PROJECT DELIVERABLE REPORT

Grant Agreement Number: 101058732

Joint Industrial Data Exchange Platform

Type: Deliverable Report

D2.1 Report on inter-project cooperation and data collection

Issuing partner	University of Cambridge (UCAM)
Participating partners	Universita di Trento (UNITN) Technovative Solutions (TVS)
Document name and revision	D2.2 Interoperability specifications and FAIRness compliance
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Deliverable due date	30 November 2023
Actual submission date	06 November 2023

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Dissemination Level		
PU	Public	✓
PP	Restricted to other programme participants (including the Commission services)	
CO	Confidential, only for members of the consortium (including the Commission services)	
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Acronyms and Abbreviations

CEN	European Committee for Standardisation
DC	Dublin Core
DIN	German Institute for Standardisation
DLT	Distributed Ledger Technology
EMMC	European Materials Modelling Council
EMMO	Elementary Multiperspective Material Ontology
EOSC	European Open Science Cloud
ERA	European Research Area
KBE	Knowledge-Based Engineering
IAOA	International Association for Ontology and its Applications
IOF	Industrial Ontologies Foundry
IRI	Internationalised Resource Identifier
ISO	International Organisation for Standardisation
OBDI	Ontology-Based Data Integration
OEM	Original Equipment Manufacturer
OPC	Open Platform Communications
OPC UA	OPC Unified Architecture
OWL	Web Ontology Language
PCB	Printed Circuit Board
PUR	Polyurethane
PVC	Polyvinyl Chloride
RDA	Research Data Alliance
SIG	Special Interest Group
TVS	Technovative Solutions
UCAM	University of Cambridge
UNITN	University of Trento

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1. Executive Summary

The objectives of this deliverable include observing and analysing approaches and best practices applied in ontology modelling, ontology-centric tool development, rule creation, interoperability enhancement, data sharing and reusability, and data collection from different sources. We have established collaboration with EU-funded initiatives and organisations such as WeldGalaxy and EMMC and collected methodological, technological and ontological resources that have contributed to the synchronisation of our activities in ontology-based tool development, rule creation, ontological model definition and enabling interoperability with existing top-level initiatives. We have been monitoring the advancement of the European Open Science Cloud, the Research Data Alliance, and the International Data Space Associations to develop an understanding of practical data-sharing approaches across industrial and academic entities. We have been analysing the approaches and best practices recommended by the Industrial Ontologies Foundry, the Industry Commons Foundation, and the International Association for Ontology and its Applications to apply a systematic approach to ontological modelling and achieving interoperability. We have collected data from all use case partners and partner-recommended online resources for the successful execution of JIDEP ontology, tool and platform development activities. Finally, we have reviewed ontology-based data integration (OBDI) methods to choose the most effective one for our purpose.

2. Introduction

The overall objective of this deliverable is to align project activities related to, for example, ontology modelling, ontology-based tool development, rule creation and enabling interoperability with EU-funded initiatives and EU and international organisations and collect data from use case partners, related projects and initiatives. A collaboration has been established with the Horizon 2020 WeldGalaxy project that developed a Knowledge-Based Engineering (KBE) tool by creating and applying rules for proposing a welding specification to address a specific welding problem. An interactive user interface is provided to allow users to specify the problem. User inputs are matched with rules to identify the intended one for proposing the solution consisting of the type of welding, welding equipment, consumables, etc. The collaboration has enabled us to develop an understanding of the knowledge-based tool development, rule creation and rule optimisation approaches. Furthermore, the WeldGalaxy project generated an ontology from a thesaurus to instantiate welding data and explore the possibility of creating ontology-based rules and their effective use in the KBE tool. This has helped us learn their approach to ontology-based rule development and enabled us to expedite our rule creation activity.

Our collaboration with the European Materials Modelling Council (EMMC) has provided us with the opportunity to collect, analyse and understand the Elementary Multiperspective Material Ontology (EMMO), reuse it in the JIDEP project as the domain ontology for materials and extend it with the concepts describing a hierarchy and manufacturing process of composite materials. In the discussion with EMMC, we have learned the approach used in the development of EMMO. EMMC has shared their research outcomes published in the reference language and ontology for materials modelling and interoperability and ontology for the harmonisation of material characterisation methodologies papers. This has equipped us with their approach to creating ontologies and using ontologies for achieving interoperability.

In addition, we have been monitoring the activities of the EU and international organisations to ensure consistency of the JIDEP project with their initiatives regarding best practices in publishing and sharing data, creating ontologies and enabling interoperability. European Open Science Cloud (EOSC) allows publishing, discovering and utilising data, tools and services to support research, innovation and education. We have been observing their technological and methodological advancement in creating a web of FAIR data to adopt as much as we can in JIDEP. We have also been monitoring the data sharing and reusability actions of the Research Data Alliance (RDA). For the best practices of ontological modelling, we have been following the activities of the Industrial Ontologies Foundry (IOF) and the International Association for Ontology and its Applications (IAOA). To enable interoperability, we have been observing the activities of the Industry Commons Foundation and Open Platform Communications (OPC).

Data contributing partners, mainly the JIDEP project consortium members responsible for use cases, provided us with several datasets. The Automobile Lifecycle use case partner created a dataset consisting of eight cross beams individually manufactured with constituent materials in a closed mould autoclave and then assembled by the supplier on the mainframe chassis, applying the hand lay-up process. The Wind Turbine Lifecycle use case partner analysed and provided us with publicly available wind turbine blade datasets consisting of properties including mass, length, root diameter, maximum chord of blade and quantities of materials required to manufacture the blade. The Industrial Electronics Lifecycle use case partner provided a microcontroller board dataset on the Arduino Pro Mini microcontroller board.

The rest of the document is organised as follows: Section 3 describes activities and outcomes of the relevant EU-funded projects and EU and international organisations in knowledge and rule-based tool development, ontology definition, data sharing and achieving interoperability.

Section 4 provides a detailed account of data collection from use case partners and external sources. Section 5 shows the ontology-based approach for data integration, and Section 6 concludes the document.

3. Relevant Initiatives and Organisations

3.1 WeldGalaxy

The WeldGalaxy project [1] aimed to create a B2B online platform to connect global buyers, i.e. end-users/OEM, with EU sellers, including manufacturers, suppliers, distributors and service providers, of welding equipment, auxiliaries and consumables, and welding services. Through digital marketing strategies, this platform would improve the visibility of EU welding products, prototypes, and services to a worldwide audience. Additionally, it would provide innovative web-based services, such as equipment selection and inventory management, as well as digital design and testing of equipment capabilities to enhance the EU's market share and competitiveness.

The core of the digital platform involved:

- Knowledge Base Engineering (KBE) tools.
- Streamlining equipment selection for end-users and enabling the digital manufacturing of customized equipment.
- Complying with customer requirements and regulations.

This dynamic B2B platform, built on a standard 3-tier architecture, prioritised scalability and reliability. Using RESTful architecture for the API layer and a cloud-based backend platform hosted on well-established cloud providers, AWS ensured scalability, load balancing, caching, and data redundancy for reliability. Incorporating blockchain and Distributed Ledger Technology (DLT) further enhanced platform stability, scalability, and uptime. The integration of blockchain/DLT also reinforced transaction security, visibility, transparency, and reliability, ultimately strengthening the competitiveness of EU manufacturing.

3.1.1 KBE tool development methodology

One of the focuses of WeldGalaxy was on developing automated KBE tools and a platform. The platform's primary function was to assist users in determining welding parameters, the welding process, and the consumables needed for welding two materials. The project initiated the process of generating welding instance-based rules. These rules were further optimised and translated into a machine-readable format within the KBE tool. Consequently, the project structured the knowledge model with input parameters that users can select from a drop-down menu and output parameters generated by the KBE tool.

The development of the KBE tool adhered to the SCRUM methodology, rooted in the Agile software development principles, focusing on an iterative approach and fostering strong collaboration among developers. This methodology relies on the development team engaging in daily discussions regarding progress and challenges. It consists of macro tasks, which were broken down into micro-tasks, each with a well-defined timeframe for completion, to simplify the process. In addition to task organisation, the SCRUM methodology underscores the importance of involving an experienced, disciplined, and organised group of developers to attain the highest levels of success in software development.

Experienced team members analysed the requirements of the KBE tool to estimate the number of sprints or iterations required to reach the final product. Each sprint encompassed five interconnected phases: requirement specification, design, implementation, validation, and evolution. After concluding each sprint, we convened meetings approximately every two weeks to showcase the KBE tool's newly developed features, demonstrate progress, and gather feedback from team members. All developers presented their sprint achievements during these sessions and benefited from the ensuing discussions.

3.1.2 KBE rule development methodology

A crucial outcome of WeldGalaxy is to define methodological steps for creating welding instance-based rules and subsequently optimise these rules to craft knowledge-based decision rules. This optimisation process contributes to the enhanced automation of the welding parameter generation system. The development of knowledge-based decision rules for the KBE tool involved the following steps, as illustrated in [2]:

Step 1: Knowledge acquisition
Step 2: Knowledge modelling and representation
Step 3: Verification of knowledge accuracy
Step 4: Conversion of knowledge into a scalable, machine-readable format
Step 5: Rule optimisation

These steps were systematically executed to create effective knowledge-based decision rules for the KBE tool.

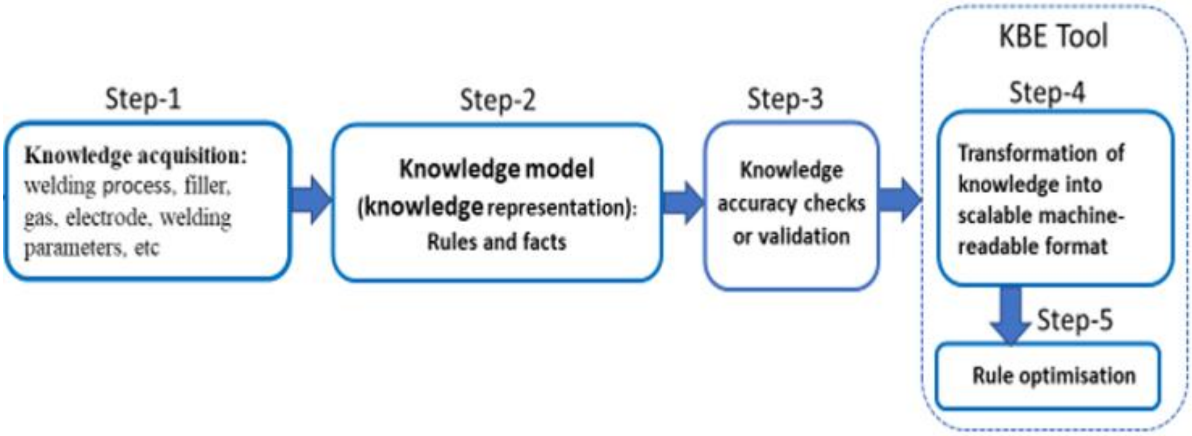

Figure 1. Methodological steps for generating knowledge-based decision rules (adapted from [2]).

Step 1: Knowledge Acquisition

In this initial step, WeldGalaxy gathered domain knowledge from various sources, including human experts, legacy data, literature, and other relevant references.

Step 2: Knowledge Model and Representation

The knowledge collected in Step 1 is consolidated from diverse sources into various documents comprising tables, copied texts, figures, and listings of standard numbers and alloy compositions. This gathered knowledge is then thoroughly analysed to identify patterns, relationships, and connections. Specifically, WeldGalaxy focused on filler materials, shielding gases, welding processes, electrodes, and welding parameters required for joining two specific materials. The results of this analysis were organised into rows in an Excel sheet, with each row representing a welding instance-based rule. The columns covered attributes like base materials, geometry, weld type, welding positions, welding process, consumables,

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electrodes, and welding parameters. Each Excel sheet served as a 'knowledge model,' summarising the insights gained in Step 1.

Step 3: Knowledge Accuracy Check

In ensuring the reliability of the knowledge documented in spreadsheets, a validation process was carried out. This step involved cross-checking the accuracy of the acquired knowledge and its suitability for integration into the system.

Step 4: Transformation of Knowledge into Machine-Readable Format

In this stage, WeldGalaxy defined rules in a structured IF-THEN format, where the "IF" part (antecedent) comprised a set of conditions, and the "THEN" part (consequent) included conclusions or actions. Each condition could be true or false; multiple conditions were linked using logical conjunctions (AND). Similarly, multiple concluding statements were also connected. This transformation facilitated the machine's understanding of these rules, making them ready for integration.

Step 5: Rule Optimisation

Rule optimisation was an automated process aimed at enhancing the performance of the KBE tool. It involved consolidating two or more existing rules into one rule, reducing the search space for matching user inputs with rules stored in MongoDB. The process identified candidate rules for conversion by considering the similarity of concluding statements within a category of materials. When exact similarities were detected, these rules were programmatically replaced with a surrogate rule that acts as a comprehensive representative. Surrogate rules were formed by combining dissimilar conditional statements using disjunction (OR) while retaining similar conditional and concluding statements and their conjunctive relationships. These optimised rules were then encoded in MongoDB and deployed within the KBE tool.

3.2 EMMC

The European Materials Modelling Council (EMMC) [3] recognises the vital importance of integrating materials modelling and digitalisation to foster more agile and sustainable product development. It also recognises that the advancement of novel materials and the innovative application of existing ones play a pivotal role in ensuring the prosperity and sustainability of European industries and society at large. Established in 2014, the EMMC has actively engaged in extensive consultations and networking initiatives, involving a diverse range of stakeholders, including modellers, materials data scientists, software developers, intermediaries, and manufacturers throughout Europe. As early as 2014, and with a greater emphasis during the H2020 EMMC-CSA project (2016-2019), the EMMC identified and proposed a comprehensive framework of foundational and facilitating actions. These actions were designed to enhance the industrial utilisation of materials modelling within the European context.

3.2.1 EMMO

The Elementary Multiperspective Material Ontology (EMMO) [4] results from a collaborative effort within the EMMC, with the primary objective of creating a standardised ontology framework that captures the current knowledge in materials modelling and characterisation. EMMO takes a different approach than many other ontologies that begin with broad, high-level concepts. It starts from the fundamental level, using the empirical insights from applied sciences, particularly physics and material sciences, to build its foundation.

EMMO's development approach begins at the scientific application field (the bottom), gradually progressing through the domain-level and mid-level ontological models towards conceptualisation (the top). This unique approach maintains a steadfast focus on its original scope while striving for the broadest possible applicability. The ontology's framework is created around core concepts such as elementary particles, wave-particle duality, and space and time intervals, all drawn from the experimental physics perspective. The middle and upper layers of EMMO were defined to provide users with a comprehension of the foundational concepts, making them accessible to users who may not possess deep knowledge about materials or lack the ability to critically analyse concepts and relationships.

As shown in **Figure 2**, the top level of the EMMO ontology consists of concepts, including Item, Collection, Void, Physical, Elementary and Quantum, represented in Protégé as classes.

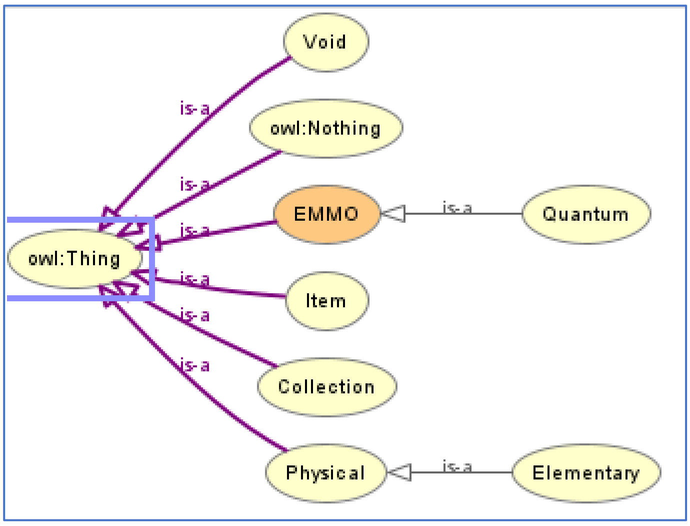

Figure 2. Graphical representation of the top-level of the EMMO ontology.

The class *Item* refers to any object with components connected to form the whole. One example of *an Item* is a car. The class *Collection* refers to a group of non-connected objects participating in the group as a member. One example of *a Collection* is a group of users of a software system. *A Void* can be defined as something empty that has no physical parts. The class *Physical* can be defined as an object with at least one element that has a physical appearance. It can possess *Void* parts. *Elementary* is a physical object that cannot be subdivided further. A *Quantum* is the smallest possible *Item*.

In **Error! Reference source not found.**, the mid-level of the EMMO ontology shows that it h as a total of 463 classes, 46 object properties, 3 data properties, 35 annotation properties, 1 individual, 623 subclass of axioms, 47 sub-object property axioms, 4 functional property axioms, 539 declaration axioms, 869 logical axioms, and 3,215 axioms including the ontological elements available in the imported top-level of the EMMO ontology.

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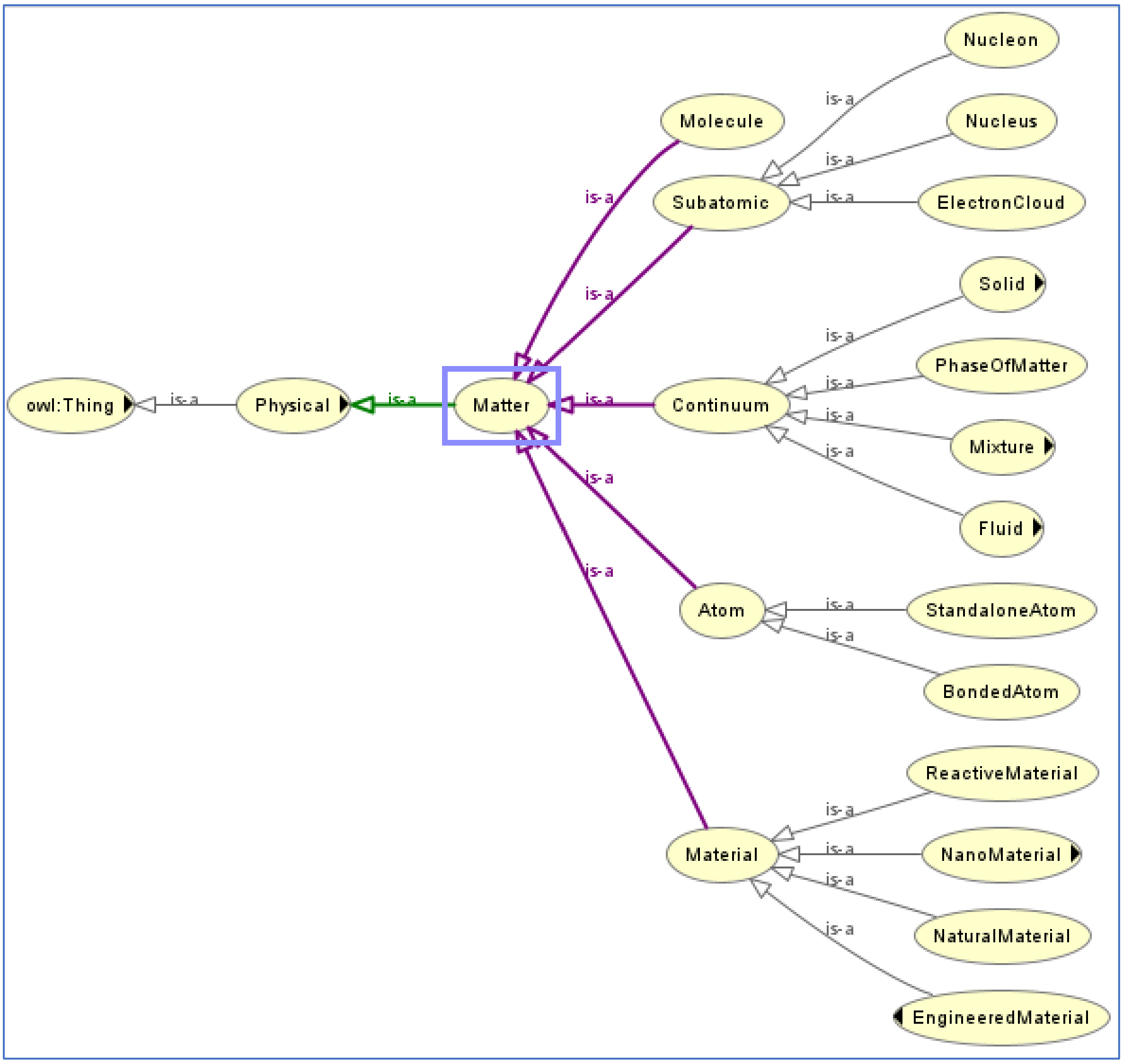


Figure 3. Graphical partial view of the mid-level of the EMMO ontology.

The relevant classes for the JIDEP project for representing data include *Matter*, *Material*, and *Engineered Material*. *Matter* is a physical object that has mass and space occupancy. *Material* is a matter or tangible thing employed in the manufacturing of a product or component. *Engineered Material* is a material produced through manufacturing processes to achieve desired characteristics.

The EMMO domain ontology was created by expanding the mid-level ontology with some domain-specific classes to demonstrate some examples for ontologists who will define EMMO-based domain ontologies. As depicted in **Error! Reference source not found.**, one s uch domain extension includes some common materials classes. EMMO domain ontology consists of a total of 492 classes, 46 object properties, 3 data properties, 35 annotation properties, 1 individual, 671 subclass of axioms, 47 sub-object property of axioms, 568 declaration axioms, 928 logical axioms and 3,355 axioms including the ontological elements available in the imported top-level and mid-level of the EMMO ontology. Some common example material classes are Argon, Acetylene, Benzene, H, H2, N and N2.

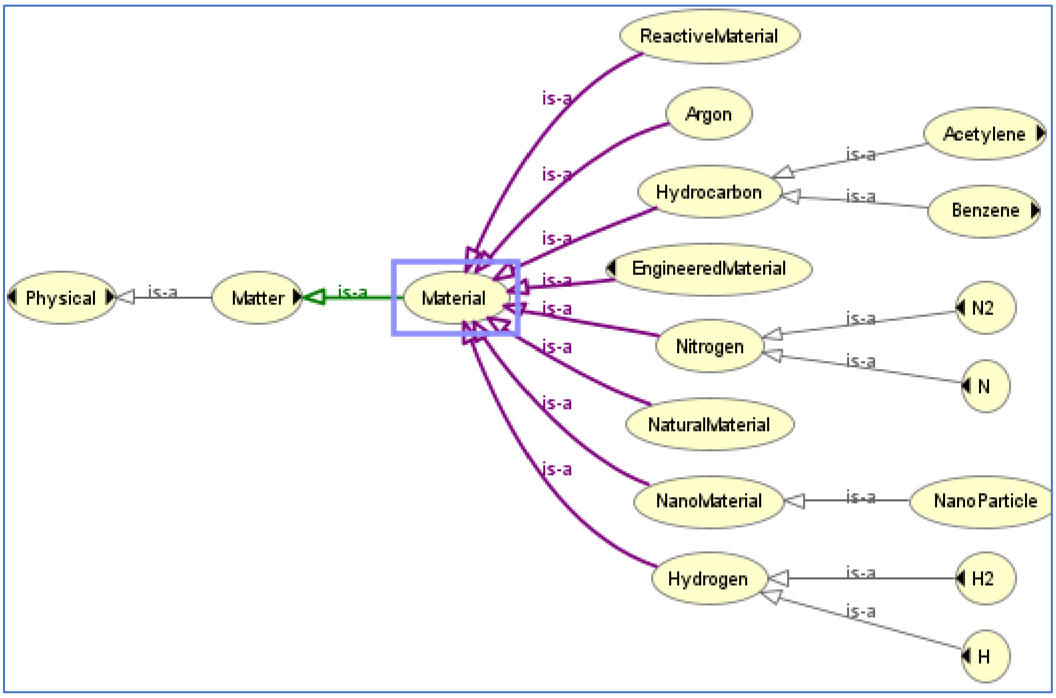


Figure 4. Graphical partial representation of the EMMO domain ontology with some common materials classes.

3.3 EOSC

The European Open Science Cloud (EOSC) aims to create a federated and open multidisciplinary ecosystem that benefits European researchers, innovators, companies, and the public. Within this ecosystem, they can easily publish, discover, and utilise data, tools, and services for research, innovation, and education. This endeavour will maintain clear conditions to ensure trust and safeguard the public interest. The EOSC seeks to drive a fundamental transformation across scientific communities and research infrastructures by emphasising seamless access to enable unhindered access to resources and FAIR management to adhere to the Findability, Accessibility, Interoperability, and Reusability principles to enhance data usability. It also emphasises the reliable reuse of research data and all digital objects generated during the research lifecycle, such as methods, software, and publications.

Ultimately, the EOSC envisions creating a 'Web of FAIR Data and services' for science in Europe. This infrastructure will serve as a foundation for a wide array of value-added services, including visualisation, analytics, long-term data preservation, and the monitoring of open science practices adoption.

The EOSC has received recognition from the Council of the European Union, being one of the 20 key actions in the European Research Area (ERA) policy agenda from 2022 to 2024. It plays a crucial role as the "science, research, and innovation data space," aligning with other sectoral data spaces outlined in the European data strategy. The full deployment of EOSC is expected to yield benefits in terms of increased research productivity, new insights, innovations, enhanced reproducibility, and greater trust in the field of science. This implementation promises a positive impact on the scientific community and the broader society.

3.4 RDA

The Research Data Alliance (RDA) fosters open data sharing and reusability by establishing social and technical connections. Launched in 2013, RDA is a collaborative initiative driven by the European Commission, the United States Government's National Science Foundation, the National Institute of Standards and Technology, and the Australian Government's Department of Innovation. Its primary aim is to construct the necessary social and technical infrastructure to facilitate the open exchange and reuse of data. RDA's approach is rooted in inclusivity and grassroots engagement, spanning all stages of the data lifecycle. It actively involves data producers, users, and stewards while addressing various aspects of data, including exchange, processing, and storage. The alliance has successfully provided a neutral social platform where international experts in research data convene to discuss and reach a consensus on numerous topics. These discussions encompass challenges related to data sharing, education, training, data management plans, certification of data repositories, disciplinary and interdisciplinary interoperability, and technological advancements.

3.5 IOF

The Industrial Ontologies Foundry (IOF) [5][6] has been established as a working group to define reference ontologies that represent common and general concepts within the realms of manufacturing and engineering industries. The key objective of the IOF is to create a set of principle-based ontologies that are openly available for use. These ontologies serve as a foundation for developing specialised domain and application-specific ontologies. Additionally, IOF seeks to establish principles and best practices for creating high-quality ontologies that facilitate interoperability within industrial domains.

IOF-compliant ontologies are expected to be understandable by humans through natural language descriptions and interpretable by machines through a formal language representation. They should also come with documentation to assist users in learning how the ontology was developed and provide clear definitions for classes and properties.

IOF follows a layered approach to organise its ontologies to maintain coherence and consistency. The top layer is the foundational or upper ontology layer, which contains more generic concepts. The layer immediately below comprises the domain-independent mid-level ontology and domain-specific reference ontology. The next lower layer is called the subdomain ontology layer, and the bottom layer is termed the application ontologies layer. IOF ontologies belong to the top two layers, and IOF places significant importance on providing an RDF/XML representation for any IFO ontology. These ontologies can be available in a formal language like Common Logic or OWL, using one of its variants, such as OWL2-XML, OWL2-Manchester Syntax, and Turtle.

Furthermore, IOF mandates that the ontologies within its framework be freely accessible to the industrial community. It allows the reuse of classes or properties from external ontologies, provided their original identifiers (IRI) are used. Using an entire external ontology through the import statement is allowed if the ontology has an open and flexible license that doesn't impose restrictions.

The IOF approach strongly recommends having only one reference ontology per domain and encourages a clear description of the scope and context in which an ontology is developed. Such clarity reduces confusion, aids users in finding the intended ontology more quickly, and enhances the potential for its use and reuse. IOF also suggests using the abstract property from the Dublin Core (DC) terms to describe the scope and context, and it mandates the explicit inclusion of dependencies on external ontologies in order to help identify the scope and context.

3.6 Industry Commons Foundation

The Industry Commons Foundation has established a set of fundamental principles and a methodology to guide the Industry Commons community [7]. This framework empowers the establishment of an accountable open innovation and production value network, facilitating the development of groundbreaking solutions for various industries. These solutions harness the industry's existing capabilities, effectively merging them to drive innovation. Industry Commons catalyses the rapid transformation of enabling technologies across different sectors by providing a platform for hybrid applications. The community is home to many experts with invaluable knowledge and hands-on experience in innovation testbeds. They conduct experiments in cutting-edge technologies, including AI, IoT, 5G, and blockchain-based Distributed Ledger Technology (DLT). Furthermore, the Industry Commons Foundation played a role in the Horizon 2020 OntoCommons project. This initiative aimed to establish ontology-based data documentation to promote standardised data formats, thus enabling greater interoperability.

3.7 IAOA

The International Association for Ontology and its Applications (IAOA) is a non-profit organisation established to strengthen interdisciplinary research and promote collaboration globally in the cross-domain encompassing areas of philosophical ontology, linguistics, logic, cognitive science, and computer science [8]. IAOA is devoted to the applications of ontological analysis in fields including conceptual analysis and modelling, knowledge engineering, knowledge modelling and management, information systems development, library and information science, and semantic technologies. One of the primary activities of the association that is related to the JIDEP project is to educate interested stakeholders on how to effectively utilise ontologies in building practical applications.

The association carries out crucial long-term activity in different scientific areas via the following scientific committees and special interest groups (SIGs): Education Committee, Industry and Standards Technical Committee and Semantic Web Applied Ontology SIG. The Education Committee actively pursues the advancement of education in applied ontology by creating shared teaching materials on applied ontologies. The Industry and Standards Technical Committee seeks the application of ontologies in initiatives dedicated to standardisation. The Semantic Web Applied Ontology SIG works towards establishing a full-blown collaboration between the Semantic Web community and the Ontology community as they aim at developing a shared understanding of domains of interest and defining them formally via formal logic languages.

3.8 OPC

Though the OPC acronym originated from Object Linking and Embedding for Process Control, it now stands for Open Platform Communications. OPC Unified Architecture (UA) is a standard specified to achieve interoperability in the industrial automation space and in exchanging information among various devices in a vendor and platform-agnostic manner [10][11]. OPC UA offers a standard infrastructure model designed and developed by combining information, communication, message and conformance models to exchange information [12]. While the information model represents the structure and semantics of the information, the communication model supports the information transfer across endpoints. While the message model facilitates the interaction between applications or systems, the conformance model enables interoperability between applications.

The OPC UA standard applies request and response messages to support communications among devices and applications over various networks [12]. It ensures security against attacks via the publisher-subscriber model of communication that forces interacting applications to reveal their identity. The publisher-subscriber model is called the PubSub model in the OPC UA architecture that publishers use to communicate information with subscribers. The OPC UA design includes an integrated service model and address space to manage the consistency of information exchanged among devices and applications [12]. Data exchanged via OPC UA has different transportation formats, including XML and JSON, that can be determined by a subscriber or client by querying the address space, allowing the retrieval of data format at runtime.

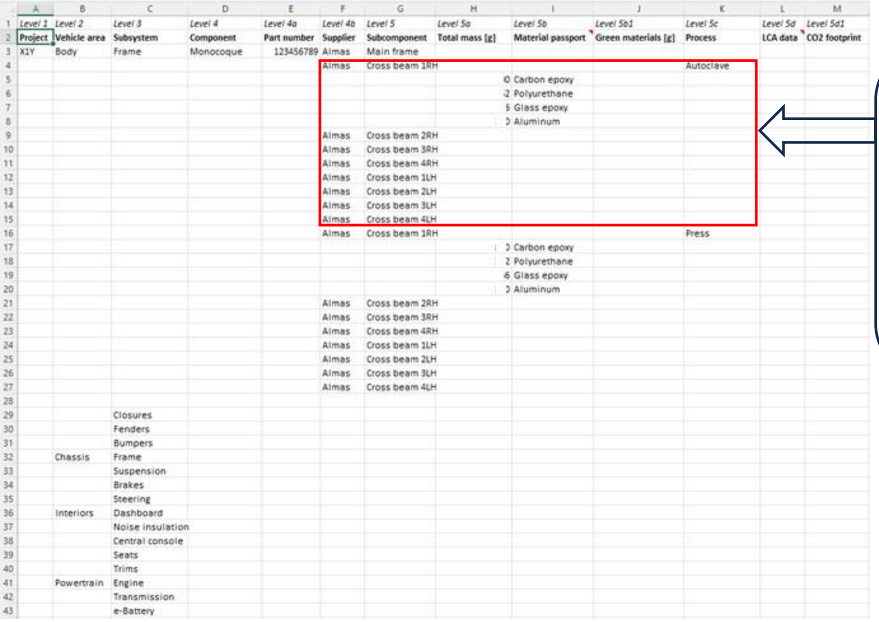
4. Data collection

4.1 Use Case Partners

4.1.1 Automotive Lifecycle

The Automotive partner created a dataset with a hierarchy of automotive vehicle components, with detailed information about cross beams, including their mass and manufacturing processes. The dataset is shown in Table 1.

Table 1. *Automotive cross-beam data describing the manufacturing process, constituent materials and their mass. Material mass is blurred partly to meet the data provider's business secret non-disclosure requirements.*



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	*Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 4a*	*Level 4b*	*Level 5*	*Level 5a*	*Level 5b*	*Level 5b1*	*Level 5c*	*Level 5d*	*Level 5d1*
2	**Project**	**Vehicle area**	**Subsystem**	**Component**	**Part number**	**Supplier**	**Subcomponent**	**Total mass [g]**	**Material passport**	**Green materials [g]**	**Process**	**LCA data**	**CO2 footprint**
3	X1Y	Body	Frame	Monocoque	123456789	Almas	Main frame						
4						Almas	Cross beam 1RH				Autoclave		
5								[redacted]	Carbon epoxy				
6								[redacted]	Polyurethane				
7								[redacted]	Glass epoxy				
8								[redacted]	Aluminum				
9						Almas	Cross beam 2RH						
10						Almas	Cross beam 3RH						
11						Almas	Cross beam 4RH						
12						Almas	Cross beam 1LH						
13						Almas	Cross beam 2LH						
14						Almas	Cross beam 3LH						
15						Almas	Cross beam 4LH						
16						Almas	Cross beam 1RH				Press		
17								[redacted]	Carbon epoxy				
18								[redacted]	Polyurethane				
19								[redacted]	Glass epoxy				
20								[redacted]	Aluminum				
21						Almas	Cross beam 2RH						
22						Almas	Cross beam 3RH						
23						Almas	Cross beam 4RH						
24						Almas	Cross beam 1LH						
25						Almas	Cross beam 2LH						
26						Almas	Cross beam 3LH						
27						Almas	Cross beam 4LH						
28													
29			Closures										
30			Fenders										
31			Bumpers										
32		Chassis	Frame										
33			Suspension										
34			Brakes										
35			Steering										
36		Interiors	Dashboard										
37			Noise insulation										
38			Central console										
39			Seats										
40			Trims										
41		Powertrain	Engine										
42			Transmission										
43			e-Battery										

Eight cross beams are assembled on the mainframe chassis. We can assume that all cross beams have the same amount of materials.

The eight cross beams are separately prepared in a closed mould autoclave in a precured shape, then assembled by the supplier on the mainframe chassis (prepared by hand lay-up) at the same time (co-cured) in a final autoclave process of the entire chassis part. The eight cross beams comprise four materials (Carbon epoxy, Polyurethane, Glass epoxy, and Aluminium).

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4.1.2 Wind Turbine Lifecycle

The Wind Turbine partner researched, analysed and provided us with publicly available data on wind turbine blades. **Figure 5** shows the different components of a wind turbine blade. One of the datasets contributed by this partner is reported in In **Table 3**, it is depicted that Glass Fibre and Epoxy Resin contribute to more than 80% of the total mass of the wind turbine blade.

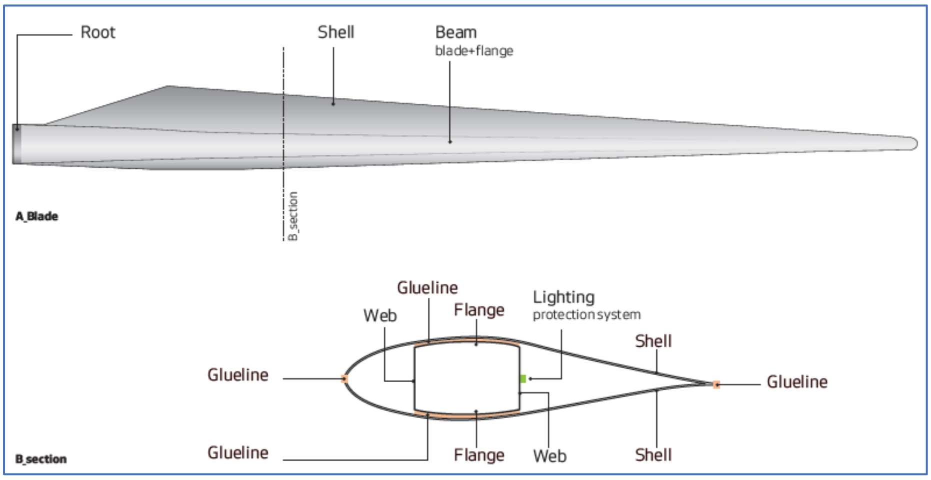

Figure 5. *Components of a wind turbine blade manufactured by Vestas, including those annotated on its B-section [9].*

Among the remaining materials, Aluminium, PVC foam, PUR adhesive and Epoxy Gelcoat contribute 4%, 4%, 6% and 3%, respectively, of the total mass.
Table 3 and In **Table 3**, it is depicted that Glass Fibre and Epoxy Resin contribute to more than 80% of the total mass of the wind turbine blade. Among the remaining materials, Aluminium, PVC foam, PUR adhesive and Epoxy Gelcoat contribute 4%, 4%, 6% and 3%, respectively, of the total mass.
Table 3. The type and quantity of materials used in manufacturing blade parts are provided in this dataset.

Table 2 shows that the dataset has several properties, including mass, length, root diameter, maximum chord length and maximum thickness of the root section of a wind turbine blade.

Table 2. *Data describing the dimension of a wind turbine blade manufactured by Vestas.*

Property	Value [unit]
Mass	1218 [kg]
Length	22900 [mm]
Root Diameter	990 [mm]
Max Chord	2088 [mm]
Max Thickness of Root Section	99 [mm]

In **Table 3**, it is depicted that Glass Fibre and Epoxy Resin contribute to more than 80% of the total mass of the wind turbine blade. Among the remaining materials, Aluminium, PVC foam, PUR adhesive and Epoxy Gelcoat contribute 4%, 4%, 6% and 3%, respectively, of the total mass.

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Table 3. *Data about the materials and quantities used in different parts of a wind turbine blade manufactured by Vestas.*

Material	Mass %	Blade Part
Glass Fibre	61	Blade Shells, Beam and Root Section (see **Figure 5**)
Epoxy Resin	21	Blade Shells, Beam and Root Section (see **Figure 5**)
Polyvinyl Chloride (PVC) Foam	4	Blade Shells, Web (see **Figure 5**)
Polyurethane (PUR) Adhesive	6	Leading Edge, Trailing Edge, Beam to Blade Shell (see **Figure 5**)
Aluminium	4	Root Section and Lighting Protection System (see **Figure 5**)
Epoxy Gelcoat	3	Outer Surfaces

Another dataset provided by this partner is about a heavy-duty blade manufactured by LM Wind Power and portrayed in **Figure 6** and **Figure 7**, where the former figure shows different components and elements in the blade, and the latter indicates materials used in the manufacturing process of the components and elements. This dataset is shown in **Table 4** and **Table 5**, where the former table includes the properties of a wind turbine blade, and the latter consists of the quantity of constituent materials in terms of mass or relative amount expressed in percentage. **Figure 6** shows the blade shell, sandwich core, embedded bushings, bulkhead, root flange and weighing chamber. It also indicates lightning receptors, conductor cables, and web and glue lines.

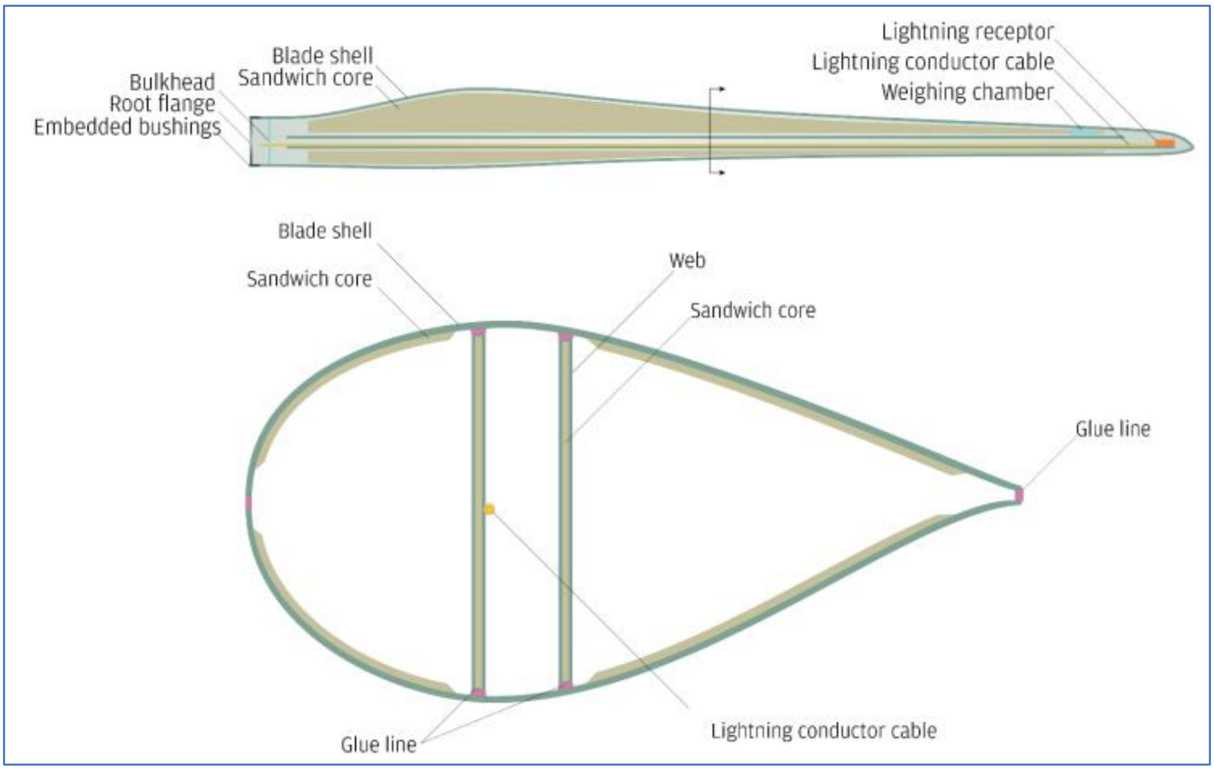

Figure 6. *Components of a wind turbine blade manufactured by LM Wind Power [15].*

In **Figure 7**, it is demonstrated that polyester resin is used as the matrix material in glass fibre composites, with polyester gelcoat covering the composites forming the outer surface. Other

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materials are balsa wood, PVC foam, vinylester adhesive, chromium molybdenum steel alloy, galvanised steel, stainless steel, copper and alloyed metal.

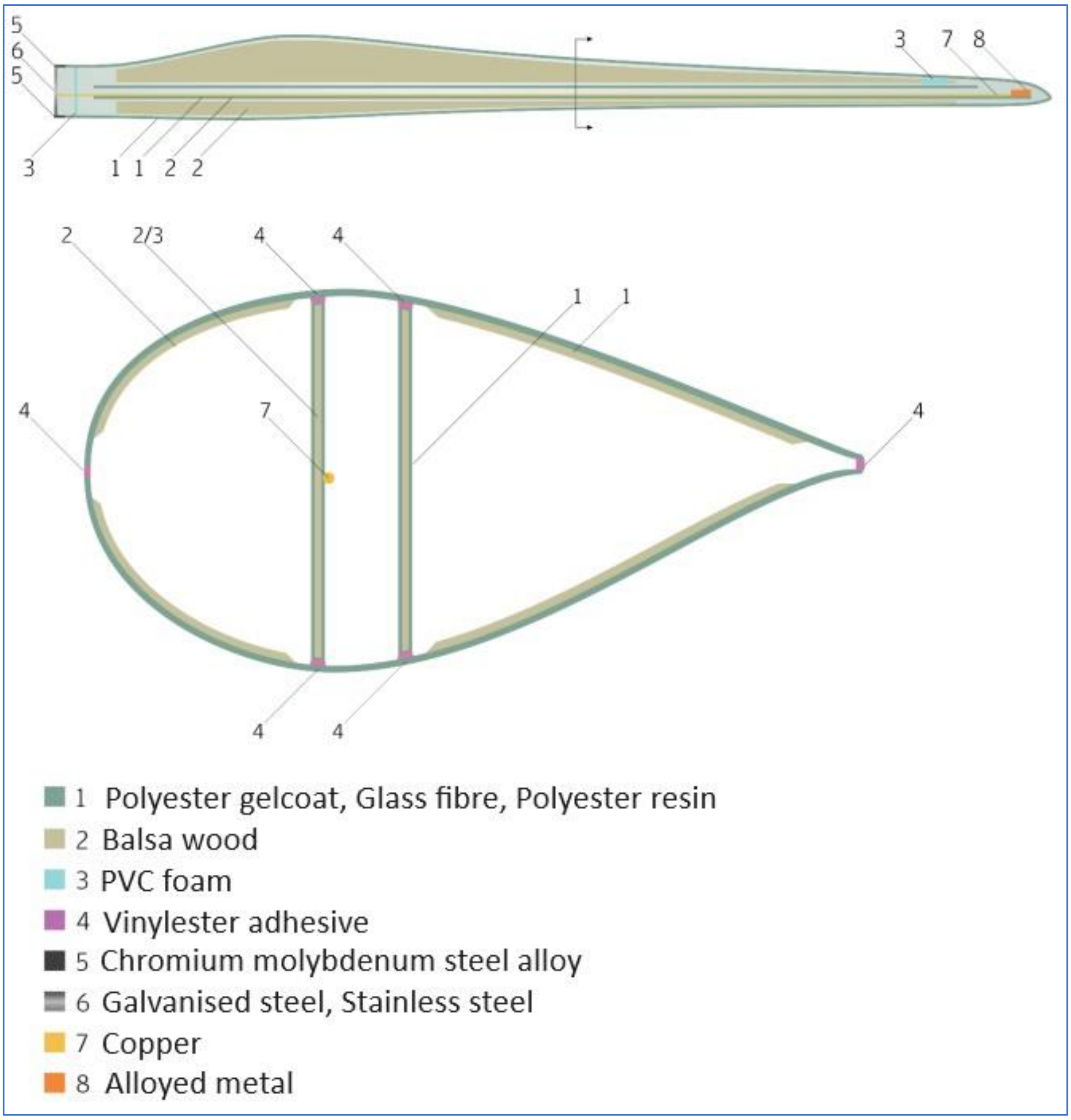

Figure 7. Materials used in different parts of a wind turbine manufactured by LM Wind Power [15].

Table 4 describes various properties of the wind turbine blade manufactured by LM Wind Power, including mass, length, root diameter, maximum chord and maximum laminate thickness, which refers to the maximum thickness of a laminate composite. In the table, it is shown that the mass is 5,590 kilograms, length 372,500 millimetres, root diameter 1,895 millimetres, maximum chord 3,097 millimetres and maximum laminate thickness 110 millimetres.

Table 4. *Data describing the dimension of a wind turbine blade manufactured by LM Wind Power.*

Property	Value [unit]
Mass	5590 [kg]
Length	372500 [mm]
Root Diameter	1895 [mm]
Max Chord	3097 [mm]
Max Laminate Thickness	110 [mm]

In **Table 5**, it has been reported that the wind turbine blade has glass fibre 58%, polyester resin 28%, balsa wood 5%, polyvinyl chloride foam 1.1%, vinylester adhesive 5% and polyester gelcoat 3% of the total mass. It also has shown that the wind turbine blade has chromium-molybdenum steel alloy of 140 kilograms, galvanised steel of 125 kilograms, stainless steel of 20 kilograms, copper of 40 kilograms and alloyed metal of 0.5 kilograms.

Table 5. *Data about the materials and quantities used in different parts of a wind turbine blade manufactured by LM Wind Power.*

Material	Mass % / kg	Blade Part
Glass Fibre	58 %	Blade Shells, Webs
Polyester Resin	28%	Blade Shells, Webs
Balsa Wood	5 %	Blade Shell Sandwich Core
Polyvinyl Chloride (PVC) Foam	1.1 %	Ribs, Bulkhead & Webs Sandwich Core
Vinylester Adhesive	5 %	Glue Line
Chromium Molybdenum Steel Alloy	140 kg	Embedded Bushings
Galvanised Steel	125 kg	Root Flange
Stainless Steel	20 kg	Root Flange
Copper	40 kg	Lighting Conductor Cable
Polyester Gelcoat	3 %	Outer Surface
Alloyed Metal	0.5 kg	Lighting Receptors

4.2 Industrial Electronics Lifecycle

The Industrial Electronics partner analysed a range of microcontroller boards, such as Raspberry Pi Pico W, which is part of the Raspberry Pi Pico family, and Arduino Leonardo and Arduino Pro Mini v12/v13 (5V), which are part of the Arduino family. **Table 6** shows the partner-provided public dataset describing the bill of materials or components included in Arduino Pro Mini. It indicates how many of each element will be required for one board, the part number provided by the DigiKey supplier and the reference label of each component on the actual printed circuit board (PCB).

Table 6. *Components available in the product Arduino Pro Mini microcontroller board [13].*

Quantity per Board	DigiKey Part Number	Description	Reference
1	490-1198-1-ND	CER RESONATOR 16.0MHZ SMD	Q1
1	ATMEGA328-AU-ND	IC MCU AVR 32K FLASH 32TQFP	U1
1	576-1261-1-ND	IC REG LDO 150MA 5.0V 1% SOT23-5	U2
1	CKN9104CT-ND	SWITCH TACT SMT SPST 160GF	S2
2	478-3859-1-ND	CAP TANT 10UF 16V 20% 1206	C13, C19

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4	311-1341-1-ND	CAP CERAMIC .100UF 25V X7R 0603	C1,C2,C3,C10
2	311-10KGRCT-ND	RES 10K OHM 1/10W 5% 0603 SMD	R2, R11
1	311-330GRCT-ND	RES 330 OHM 1/10W 5% 0603 SMD	R6
2	LNJ937W8CRACT-ND	LED BLUE HIGH BRIGHT ESS SMD	LED1, D3
1	v13 Eagle board files	Order PCB from DorkbotPDX	PCB

Table 7Table 7 shows the second dataset, which is publicly available and requires only a free registration, describing different components of the product called Arduino Leonardo microcontroller board. The table indicates the quantity of each element necessary for a board, device code or identifier, description of each device or component and part number on the board.

Table 7. *Components available in the product Arduino Leonardo microcontroller board [14].*

Quantity	**Device**	**Description**	**Parts**
6	C-EUC0603	CAPACITOR, European symbol	C1, C2, C6, C9, C13, C22
1	4R-NCAY16	Array Chip Resistor	RN1
1	R-EU_R0603	RESISTOR, European symbol	R4
3	CPOL-EUSMCB	POLARIZED CAPACITOR, European symbol	C8, C10, C12
1	PINHD-1X10	PIN HEADER	JP1
1	CRYSTAL-3.2-2.5		Y1
1	4R-NCAY16	Array Chip Resistor	RN2
1	R-EU_R0603	RESISTOR, European symbol	R1
4	C-EUC0603	CAPACITOR, European symbol	C5, C7, C11, C14
1	4R-NCAY16	Array Chip Resistor	RN3
2	C-EUC0603	CAPACITOR, European symbol	C3, C4
1	PINHD-1X6	PIN HEADER	J4
2	PINHD-1X8	PIN HEADER	J2, J3
1	ATMEGA32U4-XUAU		U2
1	ATMEGA32U4-XUMU		U1
1	DIODE-MINIMELF	DIODE	D2
2	VARISTORCN0603	VARISTOR	Z1, Z2
1	A3-FRAME		FRAME1
3	FIDUCIAL-1.5MM	Fiducial mount	FID1, FID2, FID3
4	TPTP-1.00MM	Testpoint	D+, D-, GND, VUSB
1	PMOSSOT23	MOS FET	T1
1	LEDCHIPLED_0805	LED	ON
1	PINHD-2X3	PIN HEADER	ICSP
1	LMV358MMX	Dual General Purpose, Low Voltage, Rail-to-Rail Output Operational Amplifiers	IC2
1	LP2985-XXDBVR33	ULTRALOW-POWER 50-mA LOW-DROPOUT LINEAR REGULATORS	U3
1	DIODE-SMB	DIODE	D1
1	L-EUL1812	INDUCTOR, European symbol	F1
2	WE-CBF_0805	SMD EMI Suppression Ferrite Beads	L1, L2
1	MC33269ST-3.3T3	Adjustable Output Low Dropout Voltage Regulator 800 mA	IC1
2	R-EU_R0402	RESISTOR, European symbol	R2, R3
1	POWERSUPPLY_DC21MMX		EXTPOWER
1	TS42	TS42	RESET
1	USB-MICRO-LEGACY		J1
3	LEDCHIPLED_0805	LED	L, RX, TX

5. Data integration

Ontology-based data integration (OBDI) has attracted the attention of many communities, from biomedical and life sciences to materials science and manufacturing. Widely used OBDI approaches are single ontology-based, multiple ontology-based and hybrid approaches [16]. In the single ontology-based approach, a global ontology represents concepts required for integrating all data sources; in the multiple ontology-based approach, a local ontology is required for each data source, and a mapping is established among local ontologies; and in the hybrid approach, an ontology with shared vocabularies is linked to each local ontology required for a data source [17][18]. As JIDEP has a common application ontology, OntoMPLC, that will be linked to each application-specific ontology covering the specificity of a data source, and our data integration problem naturally coincides with the hybrid approach. Therefore, we have selected the hybrid approach for integrating data from all use cases.

6. Conclusions

We have been monitoring and analysing the approaches and best practices applied in ontology modelling, knowledge-based tool development, ontology-centric rule creation, interoperability implementation, data sharing and data reusability by the EU-funded initiatives and EU and international organisations and standardisation bodies for their adoption in the JIDEP project. We have established cooperation with initiatives and organisations such as WeldGalaxy and EMMC. We have been collecting data from use case partners and online resources and observing the data platforms for the JIDEP use case-related data. We will monitor the activities of the International Data Space Association and establish cooperation with standardisation bodies such as the International Organisation for Standardisation (ISO), the European Committee for Standardisation (CEN) and the German Institute for Standardisation (DIN). The final version of this deliverable will report on our effort in establishing cooperation with standardisation bodies and further monitoring of data, ontology and interoperability-centric activities related to JIDEP, standardising data format for data-providing partners and data collection.

References

[1] WeldGalaxy. URL: https://cordis.europa.eu/project/id/822106. Accessed on 19 October 2023.
[2] WeldGalaxy Deliverable on Knowledge-Based Decision Rules Development.
[3] The European Materials Modelling Council (EMMC). URL: https://emmc.eu/. Accessed on 24 October 2023.
[4] The Elementary Multiperspective Material Ontology (EMMO). URL: https://emmo-repo.github.io/. Accessed on 24 October 2023.
[5] The Industrial Ontologies Foundry. URL: https://www.industrialontologies.org/. Accessed on 16 May 2023.
[6] Technical Principles of the Industrial Ontologies Foundry. URL: https://industrialontologies.org/technical-principles. Accessed on 16 May 2023.
[7] The Industry Commons Foundation. URL: https://digineb.eu/industrycommons. Accessed on 01/11/2023.
[8] The International Association for Ontology and its Applications. URL: https://iaoa.org/. Accessed on 01 November 2023.
[9] Material Passport. URL: https://www.vestas.com/content/dam/vestas-com/global/en/sustainability/environment/Blades-V47_Material_Passport.pdf, Accessed on 08 June 2023.
[10] GHERASIM, S.A., GĂITAN, A.M., GĂITAN, V.G. and POPA, V., 2010. New trend on OPC Middleware. Development and Application Systems, p.101.
[11] Valenzuela, E., Cano-Delgado, A., Cruz-Miranda, J., Rouret, M., Micciché, G., Ros, E., Arranz, F. and Diaz, J., 2023. The IFMIF-DONES remote handling control system: Experimental setup for OPC UA integration. *Fusion Engineering and Design*, *192*, p.113776.
[12] OPC 10000-1: UA Part 1: Overview and Concepts. URL: https://reference.opcfoundation.org/v104/Core/docs/Part1/. Accessed on 12 May 2023.

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[13] Arduino Pro Mini v12-v13 BOM. URL: https://docs.google.com/spreadsheets/d/1e3_5RCiRMwfnI58NtatPzVlbQhpfDYwknAkj7e6M3nQ/edit#gid=0. Accessed on 02/11/2023.

[14] Arduino Leonardo. URL: https://www.pcbway.com/project/shareproject/Arduino_Leonardo_1e9aa47e.html. Accessed on 02/11/2023.

[15] Blade Material Passport. URL: https://www.lmwindpower.com/sites/default/files/related_documents/LM-37_3-P2-Blade-Material-Passport_DecomBlades-project.pdf. Accessed on 08 June 2023.

[16] Stuckenschmidt, H. and Van Harmelen, F., 2005. Information sharing on the semantic web. Springer Science & Business Media.

[17] Ekaputra, F., Sabou, M., Serral Asensio, E., Kiesling, E. and Biffl, S., 2017. Ontology-based data integration in multi-disciplinary engineering environments: A review. Open Journal of Information Systems, 4(1), pp.1-26.

[18] Chang, X. and Terpenny, J., 2009. Ontology-based data integration and decision support for product e-Design. Robotics and Computer-Integrated Manufacturing, 25(6), pp.863-870.

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