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M4.2 - Processes & tools to engineer FAIR semantic artefacts

Work Package	**WP4 - Metadata and Ontologies**
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1.0	26/12/2023	María Poveda (UPM)	Changes according to reviews in the whole document.

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Terminology

Terminology /Acronym	Description
DOI	Digital Object Identifier. Persistent identifier for digital objects.
FOOPS!	Ontology Pitfall Scanner for FAIR
HTTP(S)	Hypertext Transfer Protocol (Secure). For (secure) exchange over a computer network like the Internet.
JSON-LD	JavaScript Object Notation Linked Data. RDF serialisation
LOT	Linked Open Terms methodology
LOV	Linked Open Vocabularies
MOD	Metadata for Ontology Description
O'FAIRE	Ontology FAIRness Evaluator
OWL	Web Ontology Language
PURL	Persistent URL
RDF	Resource Description Framework
RDF/XML	RDF Serialisation
RDFS	Resource Description Framework Schema
SKOS	Simple Knowledge Organization System
SPARQL	SPARQL Protocol and RDF Query Language. RDF query language
Turtle (TTL)	RDF Serialisation
URI	Uniform Resource Identifier
W3C	World Wide Web Consortium
XML	Extensible Markup Language

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1. Introduction

In the context of this document we adopt the definition of Semantic Artefacts provided by the FAIRsFAIR project [Le Franc et al., 2022] and EOSC Interoperability Framework [Corcho et al., 2020]: "*Semantic Artefact is defined here as a machine-actionable and -readable formalisation of a conceptualisation enabling sharing and reuse by humans and machines. These artefacts may have a broad range of formalisation, from loose set of terms, taxonomies, thesauri to higher-order logics, and include the concepts/terms/classes constituting these. Moreover, semantic artefacts are serialised using a variety of digital representation formats, e.g., RDF Turtle, OWL-RDF, XML, JSON-LD"*.Semantic artefacts (i.e., ontologies, vocabularies and SKOS taxonomies, among others) define the structure, guide the construction of, and help validate many existing Knowledge Graphs. While semantic artefacts include ontologies, vocabularies, SKOS terminologies, etc. the work presented in this milestone focuses on OWL and RDF(S) ontologies and vocabularies and could be taken as the basis for extending the methodology for other Semantic Artefact types.

On the one hand, a number of methodologies for building ontologies have been proposed by researchers through the years (Fernández-Izquierdo et al. 2021). However the Linked Open Terms (LOT) methodology (Poveda-Villalón et al. 2022a) is the only one considering the FAIR aspect of the ontologies being built and also includes the publication activity which is key in the alignment with FAIR Principles (Wilkinson et al. 2016). In addition, as part of the FAIR-IMPACT project, MS5.3 proposes an extension of LOT for explicitly adapting the methodology to FAIR assessment which is complementary with this milestone). This is due to the fact that most of the methodologies for building ontologies were developed prior to the publication of the FAIR Principles in 2016. For these reasons, we build our FAIR by design methodology by extending LOT.

On the other hand, a number of guidelines have been proposed in the last years (Poveda-Villalón et al. 2020; Garijo and Poveda-Villalón 2020; Hugo et al. 2020; Cox, S.J.D. et al. 2021; Le Franc et al., 2022; Xu et al. 2023; Amdouni, E. et al. 2022a) to align semantic artefact best practices against the Findable, Accessible, Interoperable and Reusable principles (FAIR Principles) (Wilkinson et al. 2016). All the leading authors of these guidelines now gather in FAIR-IMPACT's WP4 and 5 to consolidate the methodological dimensions and tooling of applying the FAIR Principles to semantic artefacts. This topic is at the centre of T5.3 "Semantic artefact FAIRness assessment" and T4.2 "Semantic artefact lifecycle and catalogues".

However, no alignment between ontology development methodologies and the guidelines/recommendations for FAIR semantic artefacts have been developed so far. In practice, the compliance with the guidelines is usually validated at the end of the semantic artefact development processes without being integrated in the whole life-cycle. In this document, we propose LOT4FAIR, a FAIR by design methodology, which is an evolution of the LOT methodology that extends LOT considering the various guidelines to improve the FAIRness level of the resulting ontologies for each ontology development phase or activity.

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This effort is complementary to M5.3, where LOT is extended adding phases for semantic artefact compliance against the FAIR Principles, whether in development (pre-assessment) or once a version is finalised. Instead, here, we focus on identifying the gaps surrounding each of the development phases to make sure best FAIR practices are followed from the beginning.

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2. Description of the milestone

In this milestone, we propose a FAIR by design methodology for developing ontologies that could be extended to address other types of ***semantic artefacts***. That is, the work developed for and reported in this milestone focuses on semantic artefacts (mostly **vocabularies** and **ontologies**) formalised in the RDF(S) and OWL representation languages mainly.

Our approach takes as an input the methodology called Linked Open Terms (LOT) (Poveda-Villalón et al. 2022a) as well as developers' (partners) experience, existing best practices and guidelines as well as existing tools for developing ontologies. By mapping the ontology development activities to the potential needs, the existing recommendations and the tools, the covered areas and gaps for a FAIR by design methodology (LOT4FAIR) are identified. This milestone provides the first version of the FAIR by design methodology and it will be refined up to the final version that will be completed in the deliverable D4.2 "Report on FAIR semantic artefact lifecycle". This document also identifies the future lines of work to be carried out in order to complete the methodology in D4.2.

The LOT methodology is organised in four phases that are further split in specific activities as shown in Figure 1. As the activities in "requirements specification" and "maintenance " phases are too detailed to be mapped to the FAIR Principles, we decided map the FAIR principles at the phase level. For the "ontology implementation" and "ontology publication" phases the FAIR Principles are mapped at activity level as the activities in these phases are more technical.

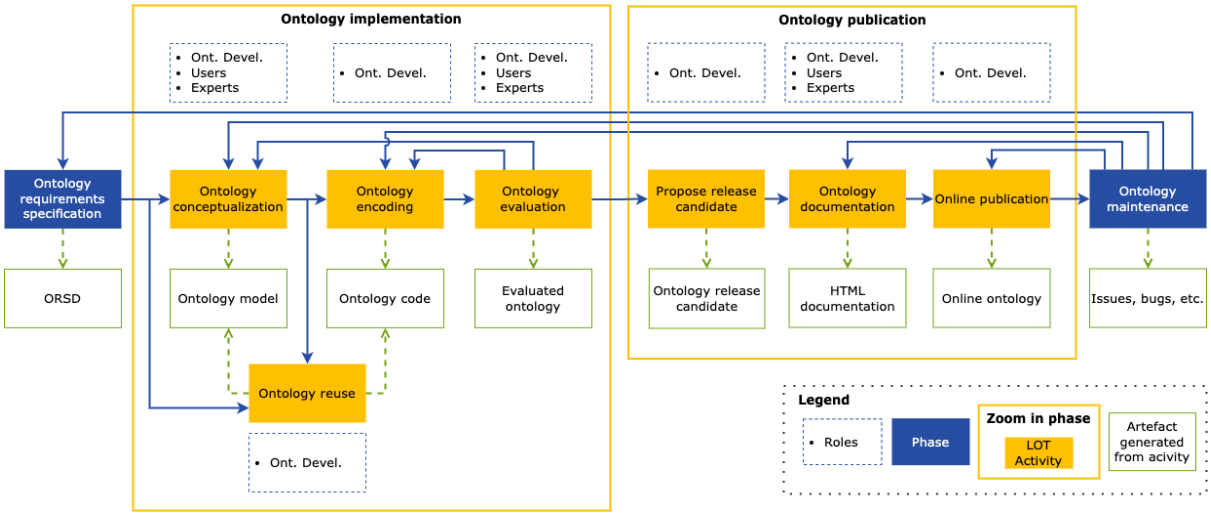

Figure 1 - Excerpt of the LOT methodology phases and activities.

2.1 Role of the milestone

This milestone has been driven by three main objectives: 1) Guiding semantic artefact (more precisely ontologies), developers in the steps that need to be followed in order to take into account the FAIR Principles along the whole process rather than at the end of the process; 2) Detecting gaps in current methodological guidelines, 3) Assist the developers regarding existing tools to be used along the process.

2.1.1 Means of verification

The required means of verification for this Milestone is to have the report containing the methodology adaptation available. This document is the verification of the methodology being publicly available online.

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3. Process followed

The process followed to devise the FAIR-by-design methodology LOT4FAIR is depicted in Figure 2.

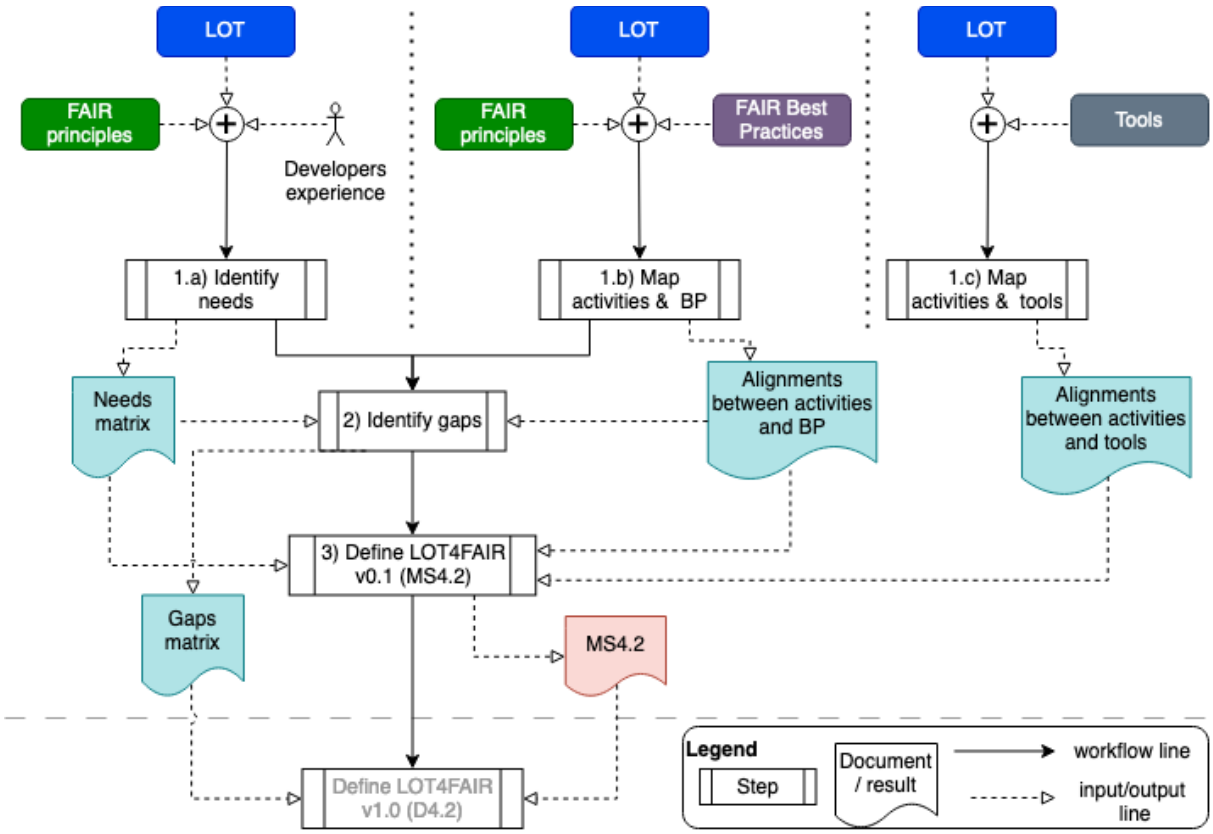

Figure 2 - Steps followed to define the FAIR by design methodology.

As it can be observed, the first step has been divided into 3 work streams, namely:

- **Step 1.a) Identify the needs:** takes as input the LOT methodology, the FAIR Principles and the partners' development experience to identify which steps of the process for building ontologies are related to the FAIR Principles, regardless if there are existing guidelines or not to cover the affected activities. That is, experts identify connections by answering the questions *"Is there something to be done while carrying out the ACTIVITY_X that could affect the FAIRness level of the final ontology with respect to FAIR_principle_Y?"* This process has been done following a brainstorming process (online and offline). The output, a matrix mapping LOT phases and activities to each of the FAIR Principles where a connection is defined, has been also reviewed by experts. This matrix identifies the needs for best practices for each activity and each

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FAIR Principle as shown in Table 1. In this table, the "X" represents whether a need, or gap, is identified for a given activity (column) and FAIR Principle (row). This table represents a schematic summary of the results for readability purposes.

Table 1 - Matrix of needs for supporting ontology development activities in relation to each FAIR Principle.

FAIR Principle	Ontology Requirements Specification	Ontology Reuse	Ontology Conceptualization	Ontology Encoding	Ontology Evaluation	Ontology Documentation	Ontology Publication	Ontology Maintenance
F1	X			X		X	X	X
F2	X	X		X		X		
F3				X		X	X	
F4							X	X
A1	X	X		X		X	X	
A1.1	X						X	
A1.2							X	
A2				X			X	X
I1	X	X	X	X		X	X	
I2		X	X	X		X		
I3		X	X	X		X		X
R1	X	X	X	X	X	X		
R1.1	X	X		X	X	X	X	
R1.2		X	X	X	X	X	X	
R1.3	X	X	X	X		X	X	

- **Step 1.b) Map activities and best practices**: takes as input the LOT methodology, the FAIR Principles and existing literature about best practices and recommendations to build FAIR semantic artefacts. FAIR-IMPACT partners have mapped the existing best practices to each FAIR Principle (only in case it was not already mapped in the original work) and to the specific LOT phases or activities in which each best practice could be applied. This process has been carried out in collaboration with best practices authors all engaged in T4.2. The output of this activity is a matrix of existing best practices for each activity and each FAIR Principle. Such output is shown in Table 2. In this table, the "Y" represents whether at least one reference provides best practices or guidelines about a FAIR Principle (row) for a given activity (column). This table represents a schematic summary of the results for readability purposes. The existing works used to analyse and map existing guidelines are: FAIR Vocabulary Features defined in (Xu, F. et al. 2023), guidelines for publishing FAIR vocabularies defined in (Garijo, D. and Poveda-Villalón, M. 2020), O'FAIRe questions defined in (Amdouni, E.

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et al. 2022a), Preliminary Recommendations defined in (Le Franc, Y. et al. 2022) and rules for making vocabularies FAIR defined in (Cox, S.J.D. et al. 2021).

Table 2 - Matrix of existing guidelines supporting ontology development activities in relation to each FAIR Principle.

FAIR Principles	Ontology Requirements Specification	Ontology Reuse	Ontology Conceptualization	Ontology Encoding	Ontology Evaluation	Ontology Documentation	Ontology Publication	Ontology Maintenance
F1				Y		Y	Y	
F2				Y		Y		
F3				Y		Y	Y	
F4							Y	
A1		Y		Y		Y	Y	
A1.1							Y	
A1.2							Y	
A2				Y			Y	Y
I1		Y	Y	Y			Y	
I2		Y	Y	Y				
I3		Y		Y		Y		Y
R1		Y	Y	Y	Y	Y		
R1.1		Y		Y		Y	Y	
R1.2		Y	Y	Y		Y	Y	
R1.3			Y	Y		Y	Y	

- **Step 1.c) Map activities and tools**: takes as input the LOT methodology and existing lists of tools (taken from OntoCommons deliverable (Poveda-Villalón et al. 2022b)) for ontology development. In this case, the tools have been filtered and aligned with the LOT methodology activities for those not aligned already. The output of this activity is an alignment between ontology development activities and existing tools, and will be provided directly for each LOT phase or activity in Section 4.

In **step 2 (Identify gaps)**, the matrix of needs and the matrix of existing best practices are compared to identify gaps for those activities in the matrix needs that have no recommendations to date. Table 3 shows the output of this activity in a matrix of needs, where each need for supporting ontology development activities is assessed in relation to each FAIR Principle. Table 1 is represented in the columns “Need” and mappings to existing guidelines (Table 2) are summarised under columns “Ref”. Cases for which there is a need but no guidelines are identified are marked with the term “Gap”.

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Table 3 - Matrix of needs for supporting ontology development activities in relation to each FAIR Principle and mappings to existing guidelines.

	Ontology Requirements Specification		Ontology Reuse		Ontology Conceptualization		Ontology Encoding		Ontology Evaluation		Ontology Documentation		Ontology Publication		Ontology Maintenance	
	Need	Ref	Need	Ref	Need	Ref	Need	Ref	Need	Ref	Need	Ref	Need	Ref	Need	Ref
F1	X	Gap					X	Y			X	Y	X	Y	X	Gap
F2	X	Gap	X	Gap			X	Y			X	Y				
F3							X	Y			X	Y	X	Y		
F4													X	Y	X	Gap
A1	X	Gap	X	Y			X	Y			X	Y	X	Y		
A1.1	X	Gap											X	Y		
A1.2													X	Y		
A2							X	Y					X	Y	X	Y
I1	X	Gap	x	Y	x	Y	X	Y			X	Gap	x	Y		
I2			x	Y	x	Y	X	Y			X	Gap				
I3			x	Y	X	Gap	X	Y			X	Y			X	Y
R1	X	Gap	X	Y	X	Y	X	Y	X	Y	X	Y				
R1.1	X	Gap	X	Y			X	Y	X	Gap	X	Y	X	Y		
R1.2			X	Y	X	Y	X	Y	X	Gap	X	Y	X	Y		
R1.3	X	Gap	X	Gap	X	Y	X	Y			X	Y	X	Y		

During **step 3 (Define LOT4FAIR)**, the actual extension of the LOT methodology for FAIR by design has been defined. That is, what is the information to be added to the current methodology. More precisely, the way selected to extend LOT methodology consists in adding to each LOT phase (ontology requirements specification and ontology maintenance) or activity (ontology reuse, conceptualization, encoding, evaluation, documentation and publication) a table containing guidelines and resource about how to increase the ontology FAIRness during that phase or activity. Table 4 shows the template to be filled in for each phase or activity specialised in the LOT4FAIR methodology. This template is used throughout Section 4.

Table 4 - Template for the LOT methodology extension LOT4FAIR.

Phase / Activity:	Phase or Activity name and brief description taken from LOT methodology

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Resources involved:	• Resource 1 • Resource …
Roles involved:	• Ontology development team • Domain experts • Ontology user • Ontology managers
Why	Describe in general terms how the FAIR Principles could be applied to the resources generated during the activity.
Tools	Links to tools and resources supporting this phase or activity.
FAIR Principle X	
Recc	• Recommendation 1 (for new recommendations) • Recommendation 2 • … • FVF-X / G&P-X/ FYQX / P-Rec-X / Rule-X (pointers to existing best practices and recommendations) • FVF-X / G&P-X/ FYQX / P-Rec-X / Rule-X • …
FAIR Principle …	
Recc	• Recommendation 1 (for new recommendations) • Recommendation 2 • … • FVF-X / G&P-X/ FYQX / P-Rec-X / Rule-X (pointers to existing best practices and recommendations) • FVF-X / G&P-X/ FYQX / P-Rec-X / Rule-X • …

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4. FAIR by design methodology

This section presents the proposed LOT4FAIR extension aiming at providing guidance to increase the ontology FAIRness level across the whole ontology development process. The extensions for each LOT phase or activities are listed in Table 5 to Table 12.

For each phase or activity the gaps identified and existing guidelines are included according to the results from the previous section. The following codes will be used in the tables to refer to existing guidelines or resources taken from the following publications:

- **FVF-X**: **F**AIR **V**ocabulary **F**eature (FVF-) **X** defined in (Xu, F. et al. 2023)
- **G&P-X**: Guideline for publishing FAIR vocabulary **X** defined in (**G**arijo, D. and **P**oveda-Villalón, M. 2020)
- **FYQX**: **Q**uestion **X** for **FAIR Principle Y** defined in (Amdouni, E. et al. 2022a)
- **P-Rec-X**: **P**reliminary **Rec**ommendation **X** defined in (Le Franc, Y. et al. 2022)
- **Rule-X**: **Rule X** for FAIR vocabularies defined in (Cox, S.J.D. et al. 2021)

For some gaps, preliminary recommendations elicited during FAIR-IMPACT task T4.2.1 are added. It should be noted that this is work in progress and the current recommendations will be refined in following versions and it is not intended to be completed at this stage. That is, for some fields only the gap is identified and marked as such in the tables. The final version of the new and existing recommendations is intended to be reported in FAIR-IMPACT D4.2

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Table 5 - LOT4FAIR extension for the Ontology Requirements specification phase.

Phase	Ontology requirements specification. The aim of the requirements specification phase is to state why the ontology is being built and to identify and define the requirements the ontology should fulfil
Resources involved	• ORSD (Ontology Requirements Specification Document) • List of Competency Questions or Functional Requirements
Roles involved	• Ontology development team • Ontology users • Domain experts
Why	Ontological requirements play a crucial role in ontology development projects defining the needs that the intended model should fulfil. Even though they are rarely published together with the resulting ontologies, ontology requirements could be valuable for potential users to understand the ontology. In addition, ontological requirements can be considered not only as metadata about the resulting ontology but also as provenance information. For these reasons, **ontology requirements** should be **treated as** first class citizens and key **resources** during the ontology development process, **applying** the**FAIR Principles** to **them** when possible.

Tools	• General documents to manage table, text, mindmaps, etc.
	  ○ OpenOffice http://www.openoffice.org/
	  ○ Google Drive https://www.google.com/drive
	  ○ MS office https://www.office.com/
	  ○ Miro https://miro.com/mind-map/
	  ○ Mural https://www.mural.co
	  ○ Coggle https://coggle.it/
	• Test specification systems
	  ○ THEMIS http://themis.linkeddata.es/
	  ○ TDD Onto2 https://github.com/kierendavies/tddonto2

F1. (meta)data are assigned a globally unique and persistent identifier	
Recc	**GAP** • Provide identifiers to functional requirements (competency questions or other forms). • Provide links to functional requirements (competency questions or other forms) either in a compiled version or separated in different files.
F2. data are described with rich metadata (defined by R1 below)	
Recc	**GAP** • Provide versioning information about the requirements and the ontology versions • Provide metadata information about requirements (e.g., authors, projects related, modification dates, status) • Identify requirements with qualified metadata

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A1. (meta)data are retrievable by their identifier using a standardized communications protocol	
Recc	**GAP** • Use HTTP URIs to identify requirements (or sets) and retrieve them.
A1.1 the protocol is open, free, and universally implementable	
Recc	**GAP** • Use HTTP URIs to identify requirements (or sets) and retrieve them.
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.	
Recc	**GAP** • Provide requirements at least in an open format file as csv. • Optimal: Provide RDF description of the requirements retrievable from their URIs (see: http://w3id.org/def/ontoreq)
R1. meta(data) are richly described with a plurality of accurate and relevant attributes	
Recc	**GAP** • Requirements are richly described as instances of formal objects from a relevant metadata vocabulary such as MOD or OntoReq.
R1.1. (meta)data are released with a clear and accessible data usage license	
Recc	**GAP** • Define a usage license for the requirements
R1.3. (meta)data meet domain-relevant community standards	
Recc	**GAP**

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Table 6 - *LOT4FAIR extension for the Ontology Reuse activity.*

Activity	Ontology reuse. This activity refers to using and employing an existing ontology or vocabulary when developing a new ontology.
Resources involved	• Ontology code • Ontology conceptualization
Roles involved	• Ontology development team • Domain experts
Why	During the ontology reuse activity, candidate ontologies to be reused are analyzed and decisions about which ontologies will be reused and how are made. As the reused parts become part of the ontology being built, they should be treated as final outputs and FAIR Principles should be applied to them.

Tools	• Ontology Repositories and other Semantic Artefact Catalogues
	  ○ LOV https://lov.linkeddata.es
	  ○ AgroPortal http://agroportal.lirmm.fr/
	  ○ IndustryPortal http://industryportal.enit.fr/
	  ○ BioPortal https://bioportal.bioontology.org/
	  ○ BARTOC https://bartoc.org/
	  ○ Ontohub https://ontohub.org/
	  ○ OntoBee https://ontobee.org/
	  ○ ODP Portal http://ontologydesignpatterns.org/wiki/Main_Page
	  ○ DBpedia Archivo https://archivo.dbpedia.org/list
	  ○ Ontology Lookup Service (OLS) https://www.ebi.ac.uk/ols/index
	  ○ Other https://github.com/agroportal/fairness/blob/master/src/main/resources/config/common/catalogs.config.json
	• Ontology matcher
	  ○ Alignment Cubes https://www.ida.liu.se/%7Epatla00/research/AlignmentCubes/
	• Ontology modularizer
	  ○ OntoFox https://ontofox.hegroup.org/
	• Ontology Design Patterns
	  ○ Reasonable Ontology Templates (OTTR) https://ottr.xyz/
	  ○ ODP Portal http://ontologydesignpatterns.org/wiki/Main_Page

F2. data are described with rich metadata (defined by R1 below)	

Recc	**GAP**
	• Provide metadata about which ontologies are being reused
	  ○ at ontology content level, with properties gathered or defined by MOD:
	  ■ owl:imports
	  ■ owl:priorVersion
	  ■ dcterms:isPartOf
	  ■ mod:specializes
	  ■ mod:generalizes
	  ■ mod:reliesOn
	  ■ mod:hasEquivalencesWith
	  ■ owl:backwardCompatibleWith
	  ■ owl:incompatibleWith

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	■ mod:hasDisparateModellingWith ■ mod:hasDisjunctionsWith ■ schema:translationOfWork ■ mod:metadataVoc ○ at term level: rdfs:isDefinedBy • Verify whether the reused ontology or terms URI should be referenced including versioning information
A1. (meta)data are retrievable by their identifier using a standardized communications protocol	
Recc	• **A1Q1**: Do the ontology URI and other identifiers, if they exist, resolve to the ontology? • **A1Q2**: Does the ontology URI (if metadata are included in the ontology file) or the external metadata URI resolve to the metadata record? • **A1Q3**: Do the ontology URI and the external metadata URI (if the metadata are not included in the ontology file), support content negotiation? • The reused ontologies or terms shall be accessible as any other objects within the ontology (all Accessibility principles affected).
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.	
Recc	**GAP** • **I1Q1**: What is the representation language used for the ontology and ontology metadata? • **I1Q2**: Is the representation language used in a W3C Recommendation? • Reuse ontologies and terms are (or are coming from) resources implemented in standard languages
I2. (meta)data use vocabularies that follow FAIR Principles	
Recc	• Assess candidate ontologies/vocabularies FAIRness level. ○ Check the FAIRness level within a repository https://wheat.agroportal.lirmm.fr/ or by stand alone applications (e.g. FOOPS! https://w3id.org/foops/) • **I2Q1**: Does the ontology import other FAIR vocabularies? • **I2Q2**:Does the ontology reuse terms from other FAIR vocabularies (URIs)? • **I2Q3**:If yes, does it include the minimum information for those terms? • **I2Q4**: Is the ontology aligned to other FAIR vocabularies? • **I2Q5**: If yes, are those alignments well represented and to unambiguous entities? If yes, are those alignments curated? • **I2Q7**: Does the ontology reuse standard and FAIR metadata vocabularies to describe its metadata?
I3. (meta)data include qualified references to other (meta)data	
Recc	• Use standard languages for implementing the reuse, for example OWL, RDF(S) primitives, SKOS properties, SSSOM, etc. • **FVF-8**: Vocabularies and terms use qualified references to other vocabularies. • **P-Rec15**: Provenance information regarding the reuse of components from third-party semantic artefacts should be made explicit
R1. meta(data) are richly described with a plurality of accurate and relevant attributes	
Recc	• **I2Q3**:If yes, does it include the minimum information for those terms?
R1.1. (meta)data are released with a clear and accessible data usage license	

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Recc	• Identify the licenses of the reused vocabularies and analyze their compatibility. • Provide a license for the ontology being built compatible with the licenses from the reused ontologies. • **FVF-10**: Vocabularies are released with a standard data usage licence, preferably machine-readable licence. • **G&P-6**: Generate ontology metadata • **Rule-2:** Verify that the legacy-vocabulary license allows repurposing, and agree on the license for the FAIR vocabulary
R1.2. (meta)data are associated with detailed provenance	
Recc	• **P-Rec15**: Provenance information regarding the reuse of components from third-party semantic artefacts should be made explicit
R1.3. (meta)data meet domain-relevant community standards	
	GAP

Table 7 - *LOT4FAIR extension for the Ontology Conceptualization activity.*

Activity	Ontology Conceptualization. During the ontology conceptualization, the domain knowledge obtained from the ORSD document is organised and structured into a model by the ontology developers in collaboration with domain experts and ontology users. Usually, diagrams are generated to sketch the ontology hierarchies and main relations between concepts. It is also possible to generate logic based representations prior to the actual implementation. During this activity notes and documentation related to modelling decisions could be generated.
Resources involved	• Ontology conceptualization, for example diagrams, concept maps, description based on logic languages (prior to the ontology implementation language code)
Roles involved	• Ontology development team • Domain experts • Ontology user
Why	The diagrams generated during this activity could be considered the first ontology version or the precursor of the ontology code, that is, this information could be considered provenance information for the final ontology and an important resource to understand the final ontology model.

Tools	• Ontology drafting tools
	  ○ Chowlk https://chowlk.linkeddata.es/
	  ○ crowd-tool https://crowd-app.fi.uncoma.edu.ar/
	  ○ Menthor Editor https://ontouml.org/ontouml/tooling/
	  ○ DiTTO https://essepuntato.it/ditto/
	  ○ Gra.fo https://gra.fo/
	• Ontology editor
	  ○ Protégé https://protegewiki.stanford.edu/wiki/ProtegeDesktopUserDocs
	  ○ WebProtégé https://protegewiki.stanford.edu/wiki/WebProtege
	  ○ TopBraid Composer https://archive.topquadrant.com/topbraid-composer-install/
	  ○ PoolParty https://www.poolparty.biz/
	  ○ Fluent Editor https://www.cognitum.eu/semantics/FluentEditor/
	• Ontology Design Patterns
	  ○ Reasonable Ontology Templates (OTTR) https://ottr.xyz/
	  ○ ODP Portal http://ontologydesignpatterns.org/wiki/Main_Page

I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation	
Recc	• **I1Q1**: What is the representation language used for the ontology and ontology metadata? • **I1Q2**: Is the representation language used in a W3C Recommendation?
I2. (meta)data use vocabularies that follow FAIR Principles	
Recc	• **I2Q6**: Does the ontology provide information about the relation to or influence of other FAIR vocabularies? • **P-Rec14:** Standard vocabularies should be used to describe semantic artefacts
I3. (meta)data include qualified references to other (meta)data	

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Recc	**GAP** ● In case potential ontologies to be reused are already known in this stage, include the ontology elements URIs in the ontology conceptualization diagrams.
R1. meta(data) are richly described with a plurality of accurate and relevant attributes	
Recc	● **R1Q5**: How much ontology objects are defined using a property restriction or an equivalent class? ● **Rule-3:** Check term and definition completeness and consistency in the legacy vocabulary
R1.2. (meta)data are associated with detailed provenance	
Recc	● Diagrams, concept maps or other conceptualization resources should be identified as provenance information from the ontology. ○ Suggested properties to be used: mod:depiction, (maybe also: http://w3id.org/nkos#basedOn, pav:derivedFrom, schema:isBasedOn) ● **G&P-6**: Generate ontology metadata ● **G&P-8**: Generate diagrams
R1.3. (meta)data meet domain-relevant community standards	
Recc	● **FVF-11**: Vocabularies meet domain relevant community standards

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Table 8 - *LOT4FAIR extension for the Ontology Encoding activity.*

Activity	Ontology Encoding. During this activity, the ontology development team generates computable models in a machine readable format, for example the OWL language.
Resources involved	• Ontology code in an formal implementation language, for example OWL or RDF(S)
Roles involved	• Ontology development team
Why	During this activity the actual machine-readable version of the ontology is produced. It is key to apply FAIR Principles to this resource as it represents the main product of the ontology development process.

Tools	• Ontology drafting tools
	  ○ Chowlk https://chowlk.linkeddata.es/
	  ○ crowd-tool https://crowd-app.fi.uncoma.edu.ar/
	  ○ Menthor Editor https://ontouml.org/ontouml/tooling/
	  ○ DiTTO https://essepuntato.it/ditto/
	  ○ Gra.fo https://gra.fo/
	• Ontology editor
	  ○ Protégé https://protegewiki.stanford.edu/wiki/ProtegeDesktopUserDocs
	  ○ WebProtégé https://protegewiki.stanford.edu/wiki/WebProtege
	  ○ TopBraid Composer https://archive.topquadrant.com/topbraid-composer-install/
	  ○ PoolParty https://www.poolparty.biz/
	  ○ Fluent Editor https://www.cognitum.eu/semantics/FluentEditor/
	  ○ SADL https://github.com/SemanticApplicationDesignLanguage/sadl

F1. (meta)data are assigned a globally unique and persistent identifier	
Recc	• **FVF-1**: Vocabulary and their terms are assigned globally unique and persistent identifiers. • **G&P-1**: Design ontology name and prefix • **G&P-5**: Use of permanent URIs • **F1Q1**: Does the ontology have a "local" identifier, i.e., a globally unique and potentially permanent identifier assigned by the developer (or developing organization)? • **P-Rec1**: Globally Unique, Persistent and Resolvable Identifiers must be used for Semantics Artefacts, their content (terms/concepts/classes and relations) and their versions • **Rule-5**: Assign a unique and persistent identifier to (a) the vocabulary and (b) each term in the vocabulary
F2. data are described with rich metadata (defined by R1 below)	
Recc	• **FVF-2**: Vocabularies and their terms have rich metadata. • **G&P-6:** Generate ontology metadata • **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content • **Rule-7**: Add vocabulary metadata
F3. metadata clearly and explicitly include the identifier of the data it describes	

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Recc	• **G&P-6**: Generate ontology metadata • **F3Q1**: Are the ontology metadata included and maintained in the ontology file? • **F3Q2**: If not, are the ontology metadata described in an external file? • **F3Q3**: Does that external file explicitly link to the ontology and vice-versa?
A1. (meta)data are retrievable by their identifier using a standardized communications protocol	
Recc	• **G&P-1**: Design ontology name and prefix • **G&P-2**: Decide between hash or slash URIs • **G&P-3**: Decide whether to use opaque URIs • **G&P-4**: Define an ontology versioning strategy
A2. metadata are accessible, even when the data are no longer available	
Recc	• **FVF-6**: Vocabularies and their terms are persistent over time and are appropriately versioned • **G&P-9**: Provide the ontology online in multiple formats (HTML and ontology serializations) • **G&P-10**: Make the ontology findable on the Web • **P-Rec8**: Human and machine-readable persistence policies for semantic artefacts metadata and data must be defined
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation	
Recc	• **FVF-7**: Vocabularies and their terms use a formal, accessible and broadly applicable, and preferably machine-understandable language for knowledge representation. • **I1Q3**: Is the syntax of the ontology informed? • **I1Q4**: Is the formality level of the ontology informed? • **I1Q5**: Is the availability of other syntaxes/formats informed? • **P-Rec9**: Semantic artefacts must be made available as a minimum portfolio of common serialisation formats • **P-Rec10**: Foundational Ontologies may be used to align semantic artefacts • **P-Rec11**: A standardised language should be used for describing high expressivity semantic artefacts • **P-Rec12**: Semantic mappings between the different elements of semantic artefacts should be serialised in machine-readable formats • **Rule-6**: Create machine readable representations of the vocabulary terms
I2. (meta)data use vocabularies that follow FAIR Principles	
Recc	• **P-Rec10**: Foundational Ontologies may be used to align semantic artefacts • **P-Rec14**: Standard vocabularies should be used to describe semantic artefacts
I3. (meta)data include qualified references to other (meta)data	
Recc	• **FVF-8**: Vocabularies and terms use qualified references to other vocabularies. • **I3Q1**: Does the ontology provide qualified cross-references to external resources/databases? • **I3Q2**: If yes, are those cross-references well represented and to unambiguous entities? • **I3Q3**: Does the ontology use valid URIs to encode some metadata values? • **P-Rec10**: Foundational Ontologies may be used to align semantic artefacts • **P-Rec12**: Semantic mappings between the different elements of semantic artefacts should be serialised in machine-readable formats
R1. meta(data) are richly described with a plurality of accurate and relevant attributes	

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Recc	• **FVF-2**: Vocabularies and their terms have rich metadata. • **FVF-9**: Vocabularies and terms are described with a plurality of accurate and relevant attributes. • **G&P-6**: Generate ontology metadata • **R1Q6**: How much ontology objects provide provenance information with annotation properties (e.g., author, date)?
R1.1. (meta)data are released with a clear and accessible data usage license	
Recc	• **G&P-6**: Generate ontology metadata
R1.2. (meta)data are associated with detailed provenance	
Recc	• **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content • **P-Rec17**: Provenance must be clear for both humans and machines • **Rule-7**: Add vocabulary metadata
R1.3. (meta)data meet domain-relevant community standards	
Recc	• **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content • **P-Rec12**: Semantic mappings between the different elements of semantic artefacts should be serialised in machine-readable formats

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Table 9 - *LOT4FAIR extension for the Ontology Evaluation activity.*

Activity	Ontology Evaluation. During this activity, the ontology developers guarantee that the ontology does not have syntactic, modelling or semantic errors and that the ontology fulfils all the requirements scheduled for the ontology during the requirements specification activity.
Resources involved	• Ontology code in an formal implementation language, for example OWL or RDF(S) • Ontology evaluation results
Roles involved	• Ontology development team • Ontology users • Domain experts
Why	During this activity, the ontology development team, possibly in collaboration with ontology users and domains experts, check that the ontology does not have syntactic, modelling or semantic errors and that it fulfils all the requirements defined during the requirements specification activity. On the one hand, evaluation results might be considered metadata associated with the ontology that could help potential users to reuse it. On the other hand, this activity might involve the execution of tests that are considered themselves valuable resources to be shared and therefore published following the FAIR Principles.

Tools	• Test running tool
	  ○ THEMIS http://themis.linkeddata.es/
	  ○ TDD Onto2 https://github.com/kierendavies/tddonto2
	• Validator
	  ○ OOPS! https://oops.linkeddata.es/
	  ○ ASTREA https://astrea.linkeddata.es/
	  ○ Shaclgen https://pypi.org/project/shaclgen/
	  ○ Shape designer https://gitlab.inria.fr/jdusart/shexjapp
	• Reasoner
	  ○ Pellet https://github.com/stardog-union/pellet
	  ○ Fact++, http://owl.cs.manchester.ac.uk/tools/fact/
	  ○ Hermit http://www.hermit-reasoner.com/
	  ○ Konclude https://www.derivo.de/en/produkte/konclude.html
	  ○ ORMiE https://gitlab.inf.unibz.it/franconi/ormie-release/
	  ○ Hets https://github.com/spechub/Hets

R1. meta(data) are richly described with a plurality of accurate and relevant attributes	
Recc	• **R1Q1**: Does the ontology provide information about how classes or concepts are defined? • **R1Q2**: Does the ontology provide metadata information about its hierarchy? • **R1Q3**: How much of the ontology objects are described with labels? • **R1Q4**: How much of the ontology objects are defined using a text description?
R1.1. (meta)data are released with a clear and accessible data usage license	
Recc	**GAP** • Provide a licence for the test suites
R1.2. (meta)data are associated with detailed provenance	
Recc	**GAP**

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Table 10 - *LOT4FAIR extension for the Ontology Documentation activity.*

Activity	Ontology Documentation. During this activity the ontology development team in collaboration with the domain experts generates the human oriented ontology documentation.
Resources involved	• Ontology human oriented documentation
Roles involved	• Ontology development team • Ontology users • Domain experts
Why	During this activity, the ontology development team, in collaboration with the domain experts and users, generates the ontology human oriented documentation. This documentation usually includes an HTML description of the ontology describing the classes, properties and data properties of the ontology This description also includes metadata, such as title, description, licence, creator, publisher, date of creation, last modification or version number. The documentation also should include diagrams, taxonomies, and examples of use. As this documentation is key for others to understand the ontology being developed, it is crucial to make it complete and available to increase the reusability of the ontology.

Tools	• Ontology documentation generator
	  ○ WIDOCO https://dgarijo.github.io/Widoco/doc/tutorial/
	  ○ LODE https://essepuntato.it/lode/
	  ○ pyLODE https://github.com/RDFLib/pyLODE

F1. (meta)data are assigned a globally unique and persistent identifier	
Recc	• **F1Q3**: Are the ontology metadata clearly identified either by the same identifier than the ontology (if included in the ontology file) or with its own globally unique and persistent identifier? • **F1Q4**: Does the ontology provide a version-specific URI, and is this URI resolvable?
F2. data are described with rich metadata (defined by R1 below)	
Recc	• **FVF-2**: Vocabularies and their terms have rich metadata. • **G&P-6**: Generate ontology metadata • **F2Q1**: Is the ontology described with additional 'MIRO must' metadata properties? • **F2Q2**: Is the ontology described with additional 'MIRO should' or 'optional' metadata properties? • **F2Q3**: Is the ontology described with another metadata property with no explicit corresponding MIRO requirement? • **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content • **Rule-7**: Add vocabulary metadata
F3. metadata clearly and explicitly include the identifier of the data it describes	
Recc	• **G&P-6**: Generate ontology metadata
A1. (meta)data are retrievable by their identifier using a standardized communications protocol	
Recc	• **FVF-3**: Vocabularies and their terms can be accessed using the identifiers, preferably by both human and machine.

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	• **A1Q1**: Do the ontology URI and other identifiers, if they exist, resolve to the ontology? • **A1Q2**: Does the ontology URI (if metadata are included in the ontology file) or the external metadata URI resolve to the metadata record? • **A1Q3**: Do the ontology URI and the external metadata URI (if the metadata are not included in the ontology file), support content negotiation?
I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation	
Recc	**GAP**
I2. (meta)data use vocabularies that follow FAIR Principles	
Recc	**GAP**
I3. (meta)data include qualified references to other (meta)data	
Recc	• **FVF-8**: Vocabularies and terms use qualified references to other vocabularies. • **P-Rec15**: Provenance information regarding the reuse of components from third-party semantic artefacts should be made explicit
R1. meta(data) are richly described with a plurality of accurate and relevant attributes	
Recc	• **FVF-9**: Vocabularies and terms are described with a plurality of accurate and relevant attributes. • **G&P-8**: Generate diagrams
R1.1. (meta)data are released with a clear and accessible data usage license	
Recc	• **FVF-10**: Vocabularies are released with a standard data usage licence, preferably machine-readable licence. • **G&P-6**: Generate ontology metadata • **R1.1Q1**: Is the ontology license clearly specified, with an URI that is resolvable and supports content negotiation? • **R1.1Q2**: Are the ontology access rights specified and permissions documented? • **R1.1Q3**: Are the ontology usage guidelines and copyright holder documented? • **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content • **P-Rec16**: Semantic artefacts must be clearly licenced for use by machines and humans
R1.2. (meta)data are associated with detailed provenance	
Recc	• **R1.2Q1**: Does the ontology provide information about the actors involved in its development? • **R1.2Q2**: Does the ontology provide information about its general provenance? • **R1.2Q3**: Are the accrual methods and policy of the ontology documented? • **R1.2Q4**: Is the ontology clearly versioned with version information and links to previous versions? • **R1.2Q5**: Are the ontology latest changes documented? • **R1.2Q6**: Are the methodology and tools used to build the ontology documented? • **R1.2Q7**: Is the ontology rationale documented? • **R1.2Q8**:Does the ontology inform about its funding organization? • **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content • **P-Rec15**: Provenance information regarding the reuse of components from third-party semantic artefacts should be made explicit

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	• **P-Rec17**: Provenance must be clear for both humans and machines • **Rule-7**: Add vocabulary metadata
R1.3. (meta)data meet domain-relevant community standards	
Recc	• **R1.3Q1**: Does the ontology provide information about projects using or organizations endorsing? • **R1.3Q2**: Is the ontology included in a specific community set or group? • **P-Rec3**: A common minimum metadata schema must be used to describe semantic artefacts and their content

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Table 11 - *LOT4FAIR extension for the Ontology Publication activity.*

Activity	Ontology Publication. During this activity the ontology is made available online and accessible via its namespace URI as a machine-readable file and a human readable documentation using content negotiation.
Resources involved	• Ontology source files • Ontology documentation
Roles involved	• Ontology development team • Ontology manager / steward
Why	During this activity the ontology development team (possibly aided by system administrators) make the ontology available online. Due to the fact that during this activity no new resources are generated, the guidelines correspond mostly to the technical aspects of the activity.

Tools	• Publication server/service
	  ○ General purpose web servers to manage web domains.
	  ○ w3id https://w3id.org/
	  ○ purl https://purl.archive.org/
	• Ontology Repository
	  ○ LOV https://lov.linkeddata.es
	  ○ AgroPortal http://agroportal.lirmm.fr/
	  ○ IndustryPortal http://industryportal.enit.fr/
	  ○ BioPortal https://bioportal.bioontology.org/
	  ○ BARTOC https://bartoc.org/
	  ○ Ontohub https://ontohub.org/
	  ○ OntoBee https://ontobee.org/
	  ○ ODP Portal http://ontologydesignpatterns.org/wiki/Main_Page
	  ○ DBpedia Archivo https://archivo.dbpedia.org/list
	  ○ Ontology Lookup Service (OLS) https://www.ebi.ac.uk/ols/index
	• Ontology FAIRnes Validator
	  ○ FOOPS! https://w3id.org/foops/
	  ○ O'FAIRE https://github.com/agroportal/fairness

F1. (meta)data are assigned a globally unique and persistent identifier	
Recc	• **FVF-1**: Vocabulary and their terms are assigned globally unique and persistent identifiers. • **G&P-5**: Use of permanent URIs • **F1Q2**: Does the ontology provide an additional "external" identifier, i.e., a guarantee globally unique and persistent identifier assigned by an accredited body? If yes, is the external identifier a DOI? • **P-Rec2**: Globally Unique, Persistent and Resolvable Identifiers must be used for Semantic Artefact Metadata Records. Metadata and data must be published separately, even if it is managed jointly
F3. metadata clearly and explicitly include the identifier of the data it describes	
Recc	• **P-Rec2**: Globally Unique, Persistent and Resolvable Identifiers must be used for Semantic Artefact Metadata Records. Metadata and data must be published separately, even if it is managed jointly
F4. (meta)data are registered or indexed in a searchable resource	

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Recc	• **FVF-4**: Vocabularies and their terms are registered or indexed in a searchable engine or a resource. • **G&P-10**: Make the ontology findable on the Web • **F4Q1**: Is the ontology registered in multiple ontology 'libraries'? • **F4Q2**: Is the ontology registered in multiple open ontology 'repositories'? • **F4Q3**: Are the ontology 'libraries' or 'repositories' properly indexed by Web search engines? • **P-Rec4**: Semantic Artefact and its content should be published in an appropriate semantic repository • **P-Rec5**: Semantic repositories must offer a common API to access semantic artefacts and their content in various serialisations for both use/reuse and indexation by search engines • **Rule-8**: Register the vocabulary
A1. (meta)data are retrievable by their identifier using a standardized communications protocol	
Recc	• **FVF-5**: Vocabularies and their terms are retrievable using a standardised communications protocol, preferably open, free and universally implementable protocols. and allows for authentication and authorisation, where necessary. • **G&P-1**: Design ontology name and prefix • **G&P-2**: Decide between hash or slash URIs • **G&P-4**: Define an ontology versioning strategy • **A1Q4**: Are the ontology and its metadata accessible through another standard protocol such as SPARQL? • **P-Rec5**: Semantic repositories must offer a common API to access semantic artefacts and their content in various serialisations for both use/reuse and indexation by search engines • **Rule-9**: Make the vocabulary accessible for humans and machines
A1.1 the protocol is open, free, and universally implementable	
Recc	• **FVF-5**: Vocabularies and their terms are retrievable using a standardised communications protocol, preferably open, free and universally implementable protocols. and allows for authentication and authorisation, where necessary. • **G&P-9**: Provide the ontology online in multiple formats (HTML and ontology serializations) • **A1.1Q1**: Is the ontology relying on HTTP/URIs for its identification and access mechanisms? • **A1.1Q2**: Is the ontology access protocol open, free, and universally implementable? • **A1.1Q3**: If the ontology and metadata are accessible through another protocol, is that protocol open, free, and universally implementable? • **P-Rec5**: Semantic repositories must offer a common API to access semantic artefacts and their content in various serialisations for both use/reuse and indexation by search engines
A1.2 the protocol allows for an authentication and authorization procedure, where necessary	
Recc	• **FVF-5**: Vocabularies and their terms are retrievable using a standardised communications protocol, preferably open, free and universally implementable protocols. and allows for authentication and authorisation, where necessary. • **A1.2Q1**: Is the ontology accessible through a protocol that supports authentication and authorization? • **A1.2Q2**: Are the ontology metadata accessible through a protocol that supports authentication and authorization? • **P-Rec7**: Repository should offer a secure protocol and user access control functionalities
A2. metadata are accessible, even when the data are no longer available	
Recc	• **FVF-6**: Vocabularies and their terms are persistent over time and are appropriately versioned • **G&P-10**: Make the ontology findable on the Web

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I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation	
Recc	• **G&P-9**: Provide the ontology online in multiple formats (HTML and ontology serializations) • **P-Rec9**: Semantic artefacts must be made available as a minimum portfolio of common serialisation formats
R1.1. (meta)data are released with a clear and accessible data usage license	
Recc	• **FVF-10**: Vocabularies are released with a standard data usage licence, preferably machine-readable licence. • **G&P-6**: Generate ontology metadata
R1.2. (meta)data are associated with detailed provenance	
Recc	• **FVF-6**: Vocabularies and their terms are persistent over time and are appropriately versioned • **P-Rec13**: Crosswalks, mappings and bridging between semantic artefacts should be documented, published and curated
R1.3. (meta)data meet domain-relevant community standards	
Recc	• **R1.3Q3**: Is the ontology openly and freely available? • **P-Rec13**: Crosswalks, mappings and bridging between semantic artefacts should be documented, published and curated

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Table 12 - *LOT4FAIR extension for the Ontology Maintenance phase.*

Phase	Ontology Maintenance. The goal of this phase is to update and add new requirements to the ontology that are not identified in the ORSD, to identify and correct errors or to schedule a new iteration for ontology development.
Resources involved	• Issues, bugs, comments, etc.
Roles involve:	• Ontology development team • Ontology users • Domain experts • Ontology manager / steward
Why	This phase does not involve active development from the ontology development team, instead the phase is a way to collect new issues, comments, bugs reports, etc, in order to trigger new ontology development or refinement cycles. As it could trigger new versions of the ontology and related resources and therefore needs for updating metadata and published resources, this phase should be taken into account when addressing FAIR Principles during the ontology lifecycle.

Tools	• Issue tracking systems (this systems are also recommended to handle all resources lifecycle)
	  ○ GitHub https://github.com/
	  ○ GitLab https://about.gitlab.com/
	  ○ Jira https://www.atlassian.com/software/jira
	  ○ Mantis https://www.mantisbt.org/
	• Ontology development management systems:
	  ○ OnToology http://ontoology.linkeddata.es/
	  ○ VocBench https://ec.europa.eu/isa2/solutions/vocbench3_en
	  ○ VocoReg https://www.vocoreg.com/

F1. (meta)data are assigned a globally unique and persistent identifier	
Recc	**GAP**
F4. (meta)data are registered or indexed in a searchable resource	
Recc	**GAP**
A2. metadata are accessible, even when the data are no longer available	
Recc	• **FVF-6**: Vocabularies and their terms are persistent over time and are appropriately versioned • **A2Q1**: Is the ontology accessible in a repository that supports versioning? • **A2Q2**: Are the ontology metadata of each version available? • **A2Q3**: Are the ontology metadata accessible even if no more versions of the ontology are available? • **A2Q4**: Is the status of the ontology clearly informed? • **P-Rec8**: Human and machine-readable persistence policies for semantic artefacts metadata and data must be defined
I3. (meta)data include qualified references to other (meta)data	
Recc	• **Rule-10**: Implement a process for publishing revisions of the FAIR vocabulary

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5. Conclusions and next steps

This milestone has described the current progress towards the definition of a FAIR by design methodology for building semantic artefacts. More precisely, one of the existing methodologies has been aligned with existing FAIR related guidelines and existing ontology engineering tools. In addition, through a brainstorming process new needs for considering FAIR Principles when building semantic artefacts have been identified and mapped to the methodology.

In order to describe the FAIR by design methodology, LOT4FAIR, a template has been defined and preliminary filled in for 2 LOT phases and 6 activities. This constitutes the baseline from which T4.2.1 partners will work in order to refine current results and provide recommendations to fill the gaps identified in the final version of the methodology to be reported in D4.2.

During this work, collaboration with partners and FAIR guidelines authors have been established. In addition, some conclusions can be raised from the analysis carried out, for example that the ontology requirements activity has been neglected by existing guidelines about how to build FAIR ontologies, while more technical activities like the encoding and publication are in general well covered by existing recommendations.

The work of this milestone will be summarised in a research paper, to be published during the lifetime of the project.

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