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Contents

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1. Executive Summary

This is the second and the final version of the deliverable (D2.3) on refined and extended domain-specific ontologies in the context of the JIDEP project. It documents both the beta version of the deliverable (D2.3 - Beta) and the final version of the deliverable (D2.3 - Final) which extends the D2.3 - Beta with two major additions. To that end, the D2.3 - Beta had two explicit goals: (i) surveying and selecting the state-of-the-art reference ontologies that can potentially be reused and extended within JIDEP, and (ii) a process grounded in taxonomic analysis following which the ontologies selected in (i) can be refined by annotating and extending them to represent knowledge on materials, especially composite materials, products manufactured using these engineered materials and manufacturing process of such materials. It detailed: (i) a selection of a first set of state-of-the-art reference ontologies that can potentially be reused and extended within JIDEP (e.g., EMMO, CHAMEO), (ii) the preliminary version of composite materials teleontology called OntoCompMat developed in JIDEP, and (iii) the first version of a knowledge annotation methodology grounded in taxonomic analysis towards refining and extending domain-specific ontologies (e.g., teleontologies) partially implemented with early results in terms of the resources engineered following the methodology. As an extension to the above beta version, the final version (D2.3 - Final) of the deliverable includes the following: (i) an extended and more detailed reference of how the JIDEP teleontology aligns to the EMMO reference teleontology and the relevant ISO standards, and (ii) the lexical-semantic annotation of the above JIDEP teleontology following the process detailed in the D2.3 - Beta.

2. Introduction

a. Scope of the Document

The scope of this JIDEP deliverable on refining and extending domain-specific ontologies includes: (i) the stratification of knowledge representation - teleology and teleontology (backed by reference ontologies) - that is proposed in the context of representing knowledge (e.g., of materials in the JIDEP project), (ii) an overview of the proposed reference ontology named the *Universal Knowledge Core (UKC)*, (iii) the state-of-the-art teleontologies in materials modelling domain, (iv) a concrete knowledge resource developed in the context of the JIDEP project named – Materials Passport, and (v) the annotation process by which the sense of the concepts modelled in the knowledge resources (e.g., teleontologies) are disambiguated to make them reusable multilingual reference knowledge schemas for the materials modelling domain. In the context of the JIDEP project, the aforementioned annotation process can be potentially applied to produce reusable reference knowledge resources (e.g., teleontologies) representing materials, composite materials as well as electrical and mechanical components to be used or recycled by the final users as described by the project use cases.

b. Intended Audience

The intended audience for this report within the context of JIDEP is as follows:

- Domain Experts: subjects involved in the project, having major competencies in the domain of interest of materials modelling as considered by the JIDEP project application use cases. As part of the iTelos methodology, these subjects support more technical roles during the data and schema modelling.

- Knowledge Engineers: technical subjects involved, as part of the overall JIDEP data and knowledge modelling process, by acting over the knowledge management activities (e.g., teleology modelling, teleontology modelling, etc.).

c. Updates with respect to the Beta Version

The final version of the deliverable documents two major extensions over and above the beta version of the deliverable. First, it includes detailed references as to how the JIDEP teleontology is aligned to the EMMO reference teleontology and to some of the relevant ISO standards in the materials science domain. This is key to formally represent and integrate data, knowledge and metadata about different concepts within the composite materials ecosystem. Second, it includes examples and illustrations of the JIDEP composite materials domain namespace and the annotated JIDEP teleontology following the teleontology annotation process developed in the D2.3 - Beta. This is key to disambiguate the precise senses of the concepts modelled in the JIDEP teleontology and also to facilitate the reuse and extension of such concepts in future research endeavours.

3. Stratified Representation

We propose a general, domain-agnostic stratified knowledge modelling formalism founded in the Teleosemantics theory of meaning [1,2]. The representation layers of the proposed formalism are listed and briefed as follows.

1. We introduce *Teleologies*, i.e., ontologies which, given a set of modelling needs, encode the interaction amongst concepts, via relationships and attributes, within a specific spatiotemporal boundary. Teleologies illustrate how entities interact within such a boundary and are each individually described. This becomes key as to how and when teleologies can be reused.

2. We introduce *Teleontologies* as ontologies that ground teleologies into the overall linguistic *reference ontology,* thus enhancing their shareability and reusability by making the teleological concepts consensual and unambiguous.

3. The overall linguistic *reference ontology* - the *Universal Knowledge Core (UKC)* [3,4], an expandable multilingual lexical-semantic knowledge base comprising natural language and domain-specific concepts and words.

4. Given teleontologies, *schemas* are generated for a specific application purpose (e.g., annotating and integrating data in the materials domain) and usually have a set of free attributes relevant to the application purpose considered.

5. The final representation layer concerns the cleaned and well-formatted *datasets,* crucial to generating the schema by contributing the important application-specific free attributes. This layer, however, is not the focus of this version of the deliverable.

In the following paragraphs and section, we now elucidate the above notions of teleology, teleontology and reference ontology in greater detail.

A *teleology* has been defined in [2] as an explicit representation of the concepts in a domain (e.g., materials) with the additional feature that, quoting [ER], “teleologies focus on the function” and are modelled according to how a chosen representation fits a specific purpose (e.g., a materials teleology focused on composite materials, a materials teleology focused on polymer materials, etc.). A teleology models the interrelations amongst the (various instantiations of) the concepts of a domain according to a purpose, and in doing so, it always commits to a fixed spatiotemporal boundary. This is crucial as there can be infinite combinations of teleological representations for even the same spatiotemporal extent. Additionally, a teleology is dependent on the modelling needs often formalized via Competency Questions (CQs), based on which the concepts in a teleology are described via data properties and related via object properties. The relations between concepts in a teleology can be spatial or temporal, or mereological in nature. Spatial relations such as locatedIn, near, etc., are often required to model the spatial positioning amongst concepts in a teleology. Temporal relations such as before, after etc., can often be necessary to model the temporal dynamicity amongst concepts. The mereological relations, e.g., spatialPartOf, are employed to capture the part-whole relationship, if any, amongst the objects in the teleology (e.g., amongst the different systems and subsystems of an automobile).

Given a teleology, a *teleontology* is the conceptual model generated by grounding a teleology in the chosen linguistic *reference ontology* - the UKC [3,4], wherein the focus of the reference ontology is to model domain appropriateness which, in other words, means capturing the shared consensus of a community of practice about a (part of a) domain of discourse. The notion and proposed use of teleontologies are crucially founded in the modelling assumption that the representation of what exists in a domain of reality should, *a fortiori*, be chosen based on the representations generated by what changes in an instantiation of a situation in that domain. Given the generation of teleology by interrelating and describing concepts as described above, the reference ontology UKC is suitably enriched by either reusing or composing relevant fragments of different domain ontological concepts (for instance, from relevant fragments of EMMO [5,6], CHAMEO [7], etc.).

There are two observations. Firstly, all the teleontologies built according to the definition above are pushed into the repository supporting the LiveKnowledge catalog [8] so that a continuous cycle of reuse and reengineering is established vis-a-vis teleontologies. Secondly, the modelling needs come from application-targeted user requirements in the form of CQs. Notice that the stratification of layers elucidated above is the knowledge representation foundation of our overall methodology called *iTelos* [9].

As a concrete JIDEP use case example for the aforementioned stratification of knowledge modelling, we consider, as input purpose, the JIDEP project's objective as the need to create a Knowledge Graph with material passports of products and components, where raw materials, such as a certain quantity of carbon fibre extracted from an automotive monocoque, being considered as products. Considering this objective, the following input data were collected from the automotive data-providing partners, and schema resources were created by the data processing and harmonisation partner.

The input data resources consist of 800 grams of carbon epoxy, 352 grams of polyurethane, 56 grams of glass epoxy and 350 grams of aluminium in a cross beam of a monocoque. The monocoque has eight equal dimension and weight cross beams, four on the right-hand side, 1RH-4RH and four on the left-hand side, and 1LH-4LH, supplied by ADL partner.

The input knowledge resources, specifically at the teleological level, include the material passport properties defined to describe products, components and their constituent materials to enable the development and publishing of material passports to develop a material circularity calculator to promote a circular economy. The material passport includes the identification properties of products and components, such as name, brand/trade name, manufacturer details, the global trade item number (GTIN) or European article number (EAN), functionality and image. It also covers physical, temporal, thermal, biological, temporal, and compositional properties. The following properties of products and components are included in their material passports:

1. Identification Properties
    a. Name
    b. Level (It can be 1, 2, 3, etc. For example, while providing input about monocoque, which can be represented as a product, the user will assign 1, but for cross beam 1RH, which is a component of monocoque, the user will assign 2)
    c. Part of (A component can be part of another product/component. For example, cross beam 1RH is part of monocoque)
    d. Trade name
    e. Brand name
    f. Manufacturer
    g. Manufacturer name
    h. Registration number
    i. Registration country
    j. GTIN
    k. EAN
    l. Functionality
    m. Automatic tracking/scanning
    n. Image
    o. URL
2. Physical Properties
    a. Density [g/cm-3]
    b. Dimension
    c. Height [cm]
    d. Width [cm]
    e. Length [cm]
    f. Resistance
    g. Compressive strength [Pa]
    h. Shear strength [Pa]
    i. Tensile strength [Pa]
    j. Rigidity
    k. Shear modulus [Pa]
    l. Young's modulus [Pa]
    m. Mass [g]
3. Thermal Properties
    a. Heat transfer coefficient
    b. Thermal conductivity [W/(m-K)]
4. Temporal Properties

   a. Expected lifetime [y]
   b. Service life [y]
5. Biological Properties
   a. Biodegradability
   b. Decomposability
6. Compositional Properties
   c. Chemical composition
   d. Ingredient [g]
   e. Recycled content [g]

4. Universal Knowledge Core (UKC) - The Reference Ontology

This section describes the *general architecture* of the reference ontology - the Universal Knowledge Core, proposed as the linguistic *reference ontology*. The Universal Knowledge Core (UKC) is a large-scale, multilingual lexical-semantic reference ontology. The UKC has two component layers - the Language Core and the Concept Core. The linguistic information of the UKC is organized in the Language Core. Thus, we have:

- Words which name things which exist in reality (e.g., in the materials domain),
- Synsets which store, for each word, its set of synonyms,
- Senses which map words to their relative synsets,
- Glosses which are natural language descriptions of the intended meaning of the set of words in the corresponding synset, and,
- Examples which are associated with glosses exemplify the meaning.

The UKC supports multiple languages, and each synset in the UKC has a unique identifier. However, as mentioned earlier, the UKC also features a conceptual layer - the Concept Core - fully separated from language. In this layer, concepts are associated with unique identifiers (ids) and are connected to language in one of three possible ways:

- The concept id is mapped (one-to-one) to a synset identifier, which means that that concept is lexicalized in that language or,
- The concept id is declared to be a lexical gap for that language, which means that that concept is not lexicalized in that language, or,
- The concept id is not mapped, which means we do not know the case.

It is possible to add a new concept only if there is at least a natural language where it is lexicalized. Furthermore, the various lexical-semantic relations (e.g., hypernym, meronym) are embedded in the conceptual layer and connect concept ids rather than synset ids. The conceptual layer is a semantic layer which provides a very powerful means for studying the diversity of domain reference ontologies while enabling language-independent reasoning, as needed, for instance, in cross-lingual and language-independent applications.

Figure (1) presents the UKC's organizational structure. Here, the English word bike has two meanings – one as a verb and the other as a noun – represented by two single-word synsets connected to the corresponding Italian words through their reference concepts.

We have a lexical gap in Italian as there is no word for the verb to bike. The two concepts, in turn, are connected in the graph of concepts.

The UKC is in continuous evolution and enrichment. There are two modalities in which the UKC can be enriched. Firstly, it can be populated via the import of freely available lexical resources, e.g., WordNets or dictionaries, which are first evaluated to satisfy specific minimum quality requirements, or via user input. Secondly, more relevant to the purpose of this deliverable, the UKC can also be enriched by a dedicated process whereby concepts and taxonomic hierarchies from domain-specific reference (tele)ontologies are imported into the UKC as domain languages.

Therefore, the UKC is critical to modelling teleontologies in two ways. Firstly, the UKC aids the teleontology modeler, a priori, to name (via words) the concepts they want to model in a (domain) teleontology, thereby, helping significantly in ascertaining what ontologically exists in a domain. Secondly, due its very design, the UKC acts as a top-level reference ontology semantically interrelating and interoperating amongst all possible teleontologies that can ever be built, e.g., in the materials domain.

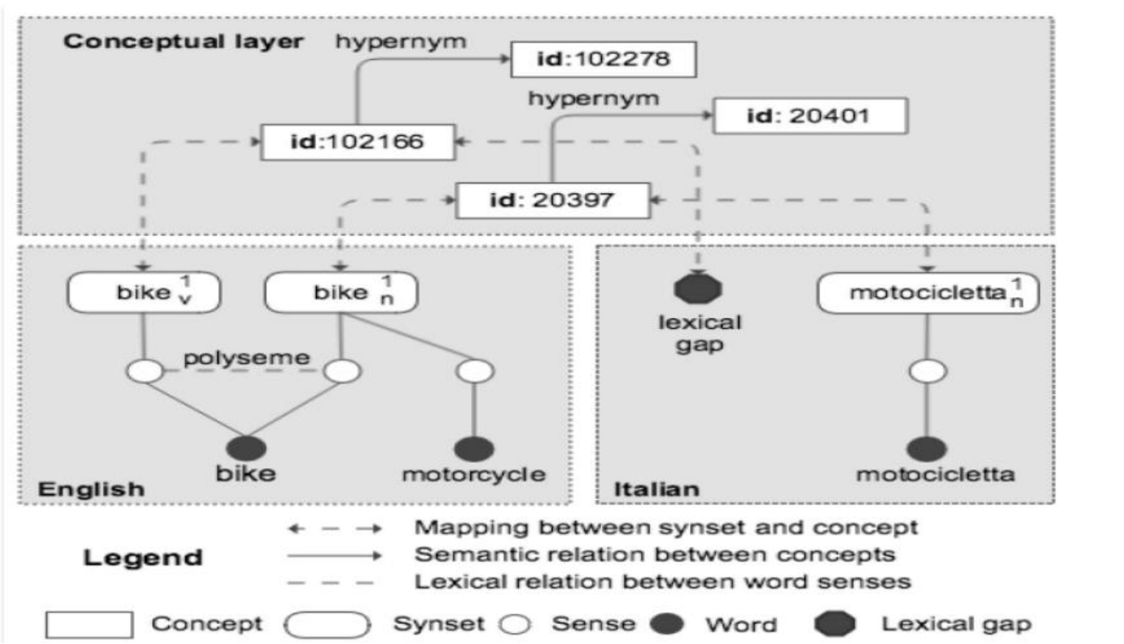

Figure 1. An exemplification of the UKC representation layers.

As of today, the UKC contains 2371 languages, 1887948 words, 2757170 senses, and more than 110579 concepts where, as should be expected, no concept is lexicalized in all languages.

5. Reference Teleontologies in Materials Modelling

We consider, in this version of the deliverable, the following reference teleontologies

- ***European Materials Modelling Ontology (EMMO)*** [5,6], an ontology focused on the materials modelling domain, was created by the European Materials Modelling Council (EMMC).

- ***OntoCompMat*** is an ontology developed by the University of Cambridge in collaboration with the University of Trento and Technovative Solutions in the context of JIDEP for describing composite materials.
- ***CHAMEO Ontology*** [7] is a reference ontology for the description of materials characterization procedures, providing definitions at the methodological level.
- ***Mechanical Testing Ontology*** [10], an application of the EMMO to the field of mechanical testing.

European Materials Modelling Ontology (EMMO): EMMO is a reference ontology for materials modelling developed as a multidisciplinary outcome of European Materials Modelling Council (EMMC). It offers a standard representational framework (the ontology) based on the latest materials modelling knowledge, including physical sciences, analytical philosophy and information technologies. The multidisciplinary basis of the EMMO is illustrated in Figure (2). It also describes how the EMMO interconnects the physical and materials characterization and modelling worlds. The various dimensions of materials characterization which the EMMO models are as follows (see also Figure (3)):

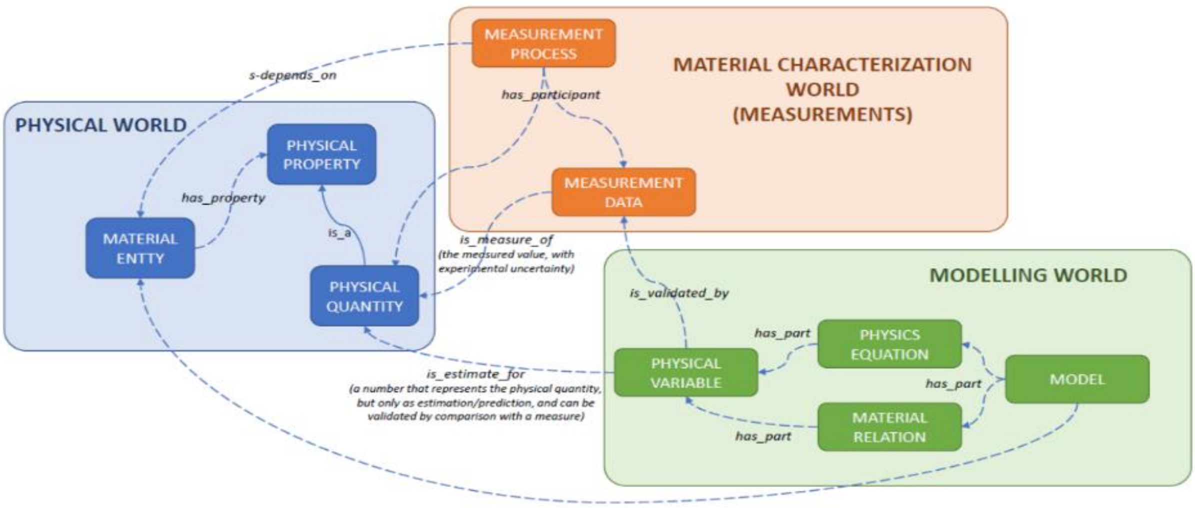

Figure 2. How EMMO interconnects the Physical, Material and Modelling Worlds.

- The multiple aspects of the material itself must be described in a detailed way via appropriate attributes
- The observation process involves an observer that perceives the real world (characterization)
- The properties of a material that are measured or modelled
- The physics laws that describe the behaviour of a material under consideration for modelling
- The physical models that approximate the physics laws with respect to the reference materials modelling domain
- The solver, including the numerical discretization method, leads to a solvable mathematical representation under certain simplifying assumptions
- The numerical solver that performs the calculations

- The post processing of experimental or simulated data

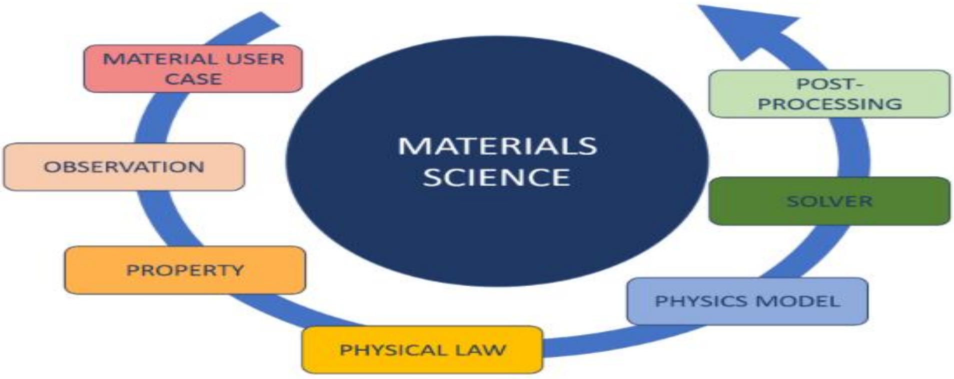

Figure 3. The EMMO modelling dimensions.

EMMO Top-Level: The top level of the EMMO ontology (see Figure (4)) models the fundamental axioms that constitute the interdisciplinary philosophical foundation of the EMMO. Adopting a physicalistic/nominalistic perspective, the EMMO defines real world objects as four dimensional (i.e., 4D) objects that are always extended in space and time (i.e., real world objects cannot be spaceless nor timeless). For this reason, abstract objects, i.e., objects that does not extend in space and time, are forbidden in the EMMO.

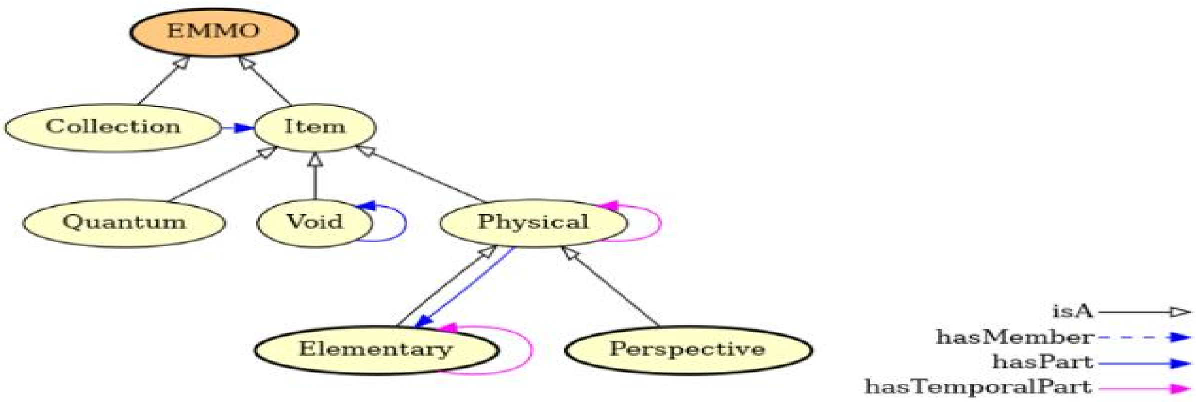

Figure 4. The EMMO Top-Level.

The EMMO ontology is foundationally grounded in the analytical philosophy discipline of semiotics. The role of abstract objects in EMMO are satisfied by semiotic objects, i.e. real world objects (e.g., symbol or sign) that stand for other real-world objects that are to be conceptually interpreted by an agent. These symbols appear in actions (semiotic processes) meant to communicate meaning by establishing relationships between symbols (signs). Additionally, another crucial building block of the EMMO from the discipline of analytical philosophy is atomistic mereology applied to 4D objects. The EMMO calls it 'quantum mereology', since there is always an epistemological limit to how fine we can resolve space and time due to the uncertainty principle.

The mereotopology module of the EMMO ontology introduces the fundamental mereotopological concepts and their relations with the real-world objects that they represent. The EMMO uses mereotopology as the foundational ground for all the subsequent ontology modules. The concept of topological connection is used to define the initial distinction between ontology entities namely the Item and Collection classes. Items are defined as causally self-connected objects, while collections are characterized as causally disconnected. Quantum mereology is represented in the EMMO ontology by the Quantum class. This module also introduces the fundamental mereotopological relations used to distinguish between space and time dimensions.

The physical module of the EMMO ontology defines the physical objects and the concept of Void is crucial for EMMO as it plays a fundamental role in the description of multiscale objects and quantum systems. It also defines the Elementary class, which restricts mereological atomism in space.

In EMMO, the only univocally defined real-world object is the Item individual called Universe which stands for the universe. Every other real-world object is a composition of elementary up to the most comprehensive object; the Universe. Intermediate objects are not univocally defined in the EMMO, but their definition is provided according to some specific philosophical perspectives. This is an expression of reductionism (i.e. objects are made of sub-objects) and epistemological pluralism (i.e. objects are always defined according to the perspective of an interpreter, or a class of interpreters).

The Perspective class collects the different ways to represent the objects that populate the conceptual region between the elementary and universe levels.

EMMO Middle-Level: The middle level ontological hierarchies of the EMMO (see, Figure (5)) act as roots for extending EMMO towards specific application domains and use case scenarios. The Reductionistic perspective class uses the fundamental non-transitive parthood relation, called direct parthood, to provide a powerful granularity description of multiscale real-world objects. The EMMO can in principle represent the Universe with direct parthood relations as a direct rooted tree up to its elementary constituents.

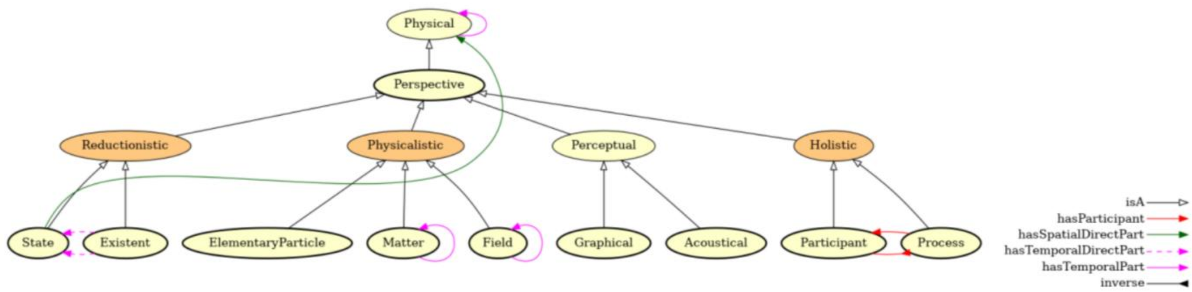

Figure 5. The EMMO Middle-Level Perspectives.

The Phenomenic perspective class introduces the concept of real-world objects that express a recognisable pattern in space or time that impresses the user. Under this class the EMMO categorises e.g., formal languages, pictures, geometry, mathematics and sounds. Phenomenic objects can be used in a semiotic process as signs.

The Physicalistic perspective class introduces the concept of real-world objects that have a meaning for the under applied physics perspective. The Holistic perspective class introduces the concept of real-world objects that unfold in time in a way that has a meaning for the EMMO user, through the definition of the classes Process and Participant. The semiotics module introduces the concepts of semiotics and the Semiosis process that has a Sign, an Object and an Interpreter as participants. This forms the basis in EMMO to represent e.g. models, formal languages, theories, information and properties.

***OntoCompMat*:** In JIDEP, we modelled the domain knowledge of composite materials in an ontology called OntoCompMat. To achieve interoperability, OntoCompMat is reusing EMMO by applying the technique of ontology import. Composite material is also called composite. As shown in Figure 6, composite has several subclasses, including composite based on matrix material, composite based on reinforcement type, composite based on the manufacturing process, composite based on the orientation of reinforcement, composite based on the functional requirement, composite based on resin type, composite based on the type of fibre and composite based on structure. Composite based on matrix material has multiple subclasses, including polymer matrix composite (PMC), metal matrix composite (MMC) and ceramic matrix composite (CMC). Composite based on reinforcement type has subclasses such as fibre-reinforced composite (FRC) and particulate-reinforced composite. Composite based on manufacturing process has many subclasses, including hand lay-up, pultrusion, filament winding, injection moulding, resin transfer moulding (RTM), compression moulding, vacuum infusion and autoclave. Composite based on the orientation of reinforcement has several subclasses, such as longitudinal orientation, transverse orientation, random orientation and uni-directional orientation.

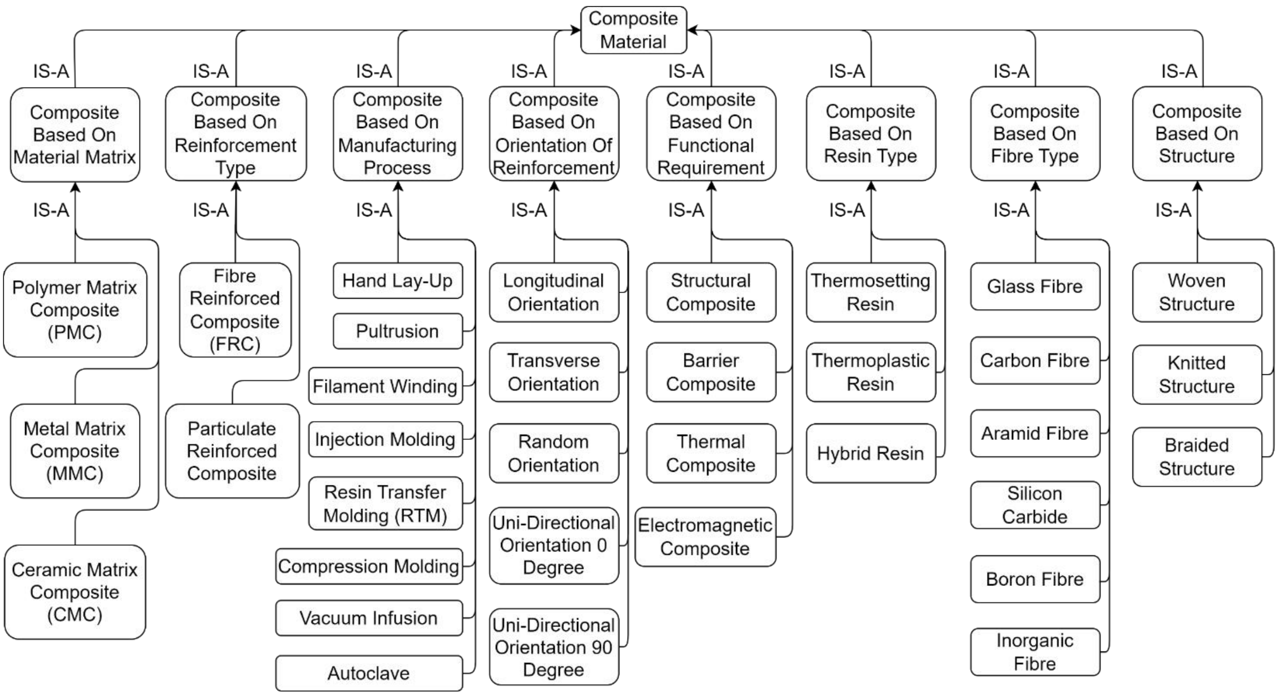

Figure 6. A fragment of OntoCompMat.

Composite based on functional requirement is classified into structural, barrier, thermal, and electromagnetic. Composite based on resin type is classified into the thermosetting, thermoplastic, and hybrid resin. Composite based on the type of fibre is classified into glass fibre, carbon fibre, aramid fibre, silicon fibre, boron fibre and inorganic fibre. Composite based on the structure has several subclasses, including woven, non-woven, knitted, and braided structures.

The OntoCompMat ontology also included the modelling of manufacturing aspects. Composite manufacturing processes include the wet lay-up process, resin transfer moulding process, pultrusion process, filament winding process, compression moulding process, injection moulding process, vacuum infusion process and autoclave process. The wet lay-up process has two subclasses: hand lay-up and spray lay-up. The resin transfer moulding process has two subclasses: closed mould RTM and open mould RTM. The filament winding method has the following subclasses: axial filament winding, helical filament winding and radial filament winding. The compression moulding process has two subclasses: hot press and vacuum-assisted compression moulding. The injection moulding process has the following subclasses: reaction injection moulding (RIM), structural reaction injection moulding (SRIM) and resin transfer injection moulding (RTIM). The autoclave process is classified into high-pressure autoclave moulding and high-temperature autoclave moulding.

OntoCompMat - EMMO and ISO Alignments (Updates with respect to the Beta Version):

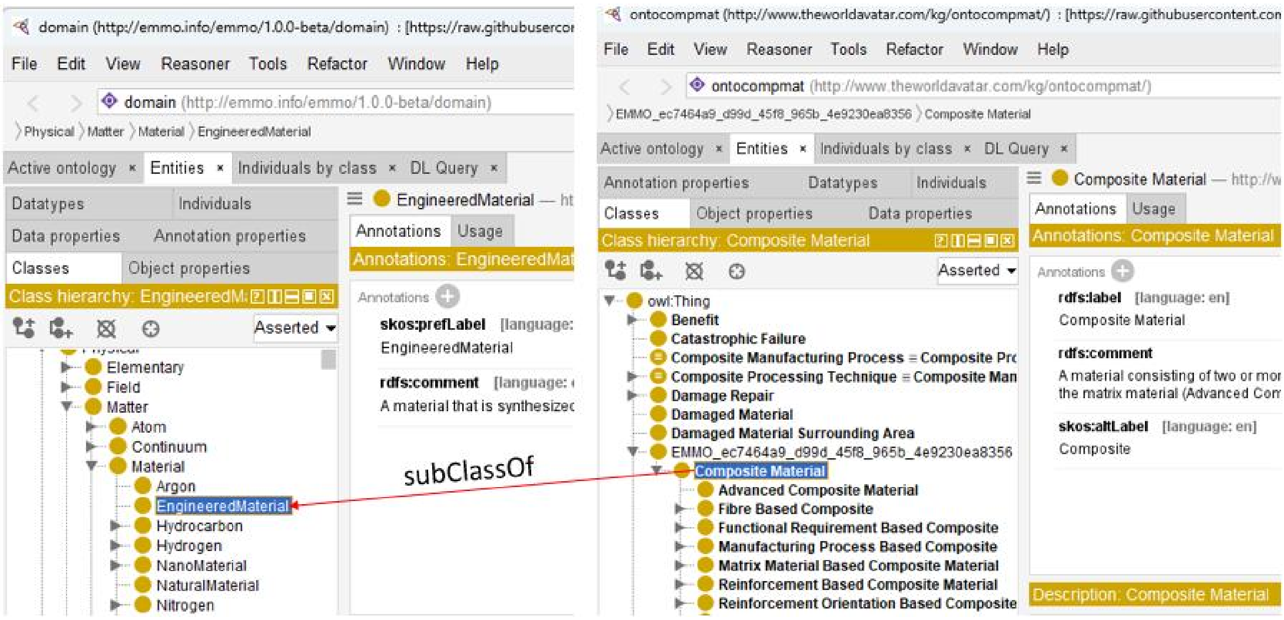

Figure 7. A subclass of relationship is established between the Composite Material concept of OntoCompMat and the Engineered Material concept of EMMO.

We performed an in-depth taxonomical and ontological analysis of the EMMO reference teleontology (see here) to identify the mapping between this ontology and the JIDEP OntoCompMat domain ontology. This was undertaken in collaboration with the developers of the EMMO. The key objective was to determine the exact concept within the EMMO which can serve as the root concept of the concept of “composite material” as modelled in the JIDEP teleontology. The outcome of the analysis was that the Composite Material class of OntoCompMat is a subclass of the Engineered Material class in EMMO (see Figure (7)). EMMO defines an engineered material as a “material that is synthesized within a manufacturing process”. To that end, the notion of composite materials as modelled in the JIDEP teleontology is a type of engineered material (i.e., CompositeMaterial - IS-A - EngineeredMaterial).

In Table 1, we describe the mapping of classes and properties required for representing data in JIDEP with the most relevant community-specific standard, ISO 10303, specialised for product data representation and exchange. The standard describes data modelling as an entity, schema, or attribute which will be used to improve and enable data interoperability and shareability in this project.

JIDEP data representation requirement	Standard meets the requirement	Description
Product	ISO 10303-41	A product is defined as an entity in ISO 10303-41.
Product.Identifier	ISO 10303-41	The identifier of a product. Product.id is defined as an attribute in ISO 10303-41.
Product.Name	ISO 10303-41	The name of a product. Product.name is defined as an attribute in ISO 10303-41.
Product.Description	ISO 10303-41	The description of a product. Product.description is defined as an attribute in ISO 10303-41.
Product.Trade_name	-	The trade name of a product
Product.Brand_name	-	The brand name of a product
Product.GTIN	-	Global Trade Identifier Number
Product.EAN	-	European Article Number
Product.Functionality	-	The functionality of a product
Product.Automatic_tracking_or_scanning	-	If the automatic tracking or scanning is supported by the product
Product.Level	-	The position of a product or component within a product-component part of hierarchy
Product.Part_of	-	Refers to the parent product
Product.Image	-	The image of a product
Image.URL	ISO 10303-41	The URL of an image. URL is described as a derived attribute of the address entity in ISO 10303-41.
Product.Manufacturer	-	The manufacturer of a product
Manufacturer.Name	ISO 10303-41	The name of a manufacturer. We will apply the name attribute described in the organisation entity

JIDEP data representation requirement	Standard meets the requirement	Description
		in ISO 10303-41.
Manufacturer.Registration_number	-	The registration number of a manufacturer
Manufacturer.Registration_country	ISO 10303-41	The country where the manufacturer is registered. Country is defined as an attribute in the address entity in ISO 10303-41.
Product.Physical_property	ISO 10303-41	The physical property of a product. The measure schema describes the physical quantities in ISO 10303-41.
Physical_property.Density	ISO 10303-41	The density of a product. Density is described as a kind of physical quantity in ISO 10303-41.
Physical_property.Dimension	-	The dimension of a product
Dimension.Height	ISO 10303-42 [36]	The height of a product. Height is an attribute of the data type positive_length_measure in ISO 10303-42.
Dimension.Width	-	The width of a product
Dimension.Length	ISO 10303-41	The length of a product. Length is described as a kind of physical quantity in ISO 10303-41.
Physical_property.Resistance	-	The resistance of a product
Resistance.Compressive_strength	-	The compressive strength of a product
Resistance.Shear_strength	-	The shear strength of a product
Resistance.Tensile_strength	-	The tensile length of a product
Physical_property.Rigidity	-	The rigidity of a product
Rigidity.Shear_modulus	-	The shear modulus of a product
Rigidity.Young's_modulus	-	The Young's modulus of a product
Physical_property.Mass	ISO 10303-41	The mass of a product. The mass measure is described in ISO 10303-41 as the quantity of matter or substance that a body contains.
Component	ISO 10303-41	Product, class of products and component are represented using

JIDEP data representation requirement	Standard meets the requirement	Description
		the product entity in ISO 10303-41.
Material	ISO 10303-1771	Material is defined in ISO 10303-1771 as one or more substances used to manufacture a product.

Table 1. Mapping between the JIDEP generic application ontology and ISO 10303

CHAMEO: The diversity and complexity of materials used in different application domains led to the formation of multiple communities of practice around knowledge modelling of the materials characterisation field, establishing different terminologies typically focusing on specific application domains intersecting one or more of the aforementioned communities. CHAMEO, an acronym for *CHAracterization MEthodology Ontology* (see, Figure (8), for a snapshot of the CHAMEO ontology), is an ontology developed to harmonize the characterization methodologies used in materials science. It aims to provide a standardized reference vocabulary that can be used to describe the different materials characterization techniques and the properties of materials that are being analyzed.

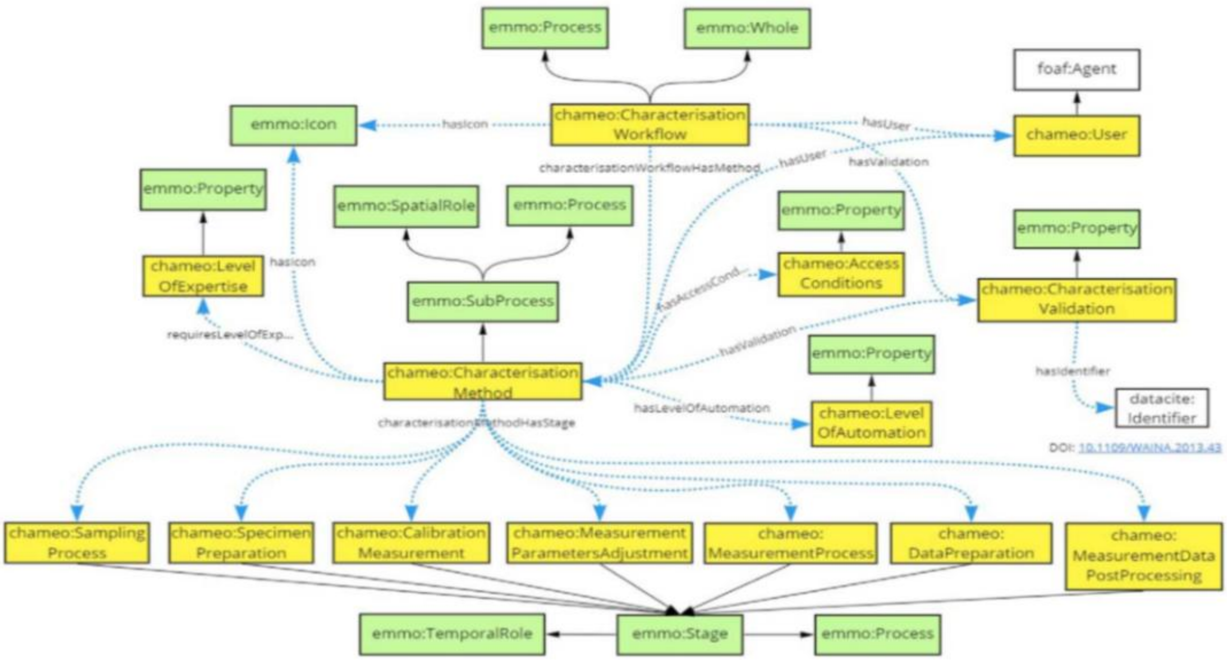

Figure 8. A fragment of CHAMEO

The ontology was developed and contextualized through a process of expert consultation, literature review, and analysis of existing ontologies in the materials modelling domain. The development of CHAMEO has been carried out under the European project NanoMECommons. The core purpose of CHAMEO is to support the knowledge representation of data-driven structure-property relationships and thus, ultimately, assist the quality assurance and material design procedures in industry. CHAMEO is expected to bring about semantics-based standards for materials characterisation and to contribute directly to Industry Commons, i.e. facilitating reusability and transferability of materials characterisation data across multiple manufacturing sectors.

We describe below some of the core concepts that are represented in CHAMEO (see, partially, in the aforementioned fragment of CHAMEO in Figure (8)). Notice that there are several other representational constructs (i.e., classes and properties) of CHAMEO (also including concepts from EMMO and FOAF), only a selection of which are described as follows.

- chameo:CharacterisationWorkflow: This class codifies the overall characterisation workflow that can be a composition of different methodologies used to obtain the final property of a material. The Characterisation Workflow can have a graphical representation, represented by emmo:Icon (coming from the EMMO; described above), linked through the EMMO object property - emmo:hasIcon. This CHAMEO class is defined as a subclass of the more abstract EMMO concepts of emmo:Process and emmo:Whole. The latter concept, i.e., emmo:Whole, is part of the overall holistic perspective of EMMO and is used to represent an entity which is defined according to a unity criteria that represents the relation of its parts to form a whole.
- chameo:CharacterisationMethod: This concept is employed to encode a specific characterisation method that is defined as a subclass of the more abstract EMMO concepts - emmo:Observation and emmo:SubProcess (being it a sub-processof the overall workflow and then a spatial part of it as a whole). For each characterisation method (encoded via this concept), there exists the possibility for the ontology modeller to *not only* specify a required level of expertise (chameo:LevelOfExpertise through chameo:requiresLevelOfExpertise) *but also* whether there is a certain level of automation (chameo:LevelOfAutomation through chameo:hasLevelOfAutomation). The characterisation method for materials modelling can be typically made up of several stages, such as, for instance, manufacturing process, sampling process, speimen preparation, calibration process, measurement, data preparation, data post processing (most of which are representational constructs encoded in CHAMEO).
- chameo:User: This is the representational construct of EMMO which encode and represent the users participating in a materials characterisation method, defined as a subclass of the more general class foaf:Agent. Each of the materials characterisation method can be run by a different user, since for each method a different expertise can be required.
- chameo:CharacterisationValidation: This representational construct can be employed to model the scientific validation of the materials characterisation technique that has been adopted for a specific case can be specified both for a single method or for the overall materials characterization workflow, using the hasValidation object property. The datatype property *hasPeerRevArt* allows to model, for each instance of chameo:CharacterisationValidation, the reference to a research paper that validates the approach (e.g. referring to a Document Object Identifier).

Following the established conventions in ontology development, concepts from existing ontologies have been reused when possible for developing the CHAMEO ontology.

Besides, the CHAMEO ontology also encodes very general aspects of the materials characterisation methodology and therefore requires alignment with other ontologies for particular application cases. Some of such ontologies are listed as follows.

- A set of EMMO-aligned domain ontological models have been designed to be integrated into the Open Innovation Environment (OIE), a web-based platform that enables share, exchange and ultimately reuse of ontological models and information across European Materials Science community members. These ontologies are known as OIE ontologies [Ref] and the CHAMEO ontology refers to some concepts about manufacturing, materials, models and software from the OIE ontologies.
- The concept of foaf:Agent from the Friend-Of-A-Friend (FOAF) ontology [11] has also been referenced to in the CHAMEO ontology.
- Some metadata specific concepts (e.g., licence) Dublin Core (DC) ontology [12], developed and curated by the Dublin Core Metadata Initiative has been reused by the CHAMEO ontology.
- The DataCite Ontology [13] has been referenced and reused to add scientific references for the validation of a specific materials characterisation method or the overall characterisation workflow. More precisely, the CHAMEO class CharacterisationValidation, for which a human-readable description can be provided, has a unique identifier, modelled by the datacite:Identifier class, through the datacite:hasIdentifier property. This identifier can belong to a specific bibliographic scheme, datacite:ResourceIdentifierScheme (e.g. DOI, ISBN, ISNN).

The CHAMEO ontology was also natively developed in alignment to the FAIR -Findable, Accessible, Interoperable, and Reusable - principles [14]. To that end, the CHAMEO ontology has a resolvable URI and also has a persistent URL, version IRI and namespace with prefix. CHAMEO's metadata is also accessible and can be retrieved via HTTP's standard open communication protocol via the ontology's URI or permanent URL. The interoperability of the CHAMEO ontology has been ensured by designing it following appropriate technologies from the W3C's semantic technology stack (e.g., RDF, RDFS, OWL) and also, by referring and aligning it to concepts from other W3C-compliant ontologies (e.g., EMMO, FOAF, DC).

Mechanical Testing Ontology: The Mechanical Testing Ontology proposes the development of a formal vocabulary, or ontology, for describing mechanical testing in the context of digital-twin technology. The goal is to improve the accuracy and efficiency of mechanical testing by providing a standardized way to represent and integrate data and models from different sources.

Mechanical testing is an essential process for evaluating the properties of materials and systems under mechanical loads. It involves applying different types of loads, such as tension, compression, or bending, to a material or system and measuring its response to these loads. The results of mechanical testing are critical for designing and optimizing many products, ranging from aeroplanes and cars to medical devices and construction materials.

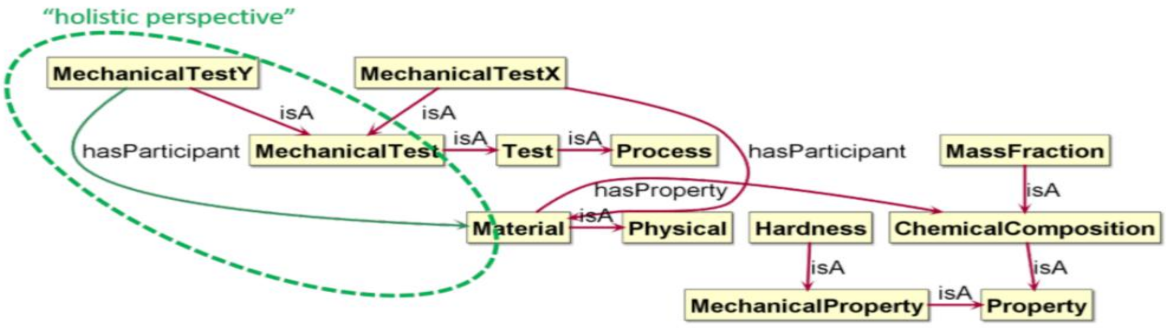

Figure 9. An excerpt from the Mechanical Testing Ontology

The proposed ontology is based on the EMMO (European Materials Modelling Ontology) framework, which is an ontology designed for materials science. EMMO provides a formal vocabulary for describing materials and their properties, and it enables the integration of data and models from different sources. The research in [10] presents a roadmap for developing and evolving the mechanical testing ontology, which involves a dedicated methodology covering several steps.

The first step of the methodology was to conduct a feasibility study about the particular domain dimensions within materials modelling for which an EMMO compliant ontology should be developed - in this case, the mechanical testing domain dimensions.

The second step of the mechanical testing ontology development process was to conceptualize the semantic model underlying the mechanical testing ontology which, mandatorily, should support the representation of a mechanical testing process that can be used to computationally model the mechanical tests and the material defined by its properties before, during and after the mechanical tests for the particular application case.

The third step of the development of the mechanical testing ontology was to concretely identify the relevant concept terms and the relationships interconnecting them that need to be included in the ontology (see, Figure (9) for an excerpt of the Mechanical Testing Ontology). This involves defining classes and properties that describe the relationships between the concepts. This includes concepts such as material properties, testing methods, measurement units, process, chemical composition and mass fraction. For example, a class is defined to represent a specific type of mechanical test, and properties might be defined to represent the various properties of the Mechanical Testing Ontology

The fourth step of the mechanical testing ontology development is to categorize the domains and applications within the EMMO modelling framework. A key design choice taken at this step of the design of the ontology was to decide the level of genericity, as to whether a particular concept belongs to the domain level or application level. For example, the class MechanicalTestX (see, Figure (9)) which models a specific type of mechanical test that has been asserted as application-specific knowledge in the mechanical testing ontology, and consequently, has been modelled as a subclass of the domain notion of MechanicalTest.

The fifth step is the creation of new modules for specific domain and application cases towards the evolution of the Mechanical Testing Ontology. The principal emphasis behind the underlying ontological modularity behind the European Materials Modelling Ontology (EMMO) is, concretely, the modelling of EMMO compliant ontologies on top of the several EMMO modules which are used to model separate domain and application-specific knowledge. This ensures the design of a modular ontology which facilitates its progress and gradual enrichment.

The sixth and final step of the proposed ontology development methodology is to collaboratively integrate and evolve the mechanical testing ontology. This will enable the platform to use the ontology to represent and analyze the results of mechanical tests.

The proposed ontology has several potential benefits. First, it provides a standardized vocabulary for describing mechanical tests, which can facilitate the annotation and integration of data and models from different sources. Second, it enables more effective simulation and optimization of physical systems by providing a detailed and dynamic representation of their behaviour under different conditions. Third, it can improve the accuracy and efficiency of mechanical testing by providing a formal and consistent way to represent and analyze test results.

6. Materials Passport

The Materials Passport is a knowledge resource developed by the University of Cambridge in collaboration with Technovative Solutions and use case partners with a specific purpose to describe products, components and their constituent materials to enable the development and publishing of material passports to develop a material circularity calculator to promote a circular economy.

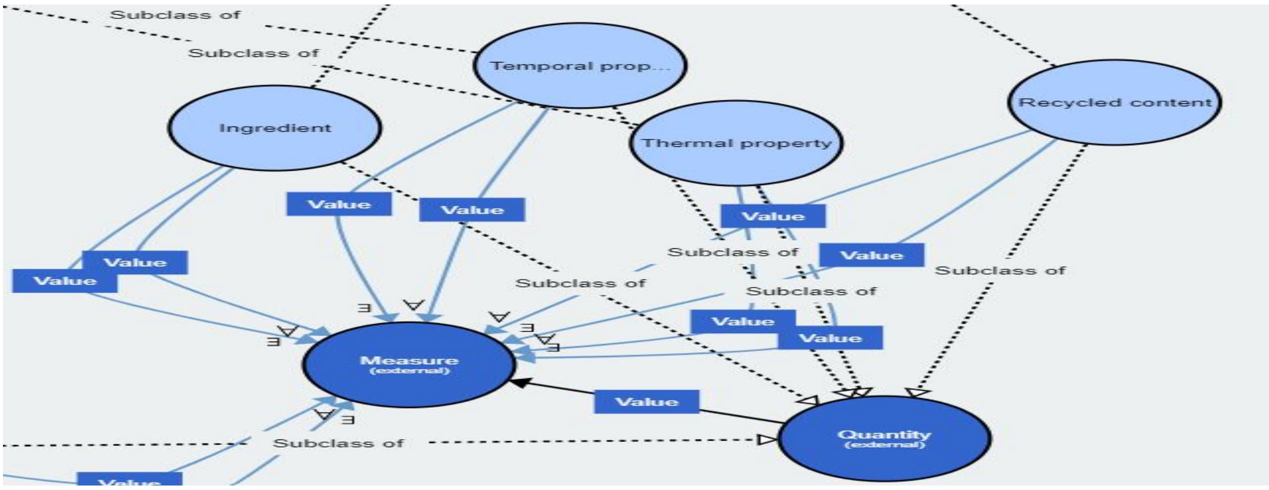

Figure 10. A Fragment of the Materials Passport

The classes axiomatized in the materials passport include: Biodegradability, Biological property, Chemical composition, Component, Compositional property, Compressive strength, Decomposability, Density, Dimension, Dimensionless Quantity, Expected lifetime, Heat transfer coefficient, Height, Image, Ingredient, Length, Physical Property, Product, Recycled content, Resistance, Rigidity, Service life, Shear modulus, Shear strength, Temporal property, Tensile strength, Thermal conductivity, Thermal property, user interface type, Mass, Width and Young's modulus.

The object properties axiomatized in the materials passport include: Empirical formula, has value, has Unit, Image, Manufacturer, Part of, Properties, Registration and country.

The data properties axiomatized in the materials passport include: Automatic tracking/scanning, Brand name, EAN, Functionality, GTIN, has Numerical Value, Is biodegradable, Is decomposable, Is hazardous Level, Manufacturer name, Name, Registration number, Trade name and URL.

An OWL RDF/XML axiomatization of the materials passport described above can be found at this link. Also, Figure (10) visualizes a fragment of the materials passport.

7. Teleontology Annotation process

The teleontology annotation process (see, Figure 11), facilitated by a GUI-based teleontology annotator tool, allows to upload an OWL/RDF teleontology file and aids the user to semantically align each of its concepts to the reference ontology, i.e., the UKC Concept Core concepts.

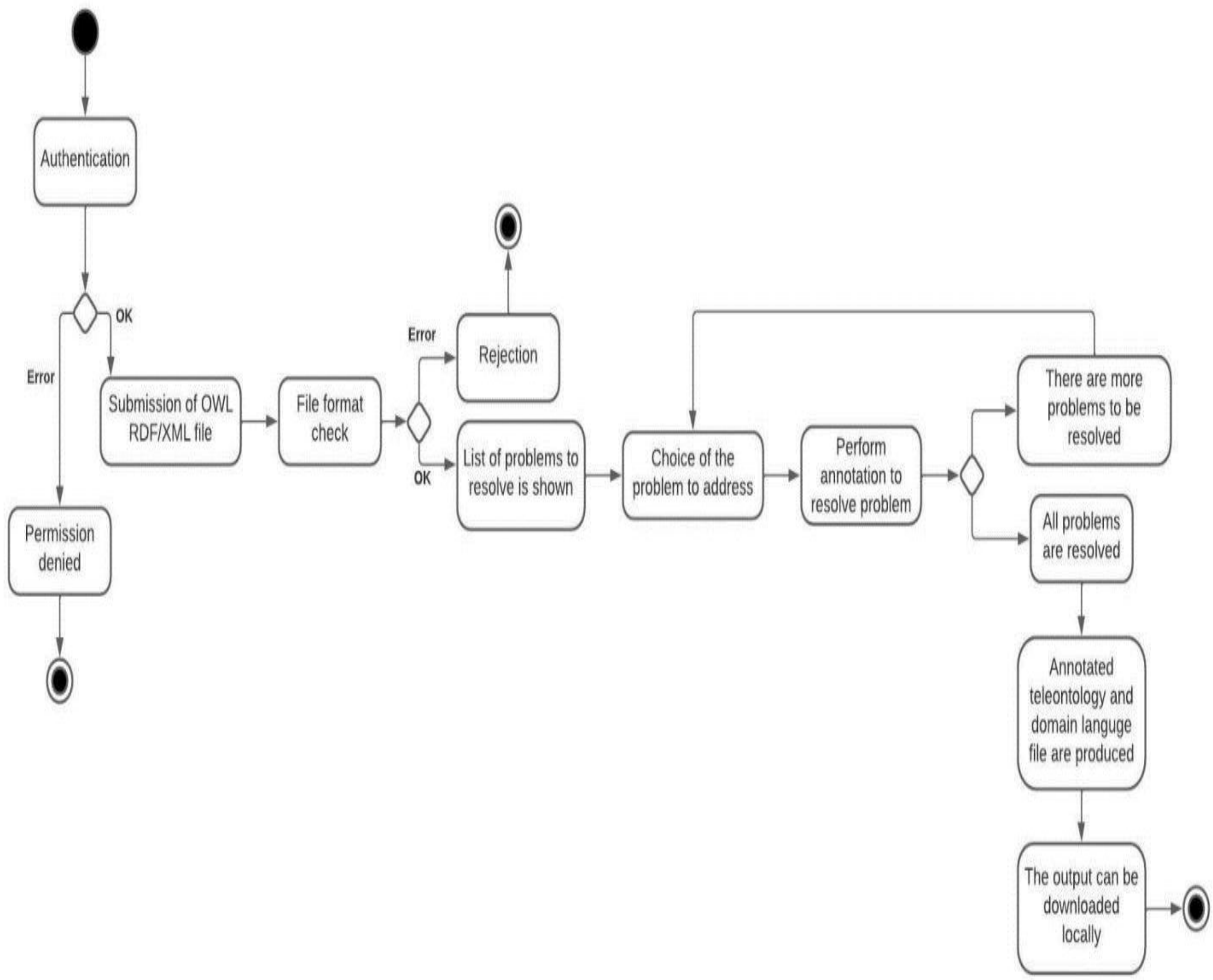

Figure 11. An Overview of the Teleontology Annotation Process

This results in two key advantages from the perspective of the knowledge modelling. Firstly, the annotation facilitates disambiguation of the semantics (sense) of the teleontology concepts in a semi-automatic way, thus, avoiding a lot of work for manual disambiguation of the semantics of the concepts. Secondly, the annotation activity also generates a taxonomically well-founded reusable domain language, with a dedicated namespace, from the teleontology being annotated. Therefore, the annotator tool not only outputs the final annotated teleontology but it also produces a domain language file containing all the linkages asserted during the annotation process. By including this tool in an architecture as the one shown in the above Figure (11) we can obtain some great benefits:

- The process can be done without having to deal with the semantic complexity that should be required
- The reuse of the domain language resources, already submitted to a validation process
- Such an annotated ontology becomes linguistically agnostic, compatible and interoperable with all the natural and domain languages supported in the UKC

The Universal Knowledge Core (UKC), as already described before, contains the domain languages generated as a result of the annotation process and the lexico-semantically disambiguated teleontology, both which can be reused. A user should select the specific resources from the UKC that are needed for the annotation of the input file (e.g., only the partition dedicated to materials modelling knowledge) adding them to a Local Knowledge Core (LKC) which is the partition of the UKC that will be available to the annotator during the annotation.

The annotator will allow the process of aligning the input teleontology to the knowledge contained in the UKC. In this way, it's possible to generate a linguistically agnostic resource that will be reusable in future processes. When resolving an ambiguity of a term, three different cases can be encountered:

2. The label is already present in the UKC knowledge base and is associated with a concept that models exactly what is intended to be described in the teleontology. In this case the label is associated with the concept's ID without modifying the UKC knowledge base, OR,
3. The label isn't already present in the UKC knowledge base or the concept associated with it does not model what is intended to be described in the teleontology. An already existing synset correctly model what's described in the ontology, so a new sense and eventually a new word associated with it is created and is annotated using the ID of the concept associated to the synset, OR,
4. In case both the aforementioned cases fail, a new word, sense, synset and concept are created.

In order to align a teleontology concept with a semantically equivalent concept in the UKC knowledge base, there will be three different procedures depending on the specific case, so the system will allow the following operations:

- A list of concept associated to the term will be available
- A list of possible synsets associated to the term will be available facilitating a search by name
- It will be possible to create a new semantic path from the term to a new concept respecting established taxonomic principles.

Only one of the previous cases will be available at once. Every time, when it is necessary to create a new object to be added to the UKC knowledge base, those additions should be reported in the domain language file generated by the teleontology annotator.

The Input-output features of the teleontology annotation process are listed as follows:

INPUT:

- The input file must be a well-formed, ontologically valid OWL RDF/XML file defining a teleontology
- If that's not the case or if the file is empty or corrupt, it will be rejected.

OUTPUT:

- It will produce a file containing the input teleontology correctly annotated with respect to the UKC knowledge base
- A domain language file describing all the updates and insertions made in the UKC Knowledge Base.
- The output files will be available to the user for the download and reuse as prescribed by the application-specific use case scenario.

USER:

- The user can only use the annotator if he/she is authenticated to use the teleontology annotation service.
- The user can start the annotation process by initially choosing a project ID, which, once done, should lead the user to upload the OWL RDF/XML file to annotate.
- The user will be prompted with a list of unannotated concepts to be resolved
- The user will have the possibility to choose in which order to address each one of them.
- The annotation process can be stopped and resumed at any time.

We attach below some screenshots exemplifying the application of the aforementioned teleontology annotator process using the annotator tool on a fragment of the materials passport briefly described in the use case example in Section (3).

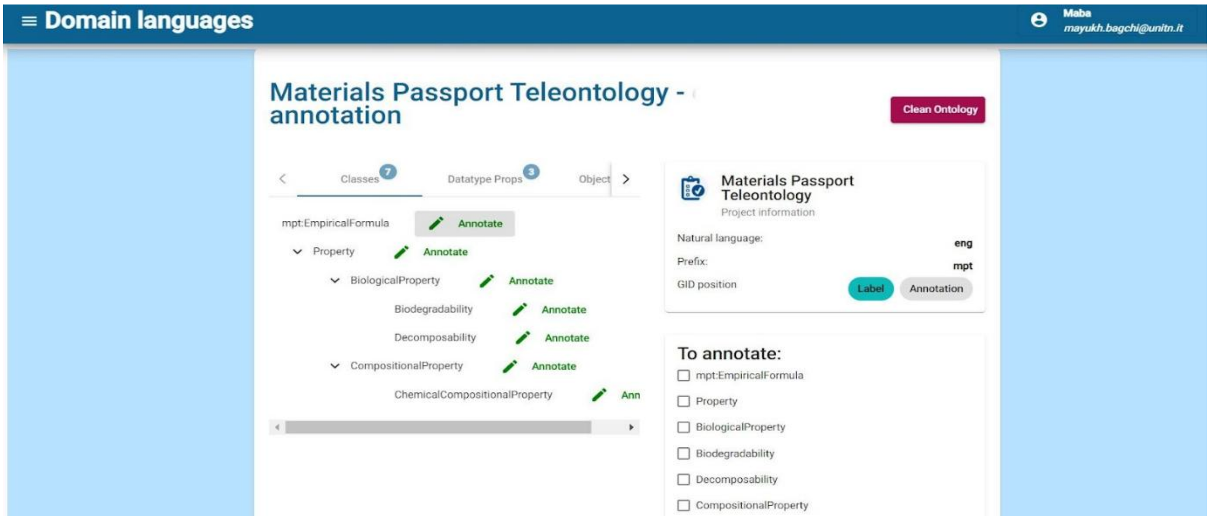

Figure 12. The input to the annotation process

Figure (12) visualizes the input to the teleontology annotator tool. As seen from the figure, a fragment of the materials passport teleontology is provided as an input to the annotator tool. The annotator shows that several concepts (property, biological property, etc.)

axiomatized within the materials passport are yet to be annotated (showed as “Annotate” in green) and thereby, enriched and integrated with the reference ontology - the UKC.

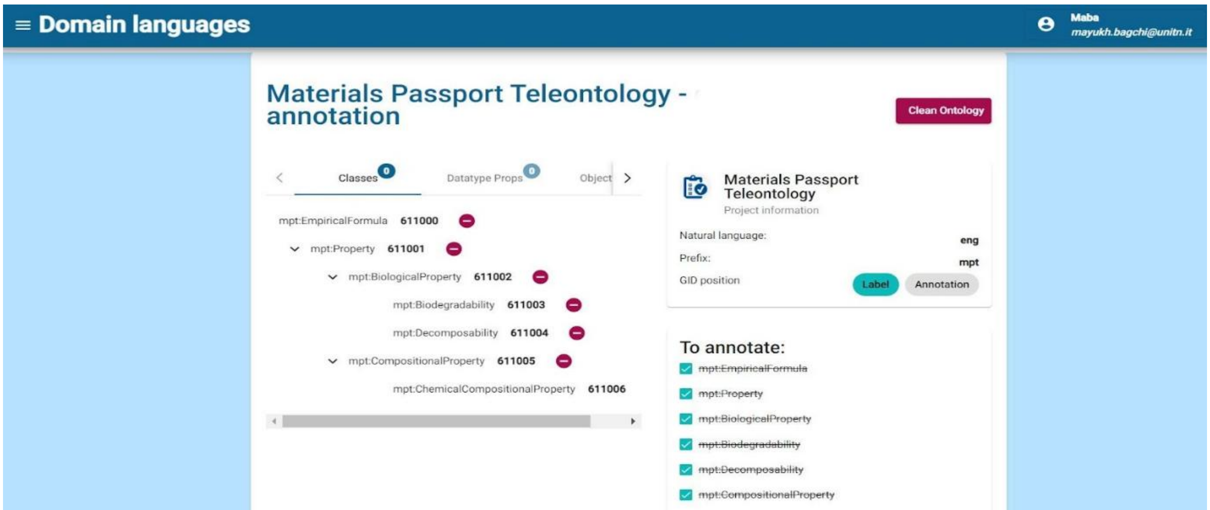

Figure 13. A fragment of the teleontology annotated with UKC IDs

Figure (13) visualizes a fragment of the teleontology annotated with unique UKC IDs. As seen from the figure, a fragment of the materials passport is provided as an input to the annotator tool. The annotator shows that several concepts axiomatized within the materials passport (property, biological property, etc.) are annotated with unique UKC identifiers (e.g., 611001 for property, 611002 for biological property) and thereby, already enriched and integrated with the reference ontology - the UKC. Also notice that each of such concepts are now part of a unique namespace of materials passport domain language, codified using the namespace prefix *mpt* (e.g., mpt:Property).

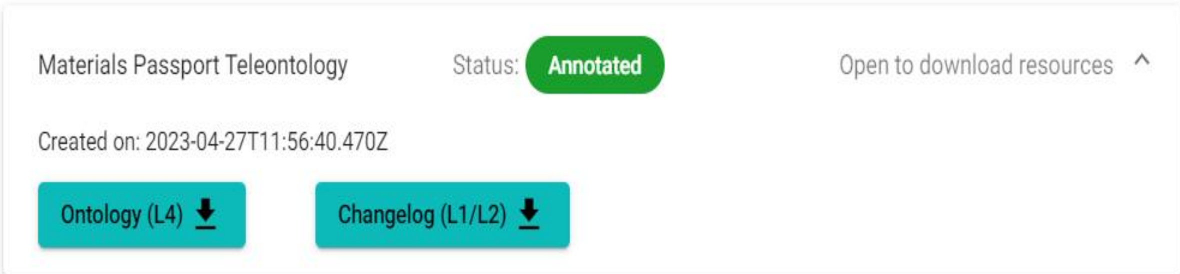

Figure 14. The output of the annotation process ready to download and (re)use

Figure (14) visualizes the output generated by the teleontology annotator tool. As seen from the previous figures, a fragment of the materials passport is provided as an input to the annotator tool. The annotator process, implemented via the tool, generates two timestamped output files - (i) an annotated teleolontology file (Ontology (L4) in the above figure), and (ii) a domain language file (Changelog (L1/L2) in the above figure), already enriched and integrated with the reference ontology - the UKC.

Updates with respect to the Beta Version:

(i) JIDEP Namespace (Annotated): Following the step-by-step teleontology annotation process as discussed above, the final version of the deliverable focused on a concrete implementation of the process to generate the annotated JIDEP composite materials domain namespace (in the form a spreadsheet in .xlsx format) which is essentially a lexical-semantic domain language composed of uniquely identified and semantically disambiguated terms (using UKC identifiers) referring to different concepts related to composite materials. Note that terms from this namespace can be partially or fully reused to develop different domain and application ontologies in different materials science use-cases. It can also be further enriched with more specialized terminology if the need arises for a specific use-case implementation. Please refer to the Figure (15) for a visualization of a fragment of the annotated JIDEP composite materials domain namespace. For example, “cmo:environmentalbenefit” is a term from the annotated namespace in Figure (15). The prefix “cmo” implies that this term is from the JIDEP composite materials namespace and it has also a natural language gloss in the English language stating that the concept represents environmental benefits. The UKC identifier “200003” uniquely identifies the term “cmo:environmentalbenefit”. Notice also, from the columns *Parent Concept* + *Parent UK ID* and *Relation* in Figure (15), that the term “cmo:environmentalbenefit” is a child (represented via IS-A relation) of the term “cmo:benefit” which is uniquely identified by the UKC identifier 200001. Finally, while this sheet (in Figure (15)) represents the specific concept terms modelled within the JIDEP composite materials domain namespace, all of these terms are already instantiated within the UKC database. The representation of internal metadata in the sheet, e.g., “creation_date”, “modification_date”, etc, represents the timestamps in which the concept terms were created and/or modified within the UKC database.

E4 fx cmo:environmentalbenefit

local_id	creation_date	modification_	is_loc	label	uk_id	kb_id	Description	Parent Concept + Parent UK ID	PoS	Relation	User Reference	Note
111901	2024-01-24 13	2024-01-24 13	f	cmo:benefit	200001	1	This concept represents some benefit r	owl:Thing 1	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111902	2024-01-24 13	2024-01-24 13	f	cmo:costreduction	200002	1	This concept represents the specific be	cmo:Benefit 200001	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111903	2024-01-24 13	2024-01-24 13	f	cmo:environmentalbenefit	200003	1	This concept represents environmental	cmo:Benefit 200001	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111904	2024-01-24 13	2024-01-24 13	f	cmo:fuelconsumptionreduction	200004	1	This concept represents fuel consumpt	cmo:EnvironmentalBenefit 200003	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111905	2024-01-24 13	2024-01-24 13	f	cmo:pollutionreduction	200005	1	This concept represents pollution redu	cmo:EnvironmentalBenefit 200003	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111906	2024-01-24 13	2024-01-24 13	f	cmo:recycleincrease	200006	1	This concept represents recycle increas	cmo:EnvironmentalBenefit 200003	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111907	2024-01-24 13	2024-01-24 13	f	cmo:weightreduction	200007	1	This concept represents weight reducti	cmo:Benefit 200001	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111908	2024-01-24 13	2024-01-24 13	f	cmo:catastrophicfailure	200008	1	This concept represents catastrophic fa	owl:Thing 1	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111909	2024-01-24 13	2024-01-24 13	f	cmo:compositemanufacturingprocess	200009	1	This concept represents composite ma	owl:Thing 1	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111910	2024-01-24 13	2024-01-24 13	f	cmo:compositematerial	200010	1	A material consisting of two or more di	owl:Thing 1	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111911	2024-01-24 13	2024-01-24 13	f	cmo:advancedcompositematerial	200011	1	This concept represents an advanced c	cmo:CompositeMaterial 200010	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111912	2024-01-24 13	2024-01-24 13	f	cmo:fibrebasedcomposite	200012	1	This concept represents fibre based co	cmo:CompositeMaterial 200010	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111913	2024-01-24 13	2024-01-24 13	f	cmo:aramidfibrebasedcomposite	200013	1	This concept represents aramid fibre b	cmo:FibreBasedComposite 200012	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111914	2024-01-24 13	2024-01-24 13	f	cmo:boronfibrecomposite	200014	1	This concept represents boron fibre co	cmo:FibreBasedComposite 200012	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111915	2024-01-24 13	2024-01-24 13	f	cmo:carbonfibrebasedcomposite	200015	1	This concept represents carbon fibre b	cmo:FibreBasedComposite 200012	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111916	2024-01-24 13	2024-01-24 13	f	cmo:glassfibrebasedcomposite	200016	1	This concept represents glass fibre bas	cmo:FibreBasedComposite 200012	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111917	2024-01-24 13	2024-01-24 13	f	cmo:inorganicfibrebasedcomposite	200017	1	This concept represents inorganic fibre	cmo:FibreBasedComposite 200012	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111918	2024-01-24 13	2024-01-24 13	f	cmo:siliconcarbidebasedcomposite	200018	1	This concept represents silicon carbide	cmo:FibreBasedComposite 200012	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111919	2024-01-24 13	2024-01-24 13	f	cmo:functionalrequirementbasedcomposite	200019	1	This concept represents a functional re	cmo:CompositeMaterial 200010	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111920	2024-01-24 13	2024-01-24 13	f	cmo:barriercomposite	200020	1	This concept represents barrier compo	cmo:FunctionalRequirementBased	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111921	2024-01-24 13	2024-01-24 13	f	cmo:electromagneticcomposite	200021	1	This concept represents electromagnet	cmo:FunctionalRequirementBased	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111922	2024-01-24 13	2024-01-24 13	f	cmo:structuralcomposite	200022	1	This concept represents structural com	cmo:FunctionalRequirementBased	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111923	2024-01-24 13	2024-01-24 13	f	cmo:thermalcomposite	200023	1	This concept represents thermal comp	cmo:FunctionalRequirementBased	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111924	2024-01-24 13	2024-01-24 13	f	cmo:manufacturingprocessbasedcomposite	200024	1	This concept represents a manufacturi	cmo:CompositeMaterial 200010	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111925	2024-01-24 13	2024-01-24 13	f	cmo:autoclavecomposite	200025	1	This concept represents autoclave com	cmo:ManufacturingProcessBasedC	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111926	2024-01-24 13	2024-01-24 13	f	cmo:compressionmouldingcomposite	200026	1	This concept represents compression	cmo:ManufacturingProcessBasedC	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]
111927	2024-01-24 13	2024-01-24 13	f	cmo:filamentwindingcomposite	200027	1	This concept represents filament windi	cmo:ManufacturingProcessBasedC	n	IS_A	Mayukh Bagchi (mayukh.bagchi@unitn.it)	USER: [CMO-1-12012024]

Figure 15. A fragment of the annotated JIDEP composite materials domain namespace

(i) <u>JIDEP Composite Materials Teleontology (Annotated)</u>: Again, following the step-by-step teleontology annotation process as discussed before, the final version of the deliverable concretely implemented the teleontology annotation process to generate the annotated JIDEP composite materials teleontology (in .owl format) composed of uniquely identified and semantically disambiguated terms from the JIDEP annotated namespace. To that end, the JIDEP teleontology is a fully formal knowledge artefact referring to different classes representing different conceptual facets of composite materials and how such concepts are interrelated with each other via object properties. Note that classes and properties from this JIDEP teleontology can be partially or fully reused to develop different domain and application ontologies in different materials science use-cases. It can also be further enriched with more specialized classes and properties if the need arises for a specific use-case implementation. Also notice that terms used to model the classes and properties in the JIDEP Composite Materials Teleontology are in complete one-to-one correspondence with the annotated JIDEP composite materials namespace. Please refer to the Figure (16) and Figure (17) for a class view and a property view of a fragment of the annotated JIDEP composite materials domain namespace. For example, “EnvironmentalBenefit_GID-200003” is a class in Figure (16) representing the knowledge of environmental benefits within the JIDEP teleontology. Notice how the unique UKC identifier “200003” within the label of the class “EnvironmentalBenefit_GID-200003” informs and represents that this class is modelled using the synonymous concept with the same UKC identifier in the JIDEP composite materials domain namespace.

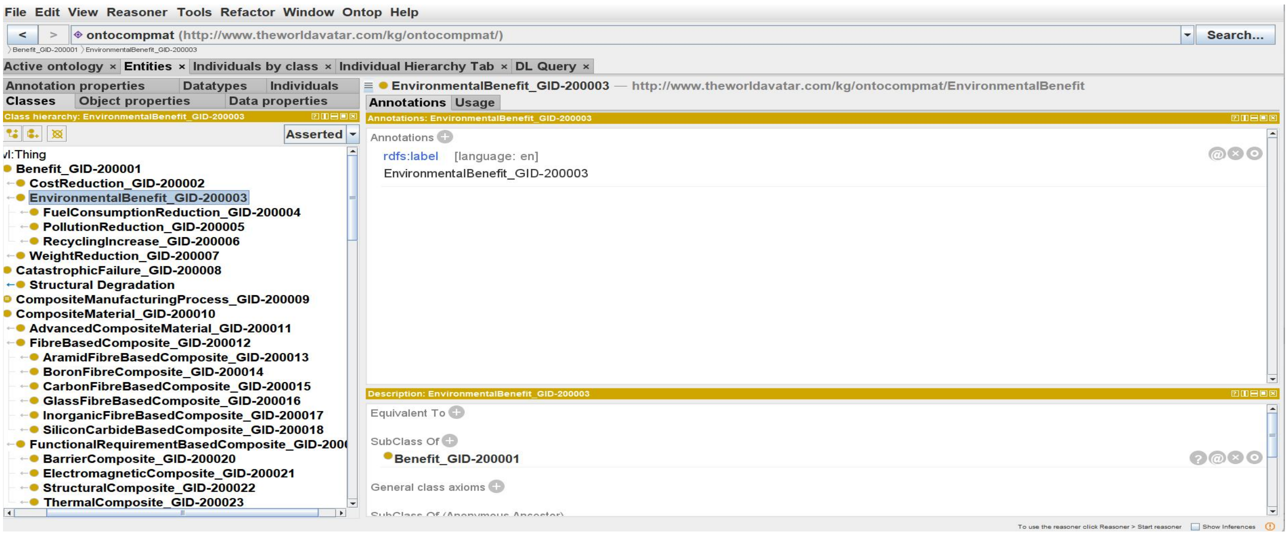

Figure 16. A fragment of the annotated JIDEP composite materials teleontology (class view)

Similarly, for example, “usedInIndustry_GID-200133” is an object property in Figure (16) representing the interrelation of knowledge of use of a specific facet of composite material to a specific industry (like automotive industry) within the JIDEP teleontology. Notice, similarly as before, how the unique UKC identifier “200133” within the label of the class “usedInIndustry_GID-200133” informs and represents that this object property is modelled using the synonymous concept with the same UKC identifier in the JIDEP composite materials domain namespace.

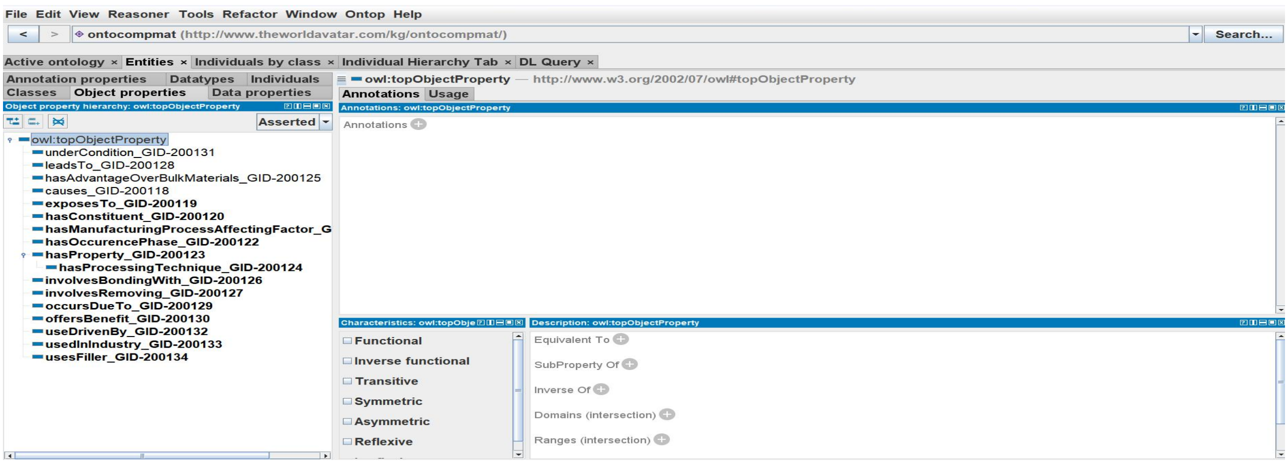

Figure 17. A fragment of the annotated JIDEP composite materials teleontology (property view)

The consolidated versions of the above exemplified annotated domain namespace and annotated teleontology are accessible via the following links:

- Annotated JIDEP composite materials domain namespace: LINK
- Annotated JIDEP composite materials teleontology: LINK

5. Conclusion

The deliverable formulated the various theoretical and practical dimensions, suitably exemplified, of the stratified knowledge representation framework of JIDEP via which we refine and extend domain-specific ontologies. To that end, the beta version of the deliverable concentrated on developing the stratified knowledge representation formalism employed to model ontologies in JIDEP, a detailed survey of different reference teleontologies in the materials science domains, a description of the JIDEP composite materials teleontology, a description of the JIDEP materials passport, and, finally, developing the process of producing fully formal, semantically disambiguated and reusable teleontologies. The final version of the deliverable, building up on the beta version, had two key additions. First, it showed how the JIDEP composite materials teleontology is aligned with the EMMO reference teleontology and the relevant ISO standards. Second, it documented the implementation of the teleontology annotation process to generate the annotated JIDEP composite materials namespace and the annotated JIDEP composite materials teleontology.

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Acronyms and Abbreviations

ADL	ALMAS Partecipazioni Industriali S.P.A.
ADS	Adscensus, MB
AVO	Arteevo Technologies Ltd
BUL	Brunel University London
CRF	Centro Ricerche Fiat Scpa
FHV	Fachhochschule Vorarlberg GMBH
PVI	Precision Varionic International Limited
TPI	TPI Composites
TVS	Technovative Solutions Ltd
UCAM	The Chancellor Masters And Scholars Of University Of Cambridge
UNITN	University Degli Studi Di Trento
UPCE	Univerzita of Pardubice
ZOREN	Zorlu Enerji Elektrik Uretim As
CFRP	Carbon fiber reinforced plastic
CO2	Carbon dioxide
DLT	Distributed ledger technology
EC	The European Commission
ELV	End-of-life-vehicle
EOL	End-of-life
GW	Giga-Watt
IC	Integrated circuit
ISO	International Organization for Standardization
Mt	Mega-tons
NMF	Non metallic fraction
PCB	Printed circuit board
R&D	Research & Development
RSD	Requirements specification document
SME	Small-medium enterprise
WEEE	Waste electrical and electronic equipment