace Agent and Expert Ontology (MAEO), both updated to the currently most recent EMMO version. These are supported by MarketPlace and OYSTER OIE. Furthermore, the field of materials characterisation has developed a Characterisation Methods Ontology (CHAMEO), also in collaboration with other projects such as Big-MAP.

Furthermore, projects are collaborating on a common representation of data using a DCAT ontology-based implementation in EMMO, developed within a DOME 4.0 public deliverable¹¹ and ready to be used in other open innovation and marketplaces projects.

Additional ontology developments of importance to marketplaces are in collaborative development in EMMC Task Groups <https://emmc.eu/focus-areas/interoperability/> including Thermodynamics and Microstructure.

3.3. Common API for Marketplaces

A “common API” between the marketplaces could be an overarching API (a layer on top of individual marketplaces) or a standard API that then can be used to implement one-to-one connectors. The benefits would be to widen the scope of activity for each marketplace and to offer cross-platform services for users and cross-market basins for providers.

A key development towards common APIs is the OTEAPI library, spearheaded by the OntoTrans project, which has become a wider collaboration among projects under the EMMC umbrella. As

¹⁰ DOME 4.0 is not listed, as the project was in its early stages of development when the FW1.1 took place.

¹¹ DOME 4.0 D3.1, “Semantic data exchange ontology”. Submitted version available at <https://dome40.eu/sites/default/files/DOME%204.0%20D3.1%20Semantic%20data%20exchange%20ontology%202022.02.28%20PU.pdf>
<https://www.ontocommons.eu/>

described in <https://github.com/EMMC-ASBL/oteapi-core>, the Open Translation Environment API uses the strategy software design pattern to implement a simple and easy to extend access to a large range of data resources. Semantic interoperability is supported via mapping of data models describing the data to ontologies. Transformations, mainly intended to transform data between representations, are also supported, but transformations can also be used for running simulations in a simple workflow.

The topic was also discussed during the EMMC 2021 International Workshop. It was agreed that there is a need to design and provide easy to use API and interface/connector aggregators. These enable any system or marketplace or data warehouse to connect to another. However, the connectors require much maintenance, and while there is a societal common benefit to all from such connectors, their business case may be undefined. Hence, there is a need for supporting such connectors based on public funding.

3.4. Demonstrators

OntoCommons initially had eleven demonstrators and, at the time of writing, another nine have been identified¹². Among the initial ones, two that are particularly relevant for the cooperation between marketplaces are the European Virtual Marketplace Framework (EVMF) and the BOSCH manufacturing demonstrator. The latter provides a direct link with DOME4.0, since the BOSCH colleagues are also developing a business-to-business DOME4.0 showcase on the same topic.

3.5. Summary of identified difficulties and suggestions

Caveat/Difficulties

- Different development stages and pace across the projects
- Shared development and wider agreement take necessarily longer time
- Legal and IP issues
- For application/domain ontologies, development and maintenance of semantic assets are often seriously underestimated and hence are mostly not addressed professionally during their foundation projects' lifetimes and often lack any support beyond it
- Mapping between ontologies and data annotation can be very demanding and time consuming, hence support from automated tools is welcome
- EMMO TLO has been undergoing significant developments and has not yet reached release 1.0, hence complete alignment even within EMMO ontologies is not yet achieved.

Suggestions/recommendations and future steps to support collaboration

¹² <https://ontocommons.eu/ontocommons-demonstrators>

- Each marketplace/project should reflect on what knowledge it would “provide to” and what it would “expect from” a Marketplace KG
- Each marketplace/project could produce prototype versions of the KGs, and then these could be shared in a collaboration workshop
- Create an EMMC Task Group for “low-level collaboration between platforms”
- Each marketplace/project should reflect on what a “common API” could look like
- Importance to publish API documentation and to use standardize APIs
- Re-use and build on existing assets at the ontological level, such as the EVMPO
- OntoCommons should offer lightweight guidelines and ontologies, to lower the barriers to adoption. However, it needs to encourage principle-based development (*via* training, tools, etc.)
- Interdisciplinary expertise is needed, with both knowledge engineering and domain experts, to avoid producing poor quality semantics assets
- Only make models as complex as needed
- Keep in mind user-friendliness of interfaces that are meant for humans
- Importance of working towards a standardisation of the OCES components where appropriate (and if feasible within the project timescale)
- Define KPIs to quantitatively assess the impact of the OCES.

3.6. Federated Data Spaces

An important development in the marketplace context is the Federated FAIR Data Spaces (F2DS), as also presented during the EMMC 2021 International Workshop: <https://www.eosc-pillar.eu/news/federated-fair-data-space-space-federate-them-all> .

The core element is the API Federation with a smart harvester that will collect the data from various entities and platforms and converting them into one common format which is DCAT, with a semantic enricher for adding semantics that are missing. This platform enables access for repository owners by offering a repository interface and provides them with information on the FAIRness of their data content by providing FAIR data evaluators. Its other form of access is for data consumers via a unified search interface. The platform’s aim is a virtualised bundle of open-source tools using Kubernetes. This allows easy registration of repositories into the F2DS and allows rapid creation of data spaces across internal resources, institutions and domains. No change is needed for the internal structure of the repositories, which makes the repository FAIR.

The registration workflow for data repository owner was presented, including metadata for the repository including Re3Data¹³ and other existing standards, and an API registration with an API alignment tool using a variant of the open API framework known as SmartAPI. Once an API is

¹³ <https://www.re3data.org/>
<https://www.ontocommons.eu/>

specified then the system can fetch and connect data. This process integrates the testing and evaluation of the FAIRness of data.

The main issue is the enrichment of metadata with semantic artifacts, as each domain is developing ontologies with their own guidelines and standards which makes it hard to find the ontology for each domain. Hence, there is a need to harmonise the ontology space so that it can be harvested, which is related to work on how to make semantic artifacts themselves FAIR. The latter has been carried out in FAIRsFAIR over the past two years. The results are already available on GitHub, mainly including recommendations of FAIRness guidelines for semantic artifacts¹⁴. The goal is creating a federated FAIR semantic space.

¹⁴ <https://github.com/FAIRsFAIR/FAIRSemantics>
<https://www.ontocommons.eu/>

4. Conclusions

During the first half of the OntoCommons project timespan, a series of events have been organised to establish a two-way communication flow with the digital marketplace projects. This has allowed us to assess the uptake of semantic technologies in these projects, their needs and to present OntoCommons goals, approach and activities.

In the second half, the EVMF demonstrator and the presence of a BOSCH use-case in both DOME 4.0 and OntoCommons will continue to provide concrete links between OntoCommons and digital marketplaces projects. The regular monthly DOME 4.0-OntoCommons meetings will continue, and we are in a position now to present OntoCommons results so that they can be iteratively integrated into DOME 4.0.

Among the future collaboration steps, we would like to point out the First International Workshop on Semantic Industrial Information Modelling (SemIIM) workshop¹⁵, organized by colleagues at BOSCH and University of Oslo and co-located with the European Semantic Web Conference (ESWC) 2022, that will take place at the end of May 2022.

Since two of the marketplace projects (MARKET4.0 and WeldGalaxy) have recently finished and another two projects are ending within 2022 (VIMMP and MarketPlace), we suggest it would be very valuable for DOME 4.0 and OntoCommons to invite them to a workshop to present their final findings and lessons learned. The final deliverables of these projects could be also reviewed for possible elements to be considered and, if appropriate, re-used in the OCES, if and where applicable.

¹⁵ <https://sites.google.com/view/semiim-2022/home>
<https://www.ontocommons.eu/>

Appendix: OntoCommons FW1.1 - *Industry Commons Marketplaces*

A.1. Workshop motivation, aim and agenda

Introduction

Digital Marketplaces are multi-sided collaborative and trading platforms that facilitate materials innovation by easing access to otherwise disparate sources and deployments of information, expertise, software applications and data. In order to provide a seamless user experience, they require a high degree of integration and interoperability of several components (e.g., translation, education and training, modelling software and applications, data). OntoCommons aims to establish a cooperation with all the relevant stakeholders for data documentation and interoperability in industrial domains. It develops recommendations for ontologies, methodologies and tools for data documentation. These recommendations will result in the delivery of the ready to use Onto Commons EcoSystem. This workshop aims to kick-start the communication between OntoCommons and the digital marketplaces, and to ensure the uptake of the OntoCommons project results.

Focused Workshop 1.1 Industry Commons Marketplaces		
When?		
Holding date	29.04.2021	
Announcement date	15.02.2021	
Invitation date	15.02.2021	
Registration date	19.04.2021	
Where?		
Organiser	Fraunhofer IWM	
Holding	Physical meeting Location	Online holding platform:
		x Teams Zoom GoTomeeting

		Webex Other
How?		
Announcement	x E-Mail x OntoCommons Website x Social media x Projects stakeholders mailing list CRM	
Invitation	Invitation only event Open event x Hybrid event	
Registration	Conference website: At Homepage of OntoCommons	
Pre-workshop actions (discussion notes will be prepared with)	x online survey Expert meeting x Other: Collect preliminary reports of EMMC marketplace workshop in March.	
Pre-workshop action topics	A tiny survey that must be filled out during registration: 1-2 questions about interests and previous activities that allow us to cluster the participants into groups during the workshop. Collect preliminary reports of EMMC marketplace workshop in March.	
Workshop program	Keynote speakers Project partner presentation x Stakeholder presentation x Panel discussion x Breakout rooms x Interactive brainstorming x Q/A session	
Why?		
Background (5-10. lines)	There are multiple EU projects aiming at providing a digital marketplace for materials data, software and education. While each is taking a slightly different approach, they all face similar challenges like interoperability and the immense effort for creating ontologies. OntoCommons can support these Marketplaces by providing recommendations on tools and methodologies, that can reduce the effort when working with ontologies. This workshop aims to kick-start the collaboration with the marketplaces and allows for open	

	discussions on the experiences of the marketplaces and next steps towards and integrated marketplace landscape.
Workshop objectives description (5-10. lines)	<p>In this workshop</p> <ul style="list-style-type: none"> • Bring together the relevant persons • Find out the needs of the marketplace projects • Discuss which technologies are in use and have proven their usefulness • Discuss which ontologies are in use • Discuss how the ontologies used by the different marketplaces could be aligned • Discuss the OntoCommons EVMF demonstrator. • Discuss how different marketplaces could interact, e.g. by a common API that allows displaying search results of another marketplace • Discuss how OntoCommons can use its community to disseminate the Marketplaces
Workshop expected outcomes description (2-3. lines)	<ul style="list-style-type: none"> • OntoCommons knows where to focus on to ensure result uptake by the marketplaces • Small groups have formed that can work in the future on a common API / compatible ontology • OntoCommons EVMF demonstrator became input for further development • Ideas for dissemination have been developed
Workshop questions (The main questions [3-6] that the workshop should answer)	<ul style="list-style-type: none"> • What are the needs of the marketplaces in terms of standardized methodologies? • Which tools are needed and used to reduce the effort of ontologizing? • What ontologies are missing and how can they become compatible? • How can the Marketplaces and OntoCommons interact in the future? • How can OntoCommons help in dissemination?
What?	
Inputs (e.g. survey results)	<p>A clustering into stakeholder groups that can be used to create subgroups for a more focussed discussion.</p> <p>Reports of EMMC marketplace workshop in March.</p>
Focused topics	<ul style="list-style-type: none"> • Current challenges and experiences in terms if ontology development • Global Marketplace API • Global marketplace ontology • Marketplace knowledge graph
Content (e.g, sessions content, running [first breakout rooms, then plenary], etc.)	<p>Agenda:</p> <p>Start: 1pm CET</p> <p>Welcome (5 min)</p> <p>Introduction to OntoCommons (15 min)</p> <p>Introduction to the Marketplaces</p>

	<ul style="list-style-type: none"> o Marketplace (25 min) o VIMMP (25 min) o Market4.0 (25 min) o Dome4.0 (20 min) <p>Introduction to breakout sessions (5min)</p> <p>Break (10 min)</p> <p>Group discussion (60 min):</p> <ul style="list-style-type: none"> o Group 1: Marketplaces Knowledge Graph <ul style="list-style-type: none"> Can there be a global Marketplaces Knowledge Graph? Providing links to between marketplaces and related services, datasets etc. o Group 2: Marketplaces Ontology framework <ul style="list-style-type: none"> How could a global ontology framework for marketplaces look like? How can marketplace ontologies be aligned using a TRO? o Group 3: Common API for Marketplaces <ul style="list-style-type: none"> How can Marketplaces interact? Global search? o Group 4: Demonstrators <ul style="list-style-type: none"> How can we demonstrate the benefits of the OntoCommons EcoSystem in the showcases of the marketplaces? <p>o Depending on the number of registrations, groups might change (e.g. be merged).</p> <p>o Groups will use output from EMMC workshops as input.</p> <p>Each group summarizes their conclusion (10 min)</p> <p>Break (10 min)</p> <p>Presentation of results (20 min)</p> <p>Final Discussion (10 min)</p> <ul style="list-style-type: none"> o New OntoCommons demonstrator? o Outlook: Regular web meetings. <p>End: 5pm CET</p>	
Who?		
x Domain expert	x Implementor	x Industrial stakeholder
x Ontologist	x Scientist	Business stakeholder

A.2. Workshop minutes (extract)

Introduction for OntoCommons, by Hedi Karray (ENIT):

The spread of new web technologies has led to organisational transitions which are the root of the digital revolution. This revolution has led to a fusion of the social, physical and digital dimensions of our environment. In this interconnected environment, data became the main asset of a company, and must be shared and monetized to generate business value.

To generate value, data need to be processed correctly to identify meaningful information and to possibly extract further knowledge from it. However, there exist barriers to reach this generation of value, so that, for example, 70% of production-generated data are not used. There are technical barriers (isolated data silos limiting the interoperability, data accessibility, inefficient workflows, data quality), managerial barriers (ignorance, lack of strategy and vision, trust, resistance to change) and lack of means and sustainability (IT experts, budget, etc.). Ontologies, as a-graph-like approach, are presented as a solution for these technical barriers.

Ontologies allow to structure and represent the meaning behind the data (turning “data” into “facts”) and can be used for: information integration (addressing interoperability), information retrieval (addressing accessibility), semantically enhanced content management (addressing data quality), knowledge management and community portals (addressing inefficient workflows) and symbolic reasoning (addressing value generation).

Ontologies can be used as the basis of heterogenous data integration to build an “enterprise knowledge graph”. However, most ontology initiatives within industry fail to drive interoperability. Furthermore, the use of ontology for practical purposes in the industrial field is still greeted with scepticism in many circles.

Typical reasons for ontology failure are:

- There are too many ontologies available
- They are built in *ad hoc* ways (by groups working independently rather than as part of larger consortia)
- There is no common methodology (50% of ontology projects did not follow a particular ontology engineering methodology and 60% of ontologies are built from scratch)
- There is no reuse strategy or such is wrongly conceived (ontology reuse was predominantly interpreted as usage of arbitrary information sources of the relevant cases)
- There are no commonly accepted quality control standards, use different philosophical paradigms (Conceptual, Realism, 3D, 4D, etc.)
- There is lack of training and any produced documentation is poor
- They have short half-life (projects often EU funded).

The fact is that ontologies are presented as a valuable solution for interoperability, but ontologies themselves are often non-interoperable.

OntoCommons' goals are summarised as follows: overcoming interoperability bottlenecks and facilitating data sharing and valorisation, providing coordination and support (bring together and coordinating activities of the most relevant EU and international stakeholders), development of an ontology commons Ecosystem (OCES) as a foundation for data documentation and its management.

The most important OntoCommons Objectives are as follows: community development (at European and International level), developing the OCES for data documentation and providing industrial use cases to validate the EcoSystem and show its added value to reach cross-domain interoperability in the manufacturing and materials domain.

The OCES consists of a hierarchy of networked ontologies of different level of generality from top level to application level following the FAIR principles. Furthermore, it comprises a set of tools and methodologies covering the full range from development to reasoning and database integration. It also includes a set of specifications for ontologies that will provide full compatibility between tools and ontologies.

This network of ontologies in OntoCommons will be harmonised through a multilevel alignment approach: syntactic alignment (OWL, FOL, etc. for all of the ontologies in OCES), terminological alignment (enable taxonomical interoperability between ontologies), semantic alignment (within TLO branches) and formatting alignment (labelling of classes, definition of terms and annotations).

OntoCommons will adopt a pluralist approach assuming the existence of many ontologies in the same domain and will consider different existing top-level ontologies.

The Top Reference Ontology (TRO) will enable a common foundation for data interoperability between TLOs and lower-level ontologies: the TRO will consist of a Meta Ontology (MO) and a set of selected TLOs.

Two kinds of interoperability of ontologies will be addressed by OntoCommons: Intra-ontology interoperability (vertical interoperability, in the same TLO within the same branch) and Cross-ontology interoperability (interoperability between different TLOs branches).

OntoCommons uses a "develop-test-validate-agree" approach.

The expected impacts from OntoCommons can be summarised as: standardized and operational intra and cross domain data documentation that meets the FAIR data principles, enabling a mechanism for practical and user-friendly reusability of data across domain and industrial sectors, enabling a maintained and continuously developed set of ontologies and data documentation to ensure long term relevance and implementation, and improving the ability to build interoperable software solutions in materials, process and manufacturing.

Introduction to the MarketPlace, by Dirk Helm (Fraunhofer IWM):

The motivations for Marketplace project are that materials modelling data is typically stored in different locations, there is limited collaboration, it is hard to find expertise, calculations or experiments are often unnecessarily repeated, it is difficult to find knowledge and each tool requires a specific expertise. The project vision is that materials modelling data, modelling tools and expertise should be available at any time and at any place: powerful modelling solutions and a platform to

ensure simplified access and exchange of knowledge are needed, for a faster development of materials.

The goal of the Marketplace project is to design, create and maintain a sustainable web-based platform focused on materials modelling including integrated open simulation platforms, as well as translation and knowledge services.

The key capabilities of the MarketPlace platform are: to explore and search data and knowledge; interact and get advice and support, and to create and execute modelling workflows and simulations. In particular, the "*knowledge service*", an ontology-based web application for registering and linking resources to one another (this could be a possible collaboration with OntoCommons): it enables to search (semantically) databases of experts (e.g., "translators"), software solutions, use cases, numerical tools and providers of numerical solutions. Another key platform capability are the modelling and workflow services, that require a seamless integration of existing materials modelling solutions, open simulation platforms and materials data.

The technical challenges and the concept of Marketplace to reach these capabilities are as follows:

1. Cross domain interoperability based on standards and ontology. The MarketPlace consortium starts some discussion with VIMMP towards the development of higher level common top-level ontologies with other marketplaces. MarketPlace also collaborates with other projects, including SimDOME, ReaxPRO, INTERSECT, FORCE etc. The goal is to have seamless communication and information exchange across communities, tools and databases. Within the MarketPlace project, an Ecosystem of Ontologies is developed, covering the marketplace MarketPlace services (translation, education, user management), modelling and workflows, simulation, Manufacturing.

2. Software and data interoperability. SimPhoNy is used in the MarketPlace: It comprises the Open Simulation Platform (OSP) core, wrappers, and uses CUDS (Common Universal Data Structures) as data structures.

Finally, an important demonstration of the Marketplace project has been presented during the workshop, namely, the use case of additive manufacturing for superalloys.

Overview of VIMMP project, by Welch Leite Cavalcanti (Fraunhofer IWM), Martin Thomas Horsch (UKRI and HLRS), Silvia Chiacchiera (UKRI)

The aim of VIMMP (Virtual Materials Marketplace) is to support accelerating the innovation of manufacturing industries by increasing the uptake of materials modelling. VIMMP benefits from having a service called Translation Router for helping customers to find Translators, i.e., experts on the connection between industrial problems and modelling solutions.

VIMMP will facilitate the translation of a scientific problem into modelling workflows ready for simulation using a range of software tools integrated into an open simulation platform and deployed on cloud services. VIMMP marketplace will be open to all interested stakeholders and facilitate the exchange of products and services between providers and users.

Users will include scientists and engineers in chemical, materials, manufacturing and process industries, R&D managers, translators and academic modelers. Providers will include commercial and academic software, open simulation platforms, repositories and databases simulation repositories, training services and hardware and cloud solutions.

There are some user cases in VIMMP which are presented during the workshop (including emulsions, complex structured fluids, polymer composites, corrosion inhibitors).

A system of ontologies has been developed within VIMMP to structure the semantic space and everything that could be relevant to data/metadata handling on the VIMMP marketplace. The purpose is to support data handling, data ingest, data retrieval, data extraction, interoperability within various components of VIMMP and with other platforms. Part of OTRAS, the ontology for training services, is the taxonomies of topic which are used to annotate a variety of entities and retrieve experts (useful to find suitable translators).

A provenance description of simulated results is developed on the basis of OSMO (the ontology version of MODA), the Ontology for Simulation, Modelling and Optimization. By construction, everything that is annotated in MODA is already annotated in OSMO.

The advantage of using ontologies, over text-based documents, for example, is that one can point to any information given anywhere in the semantic web. Another VIMMP asset is the Materials Modelling Translation Ontology (MMTO). This is essentially a formalization as an ontology of the EMMC translator's guide and EMMC translation case template.

The system of ontologies developed by VIMMP addresses everything we consider to be relevant to data metadata on a virtual marketplace for materials: as a whole, the system provides a language that is powerful enough to make any sort of statement in this domain.

The main aim for future is to establish interoperability and collaboration with as many platforms as possible so that the marketplace can effectively function.

The demonstrator case on the interaction between VIMMP and Molecular Model database MolModDB has been presented during the workshop.

For inter-platform interoperability, it is essential to align the VIMMP domain ontology with EMMO (as the common standard for most of the projects that are in NMBP Horizon 2020). Two aspects of alignments are: alignment of concepts (build in EVMPO) and alignment of relations.

The EVMF (European Virtual Marketplace Framework) as an OntoCommons demonstrator has been introduced. The goal is to improve and extend the VIMMP ontologies to reach a wider agreement with the community and to foster their perspective use by other initiatives. It focuses on two aspects: materials modelling software and formulation of use-cases. The main expected benefits are that having a concrete implementation within VIMMP will allow to discuss and improve the proposed framework via interactions with other initiatives. Also, it will provide OntoCommons with the needs from digital marketplaces. Furthermore, this is an opportunity to discuss the alignment to EMMO of applied domain ontologies.

The Translation router is an ontology-driven service and is a joint development within VIMMP and WearHealth. It is developed as an internal service, demonstrating how external apps can run within VIMMP.

MARKET4.0, by Dimitris A. Mourtzis (Univ. Patras), John Angelopoulos (LMS, Univ. Patras), Vasilis Maratos (LMS)

MARKET4.0 develops an open multi-sided digital platform for enabling production equipment and service providers to connect to and work together with manufacturing companies.

One of the main objectives of MARKET4.0 is to develop a web portal for an e-marketplace in which production equipment and services will be listed together with all their attributes. Moreover, the project is developing a peer-to-peer platform based on Industrial Data Space (IDS) for secure and trusted data sharing among the marketplace participants.

The main target groups and associated functionalities of the MARKET4.0 platform are: production equipment suppliers (offer new type of services, improve existing services, utilisation of Digital Twin data for "Plug&Produce" services to simulate production/services); software and simulation vendors (cross selling to different customer groups, reuse software components and develop specific domain application on top of the platform); Original Equipment Manufacturers (OEMs) and system integrators are provided with usage of latest services, responsiveness to changes, increased visibility of production activities and also benefit from the freemium model.

In the Business-to-Business (B2B) MARKET4.0 web portal, the production equipment supplier, service supplier and simulation service supplier can upload their product and services to the marketplace. Then the customer can search, test, compare the services and give feedbacks. It is important to create technical and financial trust to improve payment, delivery and anonymised feedback in manufacturing B2B collaboration. Furthermore, the platform will provide the capability to the customers for anonymised feedback, which can be translated from simple information to knowledge in order to improve products and services. The freemium model gives free access to public information (e.g., data sheets, videos etc.) and services (e.g., basic simulation services, VR/AR, offered by the web portal). However, there is a fee for premium information and advanced simulation services (e.g., heat transfer to produced parts).

One of the main objectives regarding interoperability in MARKET4.0 is to establish service interoperability, interoperability of designs and interoperability with the production environment. Standardization is critical element to ensure interoperability and the challenge is to address not only the technological interoperability issues but also semantic interoperability (i.e., a common understanding about the meaning of the information being exchanged between machines).

DOME 4.0, Digital Open Marketplace Ecosystem 4.0, by Amit Bhawe (CMCL):

DOME 4.0 (Digital Open Marketplace Ecosystem 4.0) is an ecosystem for transactions between data prosumers and data services providers. The initial focus is on the Materials and manufacturing sectors; however, the overall aim is to go beyond that. It is important in DOME 4.0 project to connect to other marketplaces, OSPs (Open Simulation Platforms), OTEs (Open Translation Environments),

databases and knowledge bases. The added value is demonstrated via 9 B2B showcases. The core part of the project is to focus on the FAIR principles for data.

The entire vision is to have a trusted digital ecosystem that is a first choice for businesses and organisations seeking to transact with data and data services.

The requirements of marketplaces are to have data accessible from multiple sources and deliver it to the customer, it has to be trusted, aggregated and ready-to-use data and needs to carry information on data provenance and IP/sovereignty.

The main gaps are the lack of digital collaborative ecosystem that connects with marketplaces, data bases, knowledge bases and treats market participants as "equal citizens". From the perspective of the DOME 4.0 business model, the step 0 is enabling all the 9 B2B use cases and then by improving the TRL within the project, the aim is to collaborate with other use cases and marketplaces and expand this ecosystem.

There is a dedicated WP in DOME, led by BOSCH, for Industry Commons cooperation. They are currently in month five and working on technical and business architectures, on showcases and also gathering user requirements.

One showcase of "chemistry KG – Maritime AQ" was presented during the workshop. Working with- and mapping of multiple ontologies is entailed in this show case.

Group 1: Marketplaces Knowledge Graph (Can there be a global Marketplaces Knowledge Graph? Providing links between marketplaces and related services, datasets etc.)

Moderators: Daniele Toti (GCL) and Dirk Helm (Fraunhofer IWM)

Participants: 9 people

The idea of a *marketplace knowledge graph* is to have data in an interlinked format that can be shared across marketplaces, creating metadata or metadata schemas that can encompass potential information models used in specific marketplaces. The main requirement is to understand what is the general information that we want to share and to agree upon a common schema (layer of metadata) that can be placed across various marketplaces.

Two major difficulties are: (i) identifying the level of granularity/detail at which information is going to be modelled in an interlinked way; and (ii) defining what kind of information to expose to the public.

For those marketplaces that are more mature, if they have an ontology, then the effort is to find alignments between some of their internal ontologies in certain domains; if an ontology is not available, the effort is to expose with an RDF formalism information to be interlinked in a semantic graph.

A knowledge graph is less demanding compared to an ontology, because there is no need to worry about reasoning and decidability, since reasoning is not meant to be applied there. Therefore, it would be lighter and simpler compared to a "pure" ontology. The main effort is to find shared

concepts/entities among various data in semantic form for different sources and some additional links.

After a knowledge graph is created (typically it will be a dynamic entity and grow), it can be used for data analysis, business intelligence, etc.

EVMPO (see VIMMP presentation above) in a way could be the basis for such a knowledge graph for the marketplace projects and potentially could be extended. It is an ontology and includes common concepts that we all need and how they connect (as a good starting point and nucleus).

One of the main advantages of a knowledge graph is to bring together domain ontologies. This means finding an agreement on concepts and relationships, one-to-one relationships, and not focusing on the hierarchy of upper-level ontologies. Concept agreement, taxonomy agreement and relationships can be fed into a knowledge graph and the latter can thus be constructed out of ontologies, and out of the work that is going on within upper-level ontologies.

Figure 1 shows the concept board that was used during the discussion.

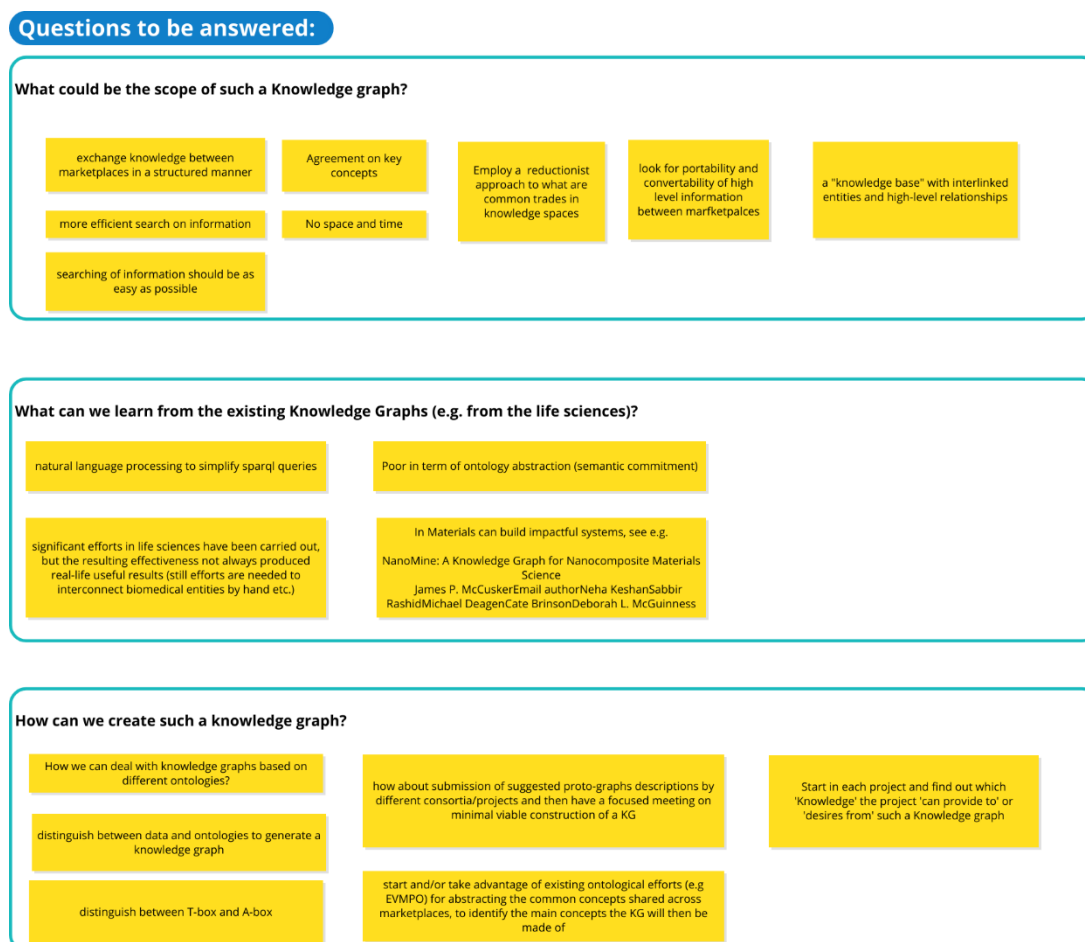


Figure 1. Snapshot of the discussion board for Group 1 - Marketplaces KG in OntoCommons FW1.1

Group 2: Marketplaces Ontology framework (How could a global ontology framework for marketplaces look like? How can marketplace ontologies be aligned using a TRO?)

Moderators: Martin Thomas Horsch (UKRI, HLRS) and Joana Francisco Morgado (Fraunhofer IWM)

Participants: 11 people

The Group 2 of the Industry Commons Marketplaces workshop focused on discussing the ontology framework, in particular the use of Top-Level Ontologies and current ongoing and necessary further efforts to align the emerging Marketplaces semantic assets.

The main objectives and topics covered within the workshop are listed below.

1. Determine the feasibility and scope of a global marketplaces' ontology framework
2. Estimate the necessary effort and quantify the benefits
3. Elaborate the first steps towards a global ontology framework for marketplaces
4. Form a group of interested people who will work on this topic in future

The session started with the collection of the URLs and names of the ontologies used within the various marketplaces including used TLO as well as relevant domain ontologies (Table 1. Marketplace ontologies (gathered in FW1.1 and updated where appropriate at time of writing)). Please note that not all the ontologies are publicly available yet, some are currently developed on private repositories.

Since then, the alignment of a some of these ontologies with the most recent version of EMMO (EMMO-beta 3) has been carried out with resources from the OYSTER Open Innovation Environment and MarketPlace projects.

Table 1. Marketplace ontologies (gathered in FW1.1 and updated where appropriate at time of writing)

MARKETPLACE NAME	TLO	DOMAIN ONTOLOGIES
MARKETPLACE	EMMO	Crystallography: https://github.com/emmo-repo/CIF-ontology
		Microstructures: https://github.com/emmo-repo/domain-microstructure
		Atomistic: https://github.com/emmo-repo/domain-atomistic
		Mappings ontology: https://github.com/emmo-repo/domain-mappings
		Expert ontology: https://github.com/emmo-repo/MAEO-Ontology

		VIMMP Software Ontology (VISO): https://gitlab.com/vimmp-semantics/vimmp-ontologies/-/raw/master/viso/viso-all-branches.ttl
		VIMMP Validation Ontology (VIVO): https://gitlab.com/vimmp-semantics/vimmp-ontologies/-/raw/master/vivo/vivo.ttl
		VIMMP Ontology of Variables (VOV): https://gitlab.com/vimmp-semantics/vimmp-ontologies/-/raw/master/vov/vov.ttl
MARKET4.0	N/A	MSDL11 ontology ¹⁷ Sensor ontology ¹⁸ from the ICP4Life project

As shown in Table 1. Marketplace ontologies (gathered in FW1.1 and updated where appropriate at time of writing), the MarketPlace, VIMMP and DOME4.0 marketplaces use the Elementary Multipersperspective Materials Ontology (EMMO) as a TLO. The MARKET4.0 marketplace does not use TLOs in its current semantic framework, however, the use of TLO is being considered for future work. The MARKET4.0 consortium has highlighted the wish and need to create a common ontology based on the similarities between the individual marketplaces which can be further extended with the additional requirements specific to each marketplace.

The importance of using different TLOs (e.g.: BFO, DOLCE) used in ongoing Digital platforms Hubs (e.g.: Material Digital) in addition to the EMMO (adopted in MarketPlace, VIMMP and DOME4.0) has also been discussed and highlighted. This is in line with the OntoCommons vision which aims at a pluralistic approach in which BFO, DOLCE and EMMO are given the same status within the project.

The alignment of the TLOs has been briefly addressed as well. The aim would be to address first the taxonomical alignment, without dropping alignment between relations. The different philosophies adopted by the TLO (e.g.: 4D and 3D assumption) make the full axiomatic alignment challenging.

The participants have clearly expressed the wish and relevance for developing a common “global” ontology framework for the marketplaces. The added value of developing such a framework has been addressed and the identified benefits are listed below:

- Facilitates the interoperability between hubs including models, workflows and data enabling information and knowledge sharing
- Enables the scalability of technologies/systems
- Facilitates reusability
- Provides a clear and common definition of concepts (a shared and common vocabulary)
- Provides a common reference system to facilitate FAIRness.

¹⁷ <https://doi.org/10.1115/DETC2006-99600>

¹⁸ <https://doi.org/10.1016/j.ifacol.2017.08.2005>
<https://www.ontocommons.eu/>

The necessary efforts and quantification of benefits of a common ontology for the marketplaces have been addressed. Given the complexity and novelty of the task it has been said that the efforts are hard to quantify. However, it was clear that a collaborative action between the marketplaces is of utmost importance in order to achieve such an ambitious goal. For this purpose, an EMMC Task Group for “low-level collaboration between platforms” will be created in which the interoperability between marketplaces facilitated by semantic artifacts will be further discussed. In the past similar action has been carried out with the objective of building a common ontology for the MarketPlace and VIMMP. As result the ontology European Virtual Marketplace Ontology (EVMPO)¹⁹ has been developed. The latter is still under development but can serve as support to pave the way for the common ontology between the four European Materials Modelling Marketplaces (EMMM).

All in all, during the Group 2 Industry Commons Marketplaces workshop the importance of aligning various TLO (BFO, DOLCE and EMMO) as well as the development of a common ontology for the EMMM has been identified and considered of utmost importance to facilitate interoperability, reusability and a shared vocabulary across the various platforms. The ongoing plans to create a EMMC Task Group to deal with the development of components to facilitate interoperability across various platforms (including the marketplaces) has been announced and constitutes the first step towards harmonising the used semantic artifacts. Embracing the inter-marketplaces collaboration from an early development stage has been considered crucial.

¹⁹ <https://gitlab.com/vimmp-semantic/vimmp-ontologies/-/raw/master/alignment/evmpo.ttl>
<https://www.ontocommons.eu/>

Group 3: Common API for Marketplaces (How can Marketplaces interact? Global search?)

Moderators: Petter Rønningen (SINTEF) and Yoav Nahshon (Fraunhofer IWM)

Participants: 9 people

Below we report the main points addressed in the discussion:

- Do we need a layer on top of the marketplaces or connectors between them so that they can communicate among themselves?
- Who is doing the search? We assume it is the client. Could also be the data proprietor²⁰ that wants to see where the assets are and how they are managed through the API. This will encourage them to deploy more data into the system.
- Are the Marketplaces interested in the same community? MarketPlace and VIMMP have some overlaps.
- Aim of the connectivity:
 - to offer something that has a wider scope.
 - Enabling workflows, exchange info between simulators, reading data between databases, useful to have a bridge that allows available tools in one platform and have post processors for another platform.
- We need to start to look for workflows and how to standardize them. Ecosystem of marketplaces to solve the cross-domain problem.
- Enable innovation to work with cross domain problems to avoid monopoly and promote competition and enable your business model on top of the marketplace API.
- Unified workflows difficulty: it is important to identify the development pace of each marketplace.
- It is important to publish APIs and standardize them.

Figure 2 shows the concept board that was used during the discussion.

²⁰ Proprietary Data: any set of statistics, information, or documentation which is controlled solely by your company.

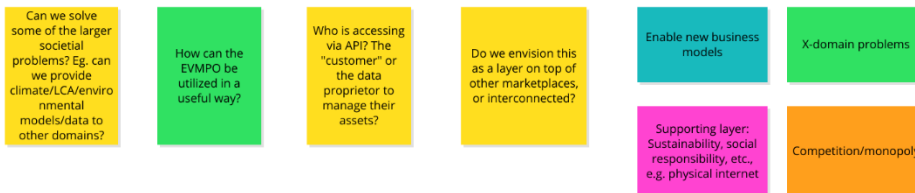
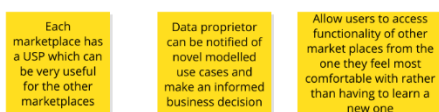
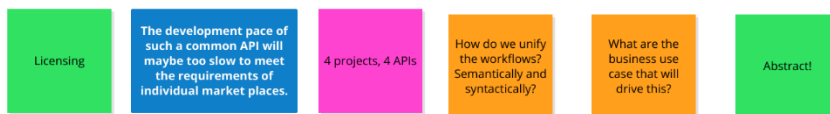
Questions to be answered:
What could be achieved with a global API? Global search, ... ?

How can marketplace users benefit from interaction between marketplaces?

What could be potential technical and legal hurdles?


Figure 2. Snapshot of the discussion board of Group 3 - Common API in OntoCommons FW1.1

Group 4: Demonstrators (How can we demonstrate the benefits of the OntoCommons EcoSystem in the showcases of the marketplaces?)

Moderator: Umutcan Simsek (STI)

Participants: 7 people

The alignment between TLOs and MLOs is important to support interoperability between data sources, software and between marketplaces.

Domain experts are not necessarily competent in semantic technologies (e.g., ontologies). We need to create community comprising knowledge engineering experts and domain experts, and create a platform (with built-in principles) that enables practitioners in each domain to build a reference ontology. Often, the semantic assets are prototyped but not standardised. Hence, we need to create standards, industrial *de facto* standards, like BFO, or ISO-like standards: we are not there yet and Ontocommons is a way to achieve this.

Poor maintenance and lack of proper methodology are issues that need to be overcome to support adoption and interoperability in a professional way.

The goal is to have a good ontology; the problem is that often there is not enough background to develop one. The attitude is often to just translate standard terminology from traditional engineering (or a certain domain) into OWL and call that “ontology”, but proper ontology engineering requires studying the domain by using ontological principles. Without that, terminologies are put in graph-like shape, but they are useless.

The lack of industry-ready tools and methodologies for alignment of various DLO and TLOs are also discussed during the session. OntoCommons should set up methodologies and tools to support these.

Ontocommons can help the digital marketplaces to better interoperate between them and within the projects, by providing best practices and reference ontologies (as the TRO).

To support tool development, it is necessary to analyse the landscape gaps and requirements in each domain.

We need to get more marketplace demonstrators to show the benefit of OntoCommons approach.

It is advised to not provide very complex ontologies, which would constitute an entry barrier, instead work out a lightweight ontology, only complex enough to be sufficient to represent the needed information. And, also, lightweight guidelines to enable easier communication within and between projects.

Is it important that KPIs are defined in the Ontocommons project to evaluate the impact of Ontocommons Ecosystem, including guidelines, ontologies and tools.

Figure 3 shows the concept board used during the Group 4 discussion.

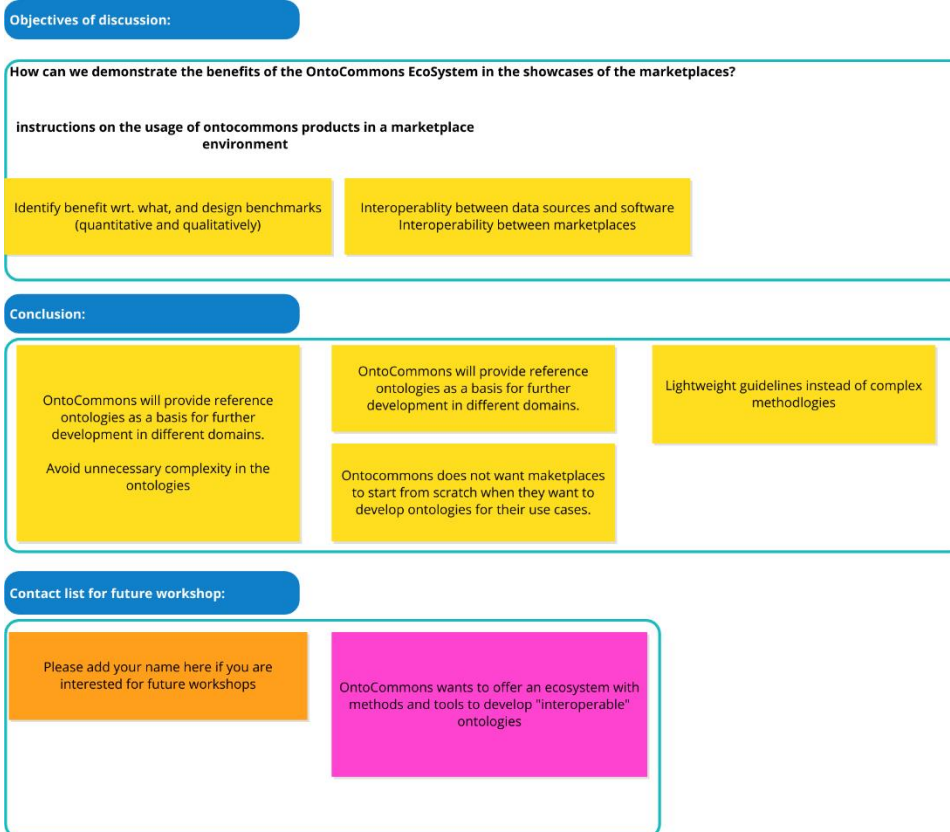


Figure 3. Snapshot of the discussion board for Group 4 - Demonstrators in OntoCommons FW1.1

Final discussion about new OntoCommons demonstrators and regular web meetings

Moderator: Dimitris Kiritsis (EPFL, Univ. Oslo)

Participants: 30 people

The collaboration between marketplaces and Ontocommons has to be done in a practical way (development, demos, common work). Almost all marketplaces, especially DOME 4.0, have as one of their core objectives to collaborate with other marketplaces, so alignment and interoperability of data between their platforms are necessary. It is useful to invite marketplaces to define a demonstrator each (this will require the agreement of individual projects).