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ONTO-DESIDE

DELIVERABLE

Ontology network architecture, methodology and alignment plan - v.1

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PROJECT INFORMATION

Project summary

Circular economy aims at reducing value loss and avoiding waste, by circulating materials or product parts before they become waste. Today, lack of support for sharing data in a secure, quality assured, and automated way is one of the main obstacles that industry actors point to when creating new circular value networks. Together with using different terminologies and not having explicit definitions of the concepts that appear in data, this makes it very difficult to create new ecosystems of actors in Europe today. This project will address the core challenges of making decentralized data and information understandable and usable for humans as well as machines. The project will leverage open standards for semantic data interoperability in establishing a shared vocabulary (ontology network) for data documentation, as well as a decentralized digital platform that enables collaboration in a secure and privacy-preserving manner.

The project addresses several open research problems, including the development of ontologies that need to model a wide range of different materials and products, not only providing vertical interoperability but also horizontal interoperability, for cross-industry value networks. As well as transdisciplinary research on methods to find, analyze and assess new circular value chain configurations opened by considering resource, information, value and energy flows as an integral part of the same complex system. Three industry use cases, from radically different industry domains, act as drivers for the research and development activities, as well as test beds and demonstrators for the cross-industry applicability of the results. The developed solutions will allow for automation of planning, management, and execution of circular value networks, at a European scale, and beyond. The project thereby supports acceleration of the digital and green transitions, automating the discovery and formation of new collaborations in the circular economy.

Project start date and duration

1st of June 2022, 36 months

Project consortium

No	Partner	Abbreviation	Country
1	Linköping University	LIU	Sweden
2	Interuniversitair Micro-Electronica Centrum	IMEC	Belgium
3	Concular Ug Haftungsbeschrankt	CON	Germany
4	+Impakt Luxembourg Sarl	POS	Luxembourg
5	Circularise Bv	CIRC	The Netherlands
6	Universitaet Hamburg	UHAM	Germany
7	Circular.Fashion Ug (Haftungsbeschrankt)	FAS	Germany
8	Lindner Group Kg	LIN	Germany
9	Ragn-Sells Recycling Ab	RS	Sweden
10	Texon Italia Srl	TEXON	Italy
11	Rare Earths Industry Association	REIA	Belgium

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1.0	2023-02-28	Eva Blomqvist	PC	LIU

Contents

Abbreviations

Abbreviation	Explanation
CE	Circular Economy
CQ	Competency Question
CS	Contextual Statement
CVN	Circular Value Network
Dx.x	Deliverable x.x
EOSC	European Open Science Cloud
FAIR	Findability, Accessibility, Interoperability, Reusability
ISO	International Organization for Standardization
LOV	Linked Open Vocabularies
ODP	Ontology Design Pattern
OGC	Open Geospatial Consortium
OWL	Web Ontology Language
RDF	Resource Description Framework
RR	Reasoning Requirement
URI	Uniform Resource Identifier
W3C	World Wide Web Consortium
WP	Work Package
XD	eXtreme Design

Summary

This deliverable describes the initial research work conducted in WP3, as part of the first project iteration, and leading up to the first set of ontology modules to be reported in D3.3. The deliverable covers the three main activities that have been performed so far, which include (1) designing and setting up the methodology for ontology development, alignment and FAIR ontology publishing, initially targeting mainly the project initiation, scoping, and requirements analysis steps, (2) performing an extensive survey of existing ontologies, as well as policies and standards, that the Onto-DESIDE ontology network needs to take into account, and potentially align to, (3) developing an initial set of ontological requirements, derived from both our own set of overall project requirements reported in D2.1, as well as use case descriptions in D6.1, and policies, emerging standards, and other resources, that lead to the outline of an initial ontology network architecture and a set of initial ontology modules that we will deliver in D3.3.

The methodology of this work package is based on an existing, agile and iterative, ontology engineering methodology. This methodology is analysed and some adaptations are being made to make it more fit-for-purpose in the context of this project. A first set of adaptations, mainly focusing on scoping and requirements analysis, are discussed in this deliverable.

Next, when analysing the existing ontologies found in our survey, we note that a main notion missing in Circular Economy (CE) ontologies is the circular value network (CVN) itself. A circular value network consists of collaborating actors, implementing some circular strategies, therefore "actor" is a central concept, as well as their capabilities and processes for implementing the strategies. Still, most existing ontologies focus heavily on the material flows, material composition of products and components, and digital product passports. We, hence, observe that there are some additional concepts to model to be able to create a digital representation of such networks themselves, i.e. creating a digital twin of a circular value network. Therefore, our ontological requirements specifically covers this aspect, and such modules will be a central part of the ontology network.

On the other hand, many of the other core concepts, such as products, processes and materials have been modelled in many existing ontologies. In these cases, the challenge will be more related to creating appropriate alignments to those ontologies, as well as being able to represent the contextual nature of some of these concepts in our ontology network. For instance, what one stakeholder in a circular value network may consider a product, i.e. something they put on the market and sell, might very well be considered a component or even material by another stakeholder. Additionally, challenges involve to be able to appropriately align to the emerging standards in the CE domain.

Next steps, following D3.1, includes the concrete modelling of the outlined modules, which will result in the release of D3.3, and the publishing of an extended version of the survey results in a scientific journal.

1 Introduction

Semantic interoperability of data is one of the biggest barriers towards data sharing in the Circular Economy (CE) domain [48]. This means that although concrete data formats may be agreed and standardised, it is still difficult to interpret the data correctly, and thereby data from different organisations can often not be integrated and used together. The Onto-DESIDE project will provide the technical foundations for semantic interoperability in information flows that has the potential to transform digitalisation and data sharing to support a (more) CE. The project makes use of open standards for semantic data interoperability in establishing a shared vocabulary, i.e. a network of ontologies for data documentation, as well as a decentralized digital platform that enables collaboration in a secure and confidential manner. Ontologies are a key enabler for semantic interoperability since they can provide formal definitions of concepts and their relations, for describing the data to be exchanged. What this project will develop is at its basis a technology for allowing data sharing about materials, components, and products, as well as actors, capabilities and processes, as part of circular value networks (CVNs), at a global scale and across industry domains. Metadata and structures for transforming data into information (semantic descriptions, vocabularies) will be open, and comply with FAIR principles (Findability, Accessibility, Interoperability, and Reusability), to enable the highest possible degree of semantic interoperability and automation in data sharing.

This deliverable presents the initial work in Onto-DESIDE WP3, which is dedicated to provide the necessary ontologies to enable semantic interoperability. The deliverable is specifically concerned with the ontology engineering methodology, strategies for ontology alignment and publishing, and the requirements of the ontology network itself. This is the first version of the deliverable, presenting initial results from the first project iteration, while the following version (D3.2) will present updates and extensions to this initial work. This concretely means that the deliverable reports ongoing work in our first project iteration, and that both survey results, and ontology requirements are to be considered as preliminary, since they are not fully validated by domain experts yet. More details on the methodological aspects and limitations can be found in the methodology description in Chapter 3.

1.1 Motivation

In order to create digital twins of circular value networks, and enable automation in both the discovery, setup and execution of such networks, a formal definition of the entities involved in such networks is needed. In the simplest case, this may be merely to be able to transfer trustworthy, semantically well-defined and documented data about the materials, components, and products themselves between actors, e.g. a deconstruction company allows data about the deconstructed building parts to be accessed by the recycling company that receives these parts, who can then make appropriate plans and decisions based on their recycling potential (c.f. D2.1 user story CUS11: Planning). However, more complex scenarios also exist, for instance when setting up new circular value networks. An example could be when trying to understand if the rest material from the production in one manufacturing company could be used by someone else, potentially in a completely different industry domain (c.f. D2.1 CUS4: Rest Material from Production). This requires both information about the potential actors that may use the material, their types and capabilities, as well as input requirements for various production processes. In our overall project description we have envisioned this as the potential of having "blueprints" of typical circular value networks, where roles can then be filled by concrete actors and concrete materials, components, and products. Hence, although we do not necessarily envision that explicit data about complete value networks exist anywhere, actors will need to be able to retrieve also semantically well-defined data about other actors, their needs and capabilities, in order to support some degree of automation when discovering, assessing, setting up and executing parts of a circular value network.

To enable such data to be understood by both humans and machines, it should be semantically well described and documented, i.e. by being linked to an ontology. Using a shared ontology enables actors to achieve not only syntactic interoperability, e.g. shared or standardised file formats, but also semantic interoperability, i.e.

ensuring a well-defined meaning of the data content itself. Although in the best case the actors share the same ontology, even if that is not the case, having such semantic data documentation at least allows actors to retrieve the intended meaning, and potentially map it to their own ontologies and data models in a reliable way. Hence, although this project will also work towards standardisation of these ontologies, as a first step merely having a formal definition of the semantics will be useful in itself.

Further, since the domain of circular economy and circular value networks is very broad, and may involve actors and products in any industry domain, it is obvious that creating one single ontology to encompass all possible data to be documented is infeasible. Hence, the focus is here on an ontology network. An ontology network is a "*collection of ontologies related together via a variety of relationships, such as alignment, modularization, version, and dependency*" [68]. This enables users to include the necessary parts of the network applicable to their use cases, without having to use a huge monolithic ontology, which both improves understandability, learnability, and reuse potential. It also enables us to reuse and align to numerous existing ontologies, some of which are already (de-facto) standards in certain fields.

1.2 Deliverable Objectives

In Onto-DESIDE, WP3 is responsible for developing one of the core outcomes of the project, the ontology network for data documentation and its alignment to relevant standards and existing ontologies, but also to manage the documentation and FAIR publishing of the ontologies. The objectives of this first version of the deliverable, and the first iteration of work in WP3 are setting the stage for the ontology network to be developed through both an extensive review of the state-of-the-art and related work, describing the methodology of the further development of the ontology network, as well as identifying and planning the architecture of the first set of core modules needed in the ontology network.

The deliverable reports preliminary results, in the sense that work is still ongoing to ensure the completeness of the survey results, as well as validating the ontological requirements with the domain experts in the project. The currently reported results have only been validated internally with the partners involved in WP3, but will in the coming months be validated also in the context of our use cases, i.e. WP6.

1.3 Tasks and Document Outline

WP3 consists of 4 separate, but interrelated, tasks. Task 3.1 concerns the ontology development methodology. The methodological setup for the ontology development will consist of both a variant of an existing ontology engineering methodology, specifically tailored for the project setup, as well as detailed guidelines for ontology specialisation (i.e. extending the ontology network) and population (i.e. mapping data to the ontology) to be used within the three industry use cases in WP6. The methodology will also be aligned to the overall project research methodology specified in WP2, and the circularity metabolism concept of WP5. In this initial version of the deliverable, we mainly focus on the first steps of the methodology, i.e. project initiation and scoping as well as the knowledge acquisition and requirements analysis tasks. Since not all principles of the original methodology are immediately applicable to our project, we discuss how the methodology has been adapted to suit our specific context. Included in this deliverable related to Task 3.1 is a presentation of the original methodology, called eXtreme Design (XD), as well as a discussion of the adaptations needed for the project context. Further methodology development will then take place in the next project iterations.

Task 3.2 concerns the ontology modelling itself. The focus of this task is on carrying out the actual modelling of the ontology network, by using the modelling methodology from Task 3.1, based on requirements (user stories) from WP2, contextualised by the use case descriptions produced in WP6, that are then transformed into ontological requirements. The modelling will include both highly reusable generic ontology modules, which could be viewed as a form of Ontology Design Patterns (ODP) forming a core module library (ODP catalogue), as well as more specific ontology modules as specialisations and extensions of the generic ones. The latter also includes alignment modules, relating our modules to existing ontologies. Quality assurance of the ontology modules will be performed through ontology testing and validation activities, before releasing each module, although the ontology network should still be considered as a prototype and subject to change until the final release at the end of the project. While we outline the intended ontology architecture and topics of the first set of core modules in this deliverable, the actual ontology modules will be delivered and described in detail in D3.3, and following updates of that deliverable.

Task 3.3 focuses on ontology alignment, which is a central issue in a cross-domain interoperability effort such as the Onto-DESIDE project. The task will ensure proper alignment to existing ontologies, such as OntoCommons core ontologies, and integration with other domain ontologies, such as existing materials ontologies. Specific alignment modules will be produced, and ontology debugging and completion tools will be used for extending and ensuring the quality of the alignments. However, in this deliverable only the overall strategy is described, while details on the actual alignment modules will be included in D3.3 (and following versions of that deliverable).

Finally, Task 3.4 is concerned with FAIR ontology publishing and maintenance. Ontology publishing will be conducted according to the FAIR principles, and using an open platform, i.e. GitHub. All ontology modules will be properly documented, for ease of use and increased reuse, version control. As well as a change request and management system, e.g. through issue tracking, which will be put into place for the later versions of the ontologies. Included in this deliverable is a description of an initial publishing pipeline, and the main principles underlying it. The task will also develop a plan for ontology maintenance and evolution beyond the project lifetime, including both methodological and practical/technical aspects, although this will only be reported in later versions of this deliverable.

This deliverable presents the initial results of the four tasks described above, i.e. the ontology development methodology (up to the requirements analysis step), the overall ontology network architecture and initial core ontology modules, as well as alignment strategies and an overview of existing ontologies, and our publishing strategy. This is the first version of the deliverable, presenting initial results, which will be further extended and properly validated in the following version of the deliverable (D3.2). Hence, this version of the deliverable puts its main focus on surveying the state-of-the-art, in terms of existing ontologies and methodologies, and setting the stage for further work in WP3.

The remainder of the document is structured as follows: In Chapter 2 we introduce some of the basic notions and technologies used in the remainder of the document, e.g. ontologies, ontology modules and networks, as well as some background on ontology engineering, ODPs and the XD methodology. This chapter is intended for readers not already familiar with these concepts. Next, we present our initial methodology and the research process applied so far in WP3 in Chapter 3. Chapters 4 and 5 then present our preliminary results, on one hand providing an overview of the existing ontologies and other resources found so far, and on the other hand our set of requirements and the initial outline of the first version of the ontology network. Finally, some concluding remarks are made in Chapter 6.

2 Background

In order for this deliverable to be understandable by a broad audience, including researchers and practitioner in the circular economy field, in this chapter we briefly introduce some of the basic notions used in this work and the deliverable. From the perspective of knowledge representation, we introduce ontologies in Section 2.1. Then in Section 2.2, we introduce ontology engineering with a focus on ontology development.

2.1 Ontologies

The term ontology is used in several fields, including both philosophy and computer science. In this project we focus on the computer science-related notion of ontology. There are multiple definitions of the term "ontology", even within the field of computer science, but one of the most commonly cited definitions states that an ontology is an "*explicit specification of a conceptualization*" [25]. Some later definitions have also added aspects, such that the ontology should represent a *shared* conceptualisation, and that the explicit specification should be *formal*, in the sense of being expressed in some (logical) language with formal semantics. Another common definition explains it like this: "*An ontology is a logical theory accounting for the intended meaning of a formal vocabulary, i.e., its ontological commitment to a particular conceptualisation of the world. The intended models of a logical language using such a vocabulary are constrained by its ontological commitment. An ontology indirectly reflects this commitment by approximating these intended models.*" [27]. More informally, this means that and ontology in computer science is an artefact, that consists of a formal structure that explicitly defines the concepts and relations between concepts existing within some domain, or related to a specific application. Depending on how narrow and well-specified the definitions in the ontology are, the ontology could make more or less ontological commitments.

To explain this a bit more, let's take an example of a small (naïve) ontology relating to university courses. This ontology may contain the three concepts "Person", "University" and "Course". In addition to these concepts, the ontology would contain relevant relations between the concepts, such as that a course is given at a certain university, and that persons take courses. An informal illustration of such an ontology, in the form of a simple conceptual diagram, can be seen in Figure 1. This ontology can now be used to annotate, or describe, data by expressing that certain instances are of the type "Person" and others have the type "University", for instance, and that certain relations from the ontology hold between the instances, i.e. specific persons are related to specific courses via the "takes"-relation. So far, this is not very different from adding descriptive column headings to a data table, in case of tabular data, except for the fact that data can be seen as a graph. However, in the case of ontologies, named concepts and relations are only the starting point, because when implementing this conceptual model in a formal logical language, we can also add further formal definitions and restriction on these concepts and relations, i.e. we can express general *axioms*. Such things could for instance be to define a new concept based on restrictions over existing ones, e.g. to say that students are exactly those persons who are enrolled at some university or who take some course, subsequently allowing an inference engine to automatically classify instances of person as being students or not. Or to restrict the types of things for which the relations apply, e.g. saying that the "given at" relation always relates a university to a course. However, the more such axioms that are added, the more we extend the ontological commitment of the ontology. The benefit is that we can then draw more conclusions based on the ontology, i.e. perform automatic inferencing, such as consistency checking or finding new facts that are derivable from our data, as in the case of finding out who is a student above. The drawback is that such axioms rarely hold universally, but merely in a restricted domain. For instance, if we express that all courses are given by a university, we exclude evening classes given by other types of organisations, and even lower grade courses given by schools and other kinds education establishments. Concepts, relations and axioms that make sense in one domain, may not make sense if that domain is extended, or if the domain is exchanged for another one. Hence, the ontology becomes less reusable outside the originally intended domain(s) and task(s). This trade-off is important to note, and will be discussed further when we discuss ontology engineering methodology and modularisation of ontologies.

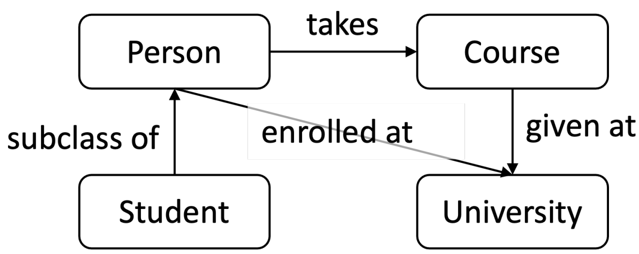

Figure 1: A small sample ontology, illustrated through an informal conceptual diagram. Concepts are represented at "boxes" and the arrows represent "relations" between concepts.

Different logical formalisms exist for representing and reasoning with ontologies, each one having its own benefits and drawbacks. The choice of representation should be made based on the requirements of the ontology, but also standardisation and tool availability may influence such a decision. However, with the emergence of the W3C standards RDF[1] [62] (for graph data) and RDFS/OWL (for ontology representation), the predominant formalism is nowadays OWL (Web Ontology Language) [51]. Especially in cases where ontologies and data will be shared over the Web, or at least using Web technologies, RDFS/OWL is considered the best choice. Therefore, also in this project we focus on ontologies expressed using these standard languages. RDFS is a basic ontology language, only allowing to express a few primitives, such as classes (concepts), subclass relations with specific semantics (allowing to express a taxonomy, i.e. hierarchy, of concepts and their subconcepts, such as the relation in the figure above where every "Student" is also a "Person"), general relations (object- and datatype properties), annotations such as labels and comments etc. OWL adds further expressivity and inferencing capabilities on top of RDFS. However, it is again important to note the trade-offs. Adding complex expressions to the ontology increases the complexity, and hence both reduces the efficiency of inferences over the ontology (e.g. increased computing time), as well as increases the time for humans to understand and assess the ontology, and narrows the domain where the ontology can be reused. On the other hand, increased expressivity of the ontology may give benefits in terms of more precise definitions and more opportunity for both consistency checking, and drawing new conclusions from existing data. Similarly, the scope of the ontology needs to be carefully considered, since a larger or more detailed ontology may be more useful in a specific case, but may again be less reusable and harder to grasp for non-experts. In an ontology development project it is therefore essential to carefully analyse the ontological requirements at hand, i.e. both in terms of what classes, properties and axioms are actually needed in the ontology (scope and expressivity), as well as other requirements, such as how much emphasis should be put on reusability, extensibility, and understandability of the ontology. Consequently, ontological requirements play a crucial role also in our ontology development effort in Onto-DESIDE.

2.2 Ontology Engineering

In order to structure the process of creating an ontology, and to ensure the quality of the resulting ontology, several methodologies for creating ontologies have emerged. Examples of commonly referenced ontology engineering methodologies include METHONTOLOGY [18], ontology development 101 [49], the method for developing enterprise ontologies by Gruninger & Fox [26] (also the first to introduce the notion of Competency Questions as ontology requirements), and the NeOn family of methods [69]. More recent methodologies commonly focus on an *agile process*, such as eXtreme Design (XD) [5], SAMOD [52], and the modular ontology development suggested in [66] (as a variant of XD), *test-driven development* [33], or on the *iterative evolution* of ontologies, such as DILIGENT [54]. Each methodology has its own benefits and drawbacks, and is suitable for certain development contexts and less suitable for others. For instance, the earlier methodologies were

[1] Original version of the standard was established already in 1999. RDF specifies a data model for representation of graph data using other Web standards, such as URIs for globally unique identifiers and data linking, and comes with a dedicated query language, SPARQL.

often describing a waterfall-like process, where careful scoping, listing of all terms to be covered, and agreeing on all definitions in the ontology, should precede the implementation of the ontology axioms. However, often this is neither suitable nor practically feasible, since most project requirements evolve, and tangible results are needed early on, in order to be able to test other components of some system or dataset that is to use the ontology. Hence, most often an iterative and incremental process is nowadays used to develop ontologies. This is also why in this project we have decided to use a variant of the XD methodology, to benefit from its focus on both incremental and iterative development, as well as modularisation of the resulting ontologies.

2.2.1 Modularisation and Ontology Design Patterns

The NeOn project was probably the first to introduce the notion of an *ontology network*, as mentioned in the introduction to this deliverable. Nowadays, most ontologies consist of an ontology network in some way, e.g. importing or relating to external ontologies, or consist of a set of modules focusing on various sub-domains of the overall ontology. Modularisation is supported by OWL in terms of the `owl:imports` statement, which effectively imports all axioms of an external ontology into the current one. This can be used in order to further extend and specialise an ontology (module), without affecting the module being imported. Note that an import statement effectively imports all axioms of the external ontology, and they cannot be modified, since the import is done based on the ontology URI, i.e. by pointing to the location of the ontology online. This on one hand ensures that the import always fetches the current version of an ontology, but this can also be a drawback if the ontology changes, since it is not always clear what axioms the importing ontology will contain at any given time. However, for modularisation of an own set of ontology modules, where we are in control over all those modules, `owl:imports` works well.

For the ontology users, e.g. developers creating an application or an interface based on the ontology, there may be an increased complexity in understanding the ontology if it has a large transitive import closure. Instead, separate alignment modules can be created anticipating the need to sometimes reuse an external ontology. In this way, the ontology user can choose to add that alignment module, and consequently the import(s), on a per-need basis, rather than having it as mandatory part of the ontology. In this way, the Onto-DESIDE project aims to manage the large amount of external and related ontologies that have been identified, which is discussed later in this deliverable.

However, apart from the technical concerns and motivations for modularisation discussed above. Modularisation can also be seen as a way to separate concerns, and focus on one modelling aspect (or small sub-domain) at a time. This helps the ontology engineer to focus, and treat a manageable amount of ontological requirements at a time. This is essential when applying an incremental and agile ontology engineering methodolody, such as XD.

In addition to modularisation, we also briefly introduce the notion of Ontology Design Patterns. Ontology Design Patterns (ODPs) [6, 19, 20] were originally proposed partly as a result of observing how difficult it is to reuse a large ontology. This observation even includes foundational ontologies clearly designed for being reused as the basis for building other ontologies. Issues include that it is difficult to get an overview of such large ontologies, foresee effects of changes or extensions to them, and it is also rarely the case that you as an ontology engineer, or the set of requirements you have for your ontology engineering task at hand, will fully agree with all the ontological commitments that are made in such a large ontology. However, not reusing any well-established practices at all, and not aligning yourself at least partly to existing ontologies, will create problems in interoperability and potentially also understandability of your ontology. Hence, there is a trade-off between interoperability on one hand and overcommitment and conflicting requirements on the other hand, where ODPs as small general “conceptual building blocks” offer one way to manage this trade-off. Hence, the idea of reusing, applying and sharing small patterns instead of complete ontologies, applies in many contexts.

There are many different types of ODPs, and they can be reused and applied in many different ways [6, 19, 20]. Even when considering only what is called Content ODPs, i.e., ODPs that focus on modelling solutions on the conceptual level and may constitute “building blocks” for your ontology, which we target here, there are a variety of ways that these can be reused and applied. At one end of the scale, ODPs can be used similarly to design patterns in architecture, or how patterns many times are used in software engineering, i.e., as mere inspiration and a conceptual framework to keep in mind when designing your own solution. An example of this way of applying a pattern would be to read about its basic idea in a book, or an online catalogue, incorporate this idea into your own knowledge, and then proceed to design your artefact according to your own interpretation of that pattern, with any modifications you see fit. This way of reusing patterns is sometimes denoted reuse by analogy.

At the other extreme, some ODPs (in particular Content ODPs) can be directly reusable through their OWL building blocks. This means that there is a small ontology, i.e. an ontology module, readily available that represents the ODP, which one can directly import and use in another ontology. This is similar to reusing an existing ontology, with the main difference that the ODP is usually small, i.e. and ontology module, has clear documentation of its capabilities, consequences, and so on, it is indeed designed for reuse, and ideally makes a minimal ontological commitment outside of its core purpose. This to some extent resembles the way classes from standard software libraries are reused in software engineering. Many ontology engineers also follow some middle path between these extremes, potentially reusing the OWL building blocks of a few well-known and stable ODPs directly, but then creating their own "ODP catalogue", or perhaps better denoted a module repository (comparable to the reuse of software libraries), for their project for the rest of their needs, or even model the rest of the ontology in a more monolithic way.

To give the reader a more intuitive idea of what an ODP might look like, we provide an example in Figure 2. In the figure, 4 different ways to model roles are provided. Again, the example is set in the context of courses, in this case a teacher who is teaching a course instance as well as a student taking it. In part a) of the figure, a naïve modelling solution is illustrated, with the class "Person" having two subclasses (subconcepts) "Student" and "Teacher". Using this modelling solution, or pattern, we are only able to statically assign roles to people, i.e. an instance (the blue ovals represent instances in our data) can be a student or a teacher, but there is no context given and the role (which is usually time-dependent) is not distinguished from the inherent property of being a person (which is usually not considered time-dependent). Parts b) and c) illustrate two alternatives where the roles are separated from the fact that p1 and p2 are persons. While the roles are modelled explicitly in alternative b), the context of holding a role can still not be represented, e.g. the course. In alternative (or pattern) c) instead the role is not modelled explicitly as a concept, but rather encoded in the naming of the property connecting an individual to a course. Finally, in alternative d) the context of holding a role in a specific course is modelled through reification of an n-ary relation between person, role and course. This last pattern would also allow us to further contextualise the participation, e.g. by perhaps specifying time and location of a person's participation in a course with a certain role. These modelling alternatives can be seen as different role-ODPs. While they can be reused just as conceptual ideas of how to model, they could also be represented as small modules and readily imported into different ontologies. It should also be noted that while alternative a) is usually discouraged, due to the fact that time-dependent and time-independent aspects are mixed in the taxonomy of classes, among the other alternatives there is not necessarily a universal "best alternative". Rather, which one should be chosen depends on the ontological requirements, and the data that we are going to map to the ontology. Alternative d) results in a quite complex structure of the data graph, e.g. RDF graph, whereby this can reduce query efficiency and understandability of the model, and should not be used by default, unless there are actually requirements motivating it.

2.2.2 eXtreme Design

The eXtreme Design (XD) ontology development methodology [59, 5] was created as one of the first agile ontology engineering methodologies, intending to address the lack of iterative, incremental and modular ontology development methodologies at that time. XD also promotes the reuse, or development, of ODPs, e.g. in the form of a module library, to ensure some interoperability of modules being produced both within and outside of the current ontology project. The overall outline of XD can bee seen in Figure 3.

The first phase of XD concerns **project initiation and scoping**. Apart from general project specification,

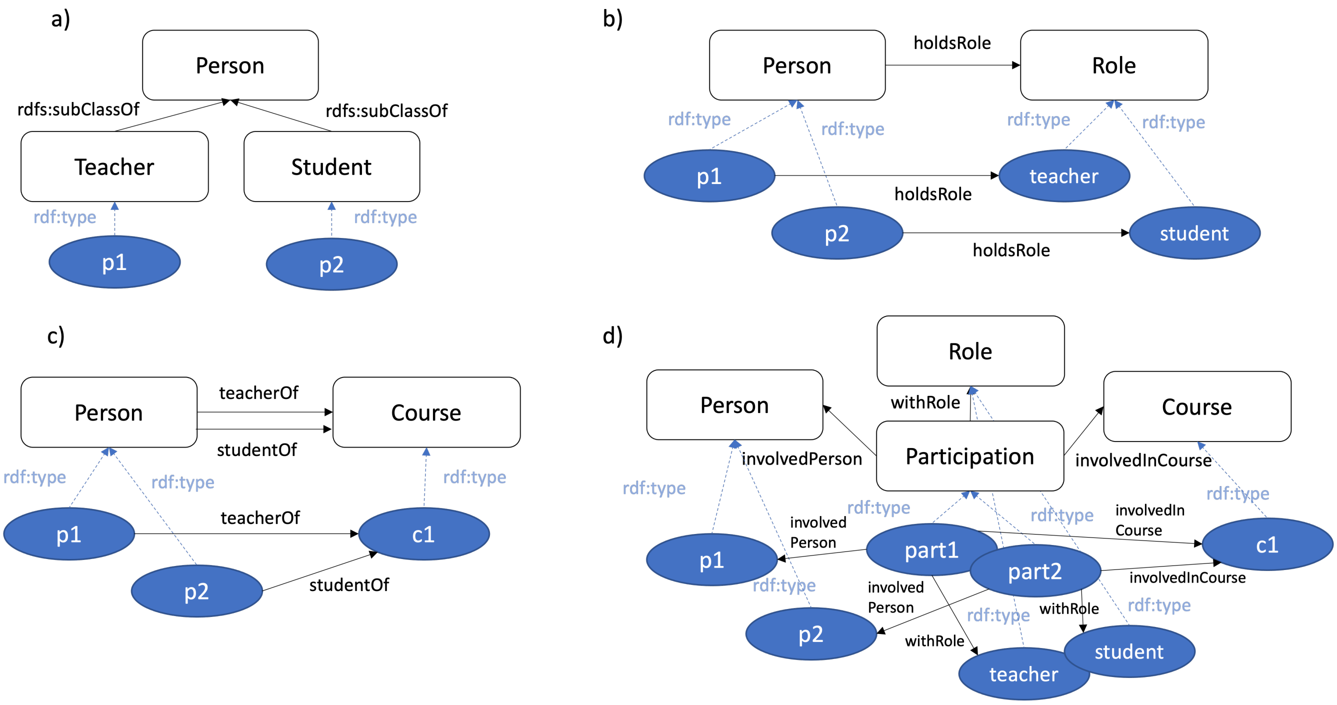

Figure 2: Examples of different ways to model roles, in the context of courses. White boxes represent concepts (classes), and the attached properties (object properties) could be given through domain and range restrictions, for instance. Below, in blue, some example data graphs are given, where ovals represent instances (individuals), and the arrows connecting them indicate RDF triples using those individuals as subjects and objects.

such as setting up project agreements, staffing, distribution of roles among project participants, setup of an appropriate technical environment, decisions on representation languages and frameworks, agreement on procedures, including release plan and integration strategies, as well as a timeline with deadlines and milestones, this also includes deciding on project scope and priorities. While many of these activities are common to any type of development project, one thing that sets ontology engineering apart from, for instance, many software engineering projects, is the need for a deeper understanding of the target domain, even among the (ontology) developers. This is due to the fact that an ontology is a “white box” artefact, hence both developers and users have to understand the inner workings of what is constructed, i.e. ontology concepts, relations, definitions. The consequence of this is that there is a greater need for developing a shared understanding of the domain, its terminology, the intended tasks of the ontology and so on, in an ontology engineering project than in, for instance, many software projects. This is usually achieved through close collaboration with end-users and domain experts, for setting the scope of the ontology, and further in the development cycle.

In general, scoping is very important for ontologies, but it is also very hard to clearly define the scope in terms of the knowledge domain to be modelled. Here the task focus of XD can be very helpful, allowing to focus on the generic tasks that the ontology should support, rather than the domain coverage in terms of concepts, attributes and terminology. This means that the ontology engineers should ask themselves "Is this necessary for the ontology to fulfil its requirements?" when deciding what should be included in the ontology or not, rather than focusing on whether the potential concept, relation or axiom considered is present and valid in the knowledge domain being modelled. In this sense, XD is suitable for contexts where clear tasks of the ontology can be defined, i.e. as functional ontology requirements, and where one wishes to prioritise functionality over completeness of the domain coverage.

Further, before starting the actual development, one needs to agree on the starting point of the project, e.g. in terms of any existing resources to take into account, or even reuse, and how to manage the shared set

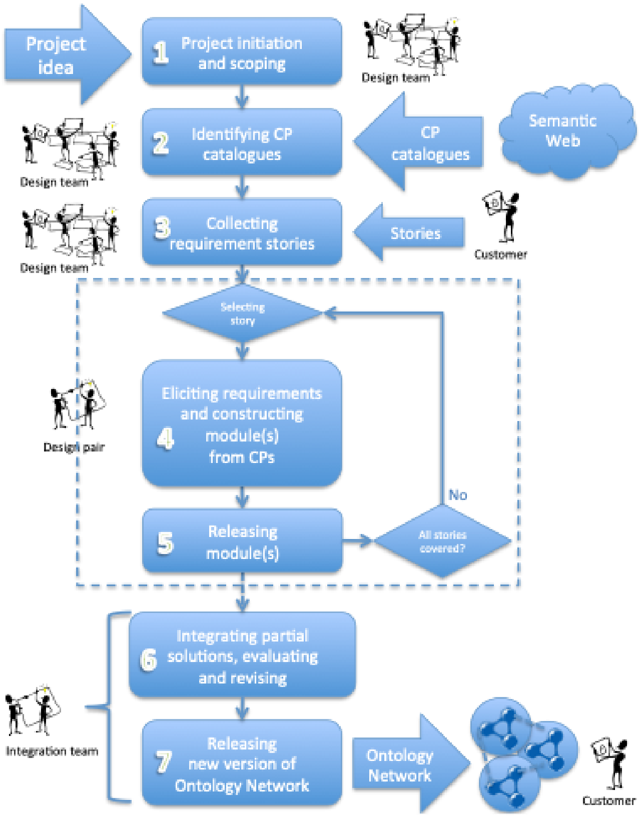

Figure 3: Overall outline of the XD phases and activities as described in [5].

of modules that will emerge during the XD development process. It is rarely the case that ontologies are constructed completely from scratch. Usually there are legacy terminologies to take into account, e.g. including standards and already existing ontologies. How each such resource is to be managed has to be determined at the start of the project, which is one of the focuses of this deliverable, i.e. to provide a map of what existing resources to take into account.

Finally, before starting the development loop, some ontology-focused user stories need to be developed (in this deliverable later called "ontology stories" or simply "stories"). Stories will later lead to the development of the functional requirements of each ontology module, e.g. Competency Questions [26]. Ontology stories can be formulated in different ways, e.g. as examples of data for which the ontology is to act a as a schema, or describing some functionality that is to be realised based on the ontology. The important thing is to keep them short and focused, i.e., on one concrete part of the domain knowledge, one specific task. A typical story might contain anything from 1-2 sentences up to about two brief paragraphs of text. Additionally, stories need to be quite specific in order not to allow for too much interpretation by the ontology engineers. Stories should also be driven entirely by the needs of ontology end-users, and not written with any specific modelling solution in mind.

Since XD is agile and iterative, it is not necessary to develop all stories beforehand, but an initial “backlog” is to be accumulated before starting the development process. This is to ensure that an appropriate prioritisation can be made within the initial set of stories. As the set of stories is allowed to emerge and evolve over time, it is important to also update the plan of what is actually going to be developed and in what order. Once some ontology stories have been collected and prioritised, and their relations to existing ontologies, standards and other resources have been assessed, the concrete development of the ontology modules can begin. As mentioned previously, this is done incrementally, one module at a time. Ideally, each story will correspond to one (or a small set of) ontology modules, however, the situation may also occur that some stories are considered too overlapping, so that their solutions have to be merged. In the original XD methodology requirements elicitation is done separately for each ontology story, by a developer team in collaboration with a "customer", i.e. domain expert or ontology end-user.

Next, the module development loop consists of module development, testing, and release, for one ontology story at a time. This is where the actual development happens, but additionally important activities such as testing and documentation are also prioritised. Once each module is released, it will then be integrated into the overall ontology network, and any needed refactoring will be performed, based on issues identified in integration, or integration testing. This effectively pushes many difficult decisions, e.g. regarding module compatibility and ontology network architecture, to the very end of the development loop. While this creates a fast development loop, where new modules can be released and tested quickly, it instead puts a lot of emphasis on the integration and refactoring, to resolve any conflicts later on. Hence, the modules released have to be viewed as "prototypes", which are then verified and potentially modified, to fit into the overall ontology network.

2.2.3 Ontological Requirements

As ontological requirements are particularly important for our chosen methodology, as well as one of the main focuses of this deliverable, we here describe a bit more in details how such requirements can be elicited and expressed. In XD requirements are elicited mainly from the ontology stories, that are produced in collaboration with domain experts and end-users. However, it is also important to validate all the requirements with those domain experts before starting the modelling, to ensure that a correct understanding of the stories have been gained, that terminology is appropriate and so that no important notions have been missed.

Although XD does not focus on first collecting all the domain terminology before modelling, terms and naming of things in the ontology modules are still an important aspect. Therefore a glossary of terms can be collected, simultaneous with the development of the requirements. Later, the coverage of these terms and alignment to the terminology of the stories can be verified based on this glossary.

The main requirements of an ontology are the Competency Questions (CQs) that the ontology should be able to answer. CQs [26, 5] are probably the most well-known category of ontological requirements, which was recognised already at the very beginning of the knowledge engineering tradition. CQs express typical tasks of the ontology, i.e., typical queries it should be able to answer, and are expressed as natural language sentences, e.g. questions. Referring to our initial example of a small ontology, illustrated in Figure 1, some CQs could have been "What courses do a specific person take?", "In which university is a specific course given?" and "Is this person a student?". However, note that CQs should not express all possible things one could ask, given the domain, but merely those things that we actually need to answer by directly using the ontology, or by querying the data annotated by the ontology. This in order to properly set the scope of the ontology to its intended task(s).

However, CQs on their own do not always suffice in order to clearly specify what is required from the ontology [5], therefore XD also specifies two additional requirement categories: Contextual Statements (CS), and Reasoning Requirements (RR). These are added to the CQs in order to completely specify the requirements, asking: "Are there any constraints that should be enforced over this knowledge, or any common-sense notions that are to be introduced to complement the knowledge needed to answer the CQ?" - Answers are CS, and "Is all the information needed to answer the CQ going to be entered explicitly into the knowledge base, or is there some inferences required either in order to derive the answer to the CQ or that should be derived as a consequence of the response?" - Answers are RR. Note that both of these questions refer to the CQ, hence the CQs are the requirements that set the scope of the module to be built and drive the need for additional requirements. However, CS and RR are sometimes needed in order to precisely specify the additional axioms of the entities mentioned in the CQs that are needed in order for the ontology to perform a certain task. Considering a CS, the task may be consistency checking, or identity resolution - in addition to answering the CQ. While considering an RR, the task may for example be classification of instances, in order to then be able to answer the CQ based on the inferred knowledge. To exemplify these two additional types of requirements we again refer to our initial example in Figure 1, where a CS related to the CQ "In which university is a specific course given?" might state that each course has to have exactly one university where it is given. An RR related to the CQ "Is this person a student?" could in turn be that persons are not going to be stored in the knowledge base as students or not, but that this will be inferred on-demand, based on whether they are enrolled in any university and/or take any courses.

3 Methodology

In this chapter we first briefly remind the reader about the overall research methodology of the project (Section 3.1), and then we describe the initial research process applied in WP3. As the foundation for our work in WP3, we are conducting an extensive survey of both research literature as well as existing ontologies and related standards, in order to properly ground our work in the state-of-the-art and to and build on existing results. The survey methodology is described in Section 3.3. However, before that, we focus on the methodology used to develop and publish ontologies in WP3, starting from WP6 and WP2 resources. Hence, Section 3.2 describes our ontology engineering workflow, inspired by the XD methodology, and how we then plan to align and publish the ontologies is discussed in Section 3.4.

3.1 Project Research Methodology

In this section we briefly remind the reader of the overall project research methodology, in terms of the three project iterations, and their steps. In order to position the work reported in this deliverable in relation to these steps. The overall process can be illustrated as in Figure 4, where each project iteration consists of a needs & requirements analysis steps, followed by research & development, and concluded through evaluation and validation, e.g. in our use cases. Overall the project is currently in the middle of the first project iteration, which lasts from M1-18 of the project duration.

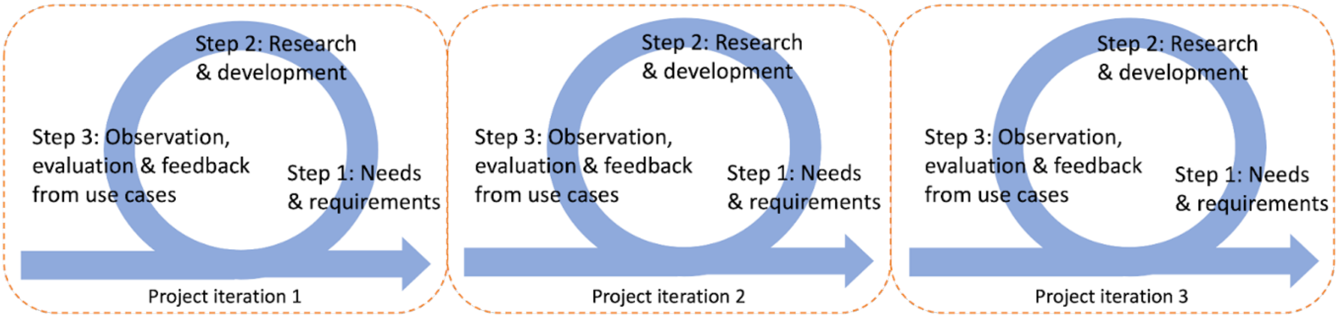

Figure 4: The overall research process of the project, conducted in three iterations.

In the case of WP3, we rely on the needs and requirements analysis done in WP2 and WP6, as reported in D6.1 and subsequently D2.1. Based on these needs and requirements, we have now conducted a first iteration of the research and development step. In this first WP3 iteration, the research consisted of conducting several surveys, to map the state-of-research in this area (i.e. both surveying current research literature, and existing ontologies and standards). The development consisted in developing an initial set of ontological requirements, based on the input from WP6 and 2, as well as a first outline of an ontology network architecture. All these results still need to be validated with domain experts in the project, i.e. we have not yet started the third step of observation, evaluation, and gathering feedback on these results from the use cases. Therefore, all the results presented in this deliverable have to be considered as preliminary, until properly validated in the coming period (until M18). The results of that validation will then feed into the next iteration, and be part of the needs and requirements that are taken into account for the next iteration of WP3.

3.2 Ontology Engineering Methodology

On one hand the ontology engineering methodology in WP3 is part of the project's overall methodology to develop our results. However, in WP3 we also have the objective to further develop the methodology into something that can be useful after the project lifetime, for better guiding future extensions to the ontology network we are building. For instance, when covering new industry domains outside of our three use cases.

Therefore, we pay specific attention to the adaptations made to the XD methodology in the project, and discuss their motivations, in order to gather some experiences and guidelines for future use of a similar approach.

However, based on where we are in the overall project methodology, in this first version of the deliverable we focus mainly on the project initiation and scoping, identification of existing resources, and requirements analysis, since these are the method steps that have been conducted so far in WP3. In addition, we only make a brief outlook towards the actual ontology development that is our next development focus in WP3.

3.2.1 Modular modelling and the XD Methodology

Following the discussion in Chapter 2, there is a trade-off between modularity and architectural complexity of the ontology. However, when modelling for the CE domain it is clear that we need to prioritise modularity over a simpler ontology architecture, to (i) increase the reuse potential of the ontologies, (ii) separate concerns and allow for alternative models, and alignments to different related ontologies, for certain specific domains, and (iii) increase the understandability of the notions we are modelling. This clearly follows from the fact that the domain of CE is highly diverse, and it would simply be impossible to model all aspects and all possible industry domains in a single ontology. In fact, we note that even in our project use cases we need to produce some models despite a certain degree of uncertainty, e.g. of exactly what actors would fill each role in the envisioned network. In addition, it is highly likely that circular value networks change over time, so modelling in ways so that changes have minimal effect on the overall solution is essential. Therefore we envision the situation where an ontology for a specific use case can be built specifically, or be composed from a library of modules or existing ontologies in that domain, and thus tailored to a specific CE use case, but where interoperability is still ensured by having a set of core modules shared by all the more specific ontology modules. This is the motivation for targeting an ontology network, composed of smaller modules, instead of one (or a set of) larger ontologies, and this is also one of the motivations why the agile XD methodology was chosen as a suitable ontology engineering methodology for the project.

The small set of core modules that are to be shared throughout the ontology network, can be viewed as instances of a set of shared ODPs. However, in practice they will be represented as well-documented ontology modules, but with a minimal ontological commitment to be as reusable as possible. These will constitute the core of the ontology network, and will then be reused and specialised (i.e. extended with further details), aligned to external ontologies etc., to fully cover our complete set of requirements. However, by taking this highly modular approach we ensure that these core modules can also be reused independently of the rest of the ontology network. In the rest of the deliverable, we denote these central components "core ontology modules", rather than ODPs, to indicate that they will not merely be abstract conceptual patterns, but come with a concrete module implementation (in OWL). Hence, they can be reused directly as modules in the ontology network.

Given these overall architecture principles of the ontology network, we then proceeded to adapt the XD methodology to our project context and use cases. Mainly the following four adaptations have so far been considered, in relation to the original description of XD in Chapter 2 and in [5]:

1. Less focus on the initial scoping of the ontology – The scope is allowed to emerge from the emerging set of requirements.
2. No fixed set of external resources identified at the project start – The set of external ontologies and non-ontological resources to relate and align to is allowed to emerge and evolve over time.
3. Increased attention to architectural principles and patterns – A core set of shared modules (representing core ODPs) is first created, as the backbone of the ontology network.
4. A modified process regarding requirements analysis – Requirements are developed outside of the development loop, and core requirements are formulated before modelling of those modules start.

Regarding point (1), the scope of the ontology network has to in our case be determined by its intended use by the various actors in the circular value networks, which are not all known beforehand - in fact, we know very few of them in detail, but mostly we only know their types an functions in the networks. Hence, in our case we can only be sure that the ontology network will need to grow, evolve and change, as new use cases emerge. Therefore, our formulation of the scope is mainly generic, and states that we intend to cover core notions and aspects that are general across all so-far known use cases, e.g. core CE concepts and concepts involved in all three project use cases, and then simply prioritise extensibility and minimal ontological commitments as much as possible, to allow for future extensions and alignments.

Regarding point (2), as our survey results show (discussed later in the deliverable) many new ontologies are being developed, and standards are not yet established and stable, hence, there is not a fixed set of external resources that we need to take into account, and align to. Therefore, we cannot determine this set at the beginning of the development process, but rather we have to allow for an evolving set of related resources. This may mean additional refactoring that will be needed later during the project, if standards or other resources emerge that change the way certain concepts are to be defined. In XD, normally, revisions and refactoring is done mainly based on requirement changes, or based on problems discovered in integration testing, while in our case, such refactoring and revisions will also be triggered directly by external factors.

Regarding point (3), the XD methodology in itself does not normally prescribe any specific ontology architecture principles, apart from modularisation. However, in our case, due to the importance of having highly reusable core modules, that make minimal ontological commitments for maximal reusability, there is a need to design an overall architecture of the ontology network up front. Therefore we diverge from the XD principle of leaving any architectural consideration and integration issues to the integration phase, and instead start by focusing on the core modules and their dependencies, thereafter the intention is to merely develop extensions and specialisations of those modules, as well as alignment modules functioning as bridges to other existing ontology concepts, rather than modifying the core set of modules, unless this is found absolutely necessary.

Finally, regarding point (4), while XD specifies that requirements should not be developed based on ontology stories until that story is ready to be modelled, this is not really a feasible approach in our project, for several reasons. First of all, while we do have continuous access to some domain experts, e.g. from our industry partners in the project, we do not have full coverage of all actors in our use cases described by WP6. Additionally, the industry partners that we do have, do not have effort allocated in WP3 for continuous interaction on ontology requirements. Instead, we partly rely on (i) the written use case descriptions from D6.1 for support in our requirements analysis, complemented by (ii) upcoming sessions for requirements validation with our industry partners, where a larger set of ontology requirements will be validated at once (i.e. not on a per-story basis). In addition, we also want to take advantage of the fact that we already know that stories originating from D2.1 are highly overlapping, a we can therefore avoid lots of refactoring of modules, by already consolidating those requirements before entering the development loop. Therefore we have decided to treat the requirement elicitation and analysis as a separate activity, parallel to the XD development loop, instead of a step conducted in each iteration. Some further details on our requirements analysis process are given in the next subsection.

These four points summarise our current methodological observations, however, it should be considered that so far these are only observations and plans. The validity of these methodology adaptations will now be validated during the project iterations. In our current project iteration we will mainly be able to validate and evaluate the adapted way to deal with requirements analysis (point 4). The other three points will be applied, but their validation and evaluation will only be possible as the project moves into the second and third iterations, where we have to adapt the scope, list of existing resources, and the set of planned ontology modules, to the updated use case descriptions and requirements from WP6 and 2, as well as based on developments external to the project (e.g. new ontologies and standards emerging).

3.2.2 Requirements Analysis Process

Since the main focus of the initial work in WP3 has been on developing a set of ontological requirements, we here describe a bit more in detail the process followed in this development.

The starting point of the ontological requirements is an initial set of ontology stories based on (1) the user stories in D2.1, contextualised by (2) the use case descriptions in D6.1, as well as emerging standards and policies describing the notion of CE and circular value networks as such. From these stories we have further collected a glossary of terms to be covered by the ontologies, and then developed CQs (as well as CS and RR belonging to them).

More concretely, from D2.1 a list of terms was extracted by first simply extracting each noun phrase in the text of the user stories, and also including any sub-terms of that phrase (i.e. the words it is composed of, and any base forms of inflected words). For instance, the noun phrase "manufacturing process" occurs frequently, and while this is a term in itself, it also consists of two sub-terms; "manufacturing" and "process". The result of this process was then transformed into a glossary of terms for the ontology development in our first iteration, by counting the frequency of use and manually assessing the relevance of the terms for CE in general. Any term occurring more than once, and assessed to be relevant for the general CE domain was included. At this stage we have thus filtered out any use case specific terms, even if they occurred frequently within that use case's user stories. Those terms will instead be included in use case specific glossaries (i.e. specific to construction, electronics and textile industries), used for the use case specific ontology extensions in collaboration with WP6. In addition, purely technical terms were excluded, since they were deemed to refer more to the functions of the intended platform, rather than the underlying information the platform should hold. Examples of the latter are terms like "interface", "click", and "query". It should be noted that this list is not final, but will be continuously updated throughout the three project iterations, as well as during the ontology development, where new stories will be added as the project progresses. Nevertheless, the intention is to use this glossary of terms as one source of, for instance, concept and property names, and as a way of assessing the coverage of the ontology network against the needs of the project. As mentioned earlier, the general glossary will also be complemented by use case-specific ones as the work in WP6 progresses.

However, simply listing terms is not enough in terms of ontological requirements. We then proceed to develop the ontology stories mentioned earlier in this section. This was done in two ways, (1) by taking each user story of D2.1 and rewriting it into one or more ontology stories, where technical aspects of the platform are left out, and instead the information needs and content aspects are detailed further, and (2) writing one additional ontology story for each core Circular Value Network concept identified as common to several of the stories developed in (1). In order to do the latter, D6.1 was used as background information about the intentions and composition of the envisioned circular value networks of our use cases, together with terminology and definitions from the Circularity Thinking framework, and emerging ISO standards, such as the CE definitions being developed by ISO/TC323. If the story was first formulated as a concrete example, it was then also generalised into instance-free sentences (i.e. mentioning types of things instead of concrete names). Once the story text was sufficiently generalised, a set of requirements (i.e. CQs) were elicited from it.

To perform a first validation of the core Circular Value Network stories (cf. point 2 above), a modelling workshop was also conducted with representatives from all project partners. The participants were divided into groups of about 4-5 people, and were asked to draw a conceptual model of the most important concepts involved in a CVN, and how they are related. Cleaned up (i.e. in terms of visual presentation, no changes were made to the content) versions of these drawings can be seen in the Appendix A, Figures 8-16. These sketches were then compared to the ontology stories written, and the overall list of CVN core concepts identified, to both identify missing concepts and relations, and to question and revise any concepts that were not core according to the workshop participants (i.e. where none of the groups had listed such a concept, or a similar one).

The development of CQs (as well as CS and RR belonging to them) was done by formulating questions to retrieve the data types mentioned in the ontology stories, and their relations, but by additionally using the user stories in D2.1 for setting the scope, i.e. excluding any questions that would not be necessary to fulfil the tasks specified by the D2.1 user stories. The latter is important, since we are creating task focused ontology modules that should support typical CE tasks, but not necessarily cover all possible data that could be collected in the domain.

3.2.3 Ontology Development

While the sections above describe work that has already been performed, although not yet validated with domain experts and end-users, in this sections we merely outline the pland and currently ongoing work for the actual ontology development process.

For the actual ontology development, we are again slightly adapting XD, i.e., creating a modified version of the XD methodology's design loop. First of all, one of the XD principles of "pair design" is modified in this project, since we do not have the resources (in terms of ontology engineers) to allow them to continuously work in pairs. Instead, we set up a method were ontology modules are created by one ontology engineer and then reviewed by another, in line with the idea of code reviews in software engineering. In this way, ontology engineers still work in pairs, but without the requirement of continuous synchronisation of efforts.

Apart from that, another important shift of focus is the prioritisation of stories, i.e. the development of a set of core modules following an already determined overall architecture of the ontology network in the first iteration of the project. Hence, we set the highest priorities on the ontology stories that were written for describing the core notions of CE. Those modules are based on the cross-cutting concerns identified in D6.1 and D2.1, and described in the additional set of stories as explained in the last section. Examples of such concepts include, circular strategies, the actors and flows involved, and the transformations of resources from materials, to components, and products. This gives the project a slightly less agile flavour, however on the other hand, we intend to create a small but effective foundation for the remaining modules, and avoid unnecessary refactoring later on.

3.3 Survey Methodology

In order to become aware of the state-of-the-art, and properly take into account related research, we are carrying out several types of structured surveys in the context of WP3. The methodologies used for these surveys are presented in this section, but the work is still to be completed during the next few months.

3.3.1 Literature Survey Methodology

In order to get a comprehensive picture of related research, and state-of-the-art in semantic technologies for CE we are conducting a structured literature survey. In this deliverable we focus specifically on the ontologies and ontology development methodology, whereby only a part of the survey results are relevant. In addition the survey is not yet completed. Nevertheless, we briefly describe the methodology of the structured literature survey, leading up to the identification of a first set of papers discussing ontologies and ontology development efforts, as input for the ontology and standards survey described below. In the next version of this deliverable a more extensive description of the complete literature survey, and its results, will be included.

The survey is conducted by searching a set of complementary databases, e.g. Scopus, Web of Science, and Business Source Premiere. Google scholar is used as a complement, which aggregates a multitude of sources, including most common publication venues in computer science, e.g. IEEE, ACM, as well as publishing houses such as Springer, Elsevier. Using Google scholar is particularly important when trying to find ontology development efforts, since some ontologies and ontology projects are only described in white papers, project reports etc., and not published in peer-reviewed venues.

The search query used consists of two parts, one part related to Circular Economy and one part related to semantic technologies, and in particular ontologies. For the first part we simply used the key phrase *"circular economy"*, since this term is the most frequently used in recent years, and adding variations and synonyms proved to mainly generate older results, not relevant for this project. For the second part of the query a more complex expression was used:

```
(ontology AND ("semantic interoperability" OR "linked data" OR "data sharing“
OR RDF OR OWL)) OR "knowledge graph" OR "semantic web"
```

Simply using the term "ontology" proved impractical, since that term has several meanings, and is also used in philosophy and theoretically oriented business research to discuss the underlying meaning of things in the world. Hence, it was necessary to combine the ontology-term with more technical terms that indicate the computer science-related use. Further, in recent years the term knowledge graph has become popular, and is sometimes used synonymous to ontology. The term Semantic Web, additionally, is used to capture more general reports of using such technologies, including variations and combinations not specifically mentioning the term ontology, but using that as a component of a larger system.

Based on this query we so far retrieved 994 entries from the databases, together with Google scholar, but this is still ongoing work and will be complemented as new results emerge. While we are still in the process of assessing these entries in detail, e.g. in terms of quality, accessibility, relevance to the project, already in the first round of assessment we have tagged the entries retrieved that present ontologies (or ontology development efforts) related to CE, and used this as input to the ontology survey described below.

A total of 11 entries presented some type of ontology related effort and these where then passed on as input to the ontologies and standards survey.

3.3.2 Ontologies and Standards Survey Methodology

In this section, we present how we conducted the direct search for ontologies and standards, in addition to the literature search already mentioned.

Focus Domains

A model for CE involves actors from different domains such as raw materials, manufacturing, production, logistics and supply chain. Hence, also ontologies for CE may need to cover such diverse sets of domains, in particular ontologies that should be applicable in scenarios of cross-industry collaboration. In order to set a reasonable scope for the initial set of ontologies to examine we therefore attempted to identify the most central domains of relevance. Based on discussions among knowledge engineers and domain experts, we identified a set of core domains in which we needed to investigate the relevant existing ontologies. These focus domains are *Circular Economy*, *Sustainability*, *Materials*, *Logistics*, *Manufacturing* and *Products*. Additionally, we also focus on the three use case domains which are *Construction*, *Electronics* and *Textiles*. The domains are shown in Table 1 together with some sub-topics that were later used to further describe the focus of the ontologies.

Collecting Ontologies

We collected ontologies in three complementary ways. First, we collect ontologies for all the domains shown in Table 1 from public ontology or vocabulary repositories. However, since CE and the use of Semantic Web-based technologies for CE is relatively new, public repositories may not include many relevant ontologies or vocabularies yet. Therefore, we also collected ontologies by searching Google and Google Scholar based on specific ontology keywords for the CE domain. Finally, these results were complemented by the papers with ontology descriptions from the literature survey described previously.

Table 1: Focus Domains.

Domain	Topics	Label
Circular Economy	business models, resource recovery, waste, recycling, circularity assessment	CE
Sustainability	sustainability goals, performance, environment, energy	SU
Materials	raw materials, material composition	MAT
Logistics	distribution, production, supply chain	LO
Manufacturing	manufacturing process	MAN
Product	product life cycle	PR
Construction	building, device	CO
Electronics	electronics, electronical appliances	EL
Textiles	textiles, fiber	TE

We searched for ontologies in the following public ontology or vocabulary repositories: MatPortal[2] (containing 21 ontologies in total), IndustryPortal[3] (52 ontologies in total), OntoCommons ontology catalogue[4] (37 ontologies in total), Ontobee[5] (259 ontologies in total), and Linked Open Vocabularies[6] (LOV, 782 vocabularies in total). For the first four repositories, we looked at each ontology in the repositories one by one and decided for each ontology whether it was relevant to our domains and should be included in our survey. For LOV, we searched the repository using the same keywords as those used for searching Google and Google Scholar (see below), before assessing the relevance of the found ontologies.

For the Google searches specific to ontologies, we used six keywords or key phrases identified through discussion between the domain expert and the knowledge engineers. These keywords or key phrases are *ontologies for circular economy*, *circularity ontology*, *materials ontology in circular economy*, *Semantic Web in circular economy*, *materials passport ontology*, and *ontology for circularity product*.

Ontology Analysis Perspectives and Categories

Once ontologies had been found, we also need to assess them and analyse their characteristics in order to better understand their relevance to the project. The analysis of collected ontologies relates to both qualitative and quantitative aspects. For the quantitative aspects, we used the ROBOT tool [29][7] to compute ontology metrics. These metrics include, e.g. the numbers of concepts (or classes), axioms, relations (or properties). By analyzing these metrics, we aim to obtain a better understanding of different ontologies regarding what design choices were made for developing these ontologies and how we can reuse or re-engineer these ontologies. For the qualitative aspects, we consider characteristics such as availability, domain of interest, and reuse of other ontologies. These characteristics are important for reusing ontologies and connecting them into an ontology network for CE.

Databases and Repositories for Searching Policies and Standards

However, it is not only already existing ontologies that are relevant and important to relate to. Many other kinds of artefacts also exist, including agreed upon terminology in policy documents and standards, semi-structured resources and data model specifications etc. To find such specifications that are relevant to the general cross-

[2] https://matportal.org
[3] http://industryportal.enit.fr
[4] https://data.ontocommons.linkeddata.es
[5] https://ontobee.org
[6] https://lov.linkeddata.es/dataset/lov
[7] http://robot.obolibrary.org

industry domains in the Onto-DESIDE project, we have taken the following organisations' repositories into account for searching:

Table 2: Organizations related to policies and standards.

Organization	Description
ISO[8]	International Organization for Standardization is an independent, non-governmental international organization with a membership of 167 national standards bodies.
GRI[9]	The Global Reporting Initiative represent global best practice for reporting pub- licly on a range of economic, environmental and social impacts. Sustainability reporting based on the Standards provides information about an organisation's positive or negative contributions to sustainable development. An organisation reporting in accordance with the GRI Standards is required to report how it manages each of its material topics.
EUR-Lex[10]	EUR-Lex is the online gateway to EU Law. It provides the official and most comprehensive access to EU legal documents. It is available in all of the EU's 24 official languages and is updated daily.
European data[11]	The official provider of publishing services to all EU institutions, bodies, and agencies. As such, it is a central point of access to EU law, publications, open data, research results, procurement notices and other official information.
Eurostat[12]	Eurostat produces European statistics in partnership with National Statistical Institutes and other national authorities in the EU Member States. This partnership is known as the European Statistical System (ESS). It also includes the statistical authorities of the European Economic Area (EEA) countries and Switzerland.
ASTM[13]	American Society for Testing and Material is a globally recognized leader in the development and delivery of voluntary consensus standards. Today, over 12,000 ASTM standards are used around the world to improve product quality, enhance health and safety, strengthen market access and trade, and build consumer confidence.
UNECE[14]	The United Nations Economic Commission for Europe (UNECE) was set up in 1947 by ECOSOC. It is one of five regional commissions of the United Nations. Its major aim is to promote pan-European economic integration.
EEA[15]	The European Environment Agency provides sound, independent information on the environment for those involved in developing, adopting, implementing and evaluating environmental policy, and also the general public.

[8] https://www.iso.org/standards-catalogue/browse-by-tc.html
[9] https://www.globalreporting.org/how-to-use-the-gri-standards/gri-standards-english-language/
[10] https://eur-lex.europa.eu/homepage.html
[11] https://data.europa.eu/en
[12] https://ec.europa.eu/eurostat/web/main
[13] https://www.astm.org/
[14] https://www.ungeneva.org/en/organizations/unece
[15] https://www.eea.europa.eu/

In addition, to find existing standards that are specifically relevant to the three project use cases in Onto-DESIDE, we took the following organisations' repositories into account:

Table 3: Standard organizations relevant to the respective use cases of Onto-DESIDE.

Organization	Description and related use case
CP-DS[16]	The CP-DS database is designed to help all interested parties to identify all relevant regulations in the field of dangerous substances in construction products. Related to use case: Construction
EUOS[17]	EUOS thoroughly monitor the global Standardisation landscape, providing a comprehensive and accurate coverage of the most important ICT Standards, Working Groups and Technical Committees that affect the key ICT topics of the Digital Single Market and the EU ICT Rolling Plan for Standardisation. Related to use case: Electronics
ETSI[18]	ETSI provides members with an open, inclusive and collaborative environment. This environment supports the timely development, ratification and testing of globally applicable standards for ICT-enabled systems, applications and services. Related to use case: Electronics
ITU[19]	The International Telecommunication Union facilitate international connectivity in communications networks, we allocate global radio spectrum and satellite orbits, develop the technical standards that ensure networks and technologies seamlessly interconnect, and strive to improve access to ICTs to underserved communities worldwide. Related to use case: Electronics
ITU-T Study Group 5[20]	ITU-T Study Group 5 is responsible for studies on methodologies for evaluating ICT effects on climate change and publishing guidelines for using ICTs in an eco-friendly way. Under its environmental mandate SG5 is also responsible for studying design methodologies to reduce ICTs and e-waste's adverse environmental effects, for example, through recycling of ICT facilities and equipment. Related to use case: Electronics

[16] https://single-market-economy.ec.europa.eu/tools-databases/cp-ds-legislation-substances-construction-products_en
[17] https://www.standict.eu/standards-repository
[18] https://www.etsi.org
[19] https://www.itu.int/en/Pages/default.aspx
[20] https://www.itu.int/en/ITU-T/about/groups/Pages/sg05.aspx

GOTS[21]	Global Organic Textile Standard (GOTS) was founded by four well-reputed organisations: Organic Trade Association (OTA, USA), Internationaler Verband der Naturtextilwirtschaft (IVN, Germany), The Soil Association (UK) and Japan Organic Cotton Association (JOCA, Japan). Two of these (IVN and JOCA) are textile industry organisations, while the other two (OTA and Soil Association) are organic organisations rooted in organic agriculture and food. Together, they hold extensive experience in promoting 'organic' and all had developed individual processing standards for organic textiles. GOTS came about from the desire to harmonise these standards so that they were internationally recognised. Related to use case: Textile

This list is most likely not complete, but has been used as a starting point, based on discussions with domain experts in the project. The overview will be made more complete for the second version of this deliverable, including also a more detailed analysis of the resulting standards. At the moment, we simply list the relevant standards in the result Section 4.5.

3.4 FAIR Ontology Publishing

Once ontologies have been modelled, they also need to be shared with the community. In order to actually be useful, they need to be both findable, accessible, interpretable and interoperable with standards and other ontologies, as well as highly reusable. In general, this holds for all scientific results and artefacts, but perhaps specifically for ontologies, that are supposed to act as mediators and provide semantic interoperability in a domain. To guide and support the sharing of scientific results in general, and artefacts in particular, the FAIR principles were proposed [74]. In this section we therefore discuss how the FAIR principles are related to our project, and what aspects are important to take into account, as well as outline some specific methodological practices for the project.

The ontologies developed by the project will be published according to the FAIR principles. However, recent analyses by several researchers and projects [55, 36, 13, 30] come to the conclusion that there are different ways to fulfil the FAIR principles, and it is not always clear exactly what is the best solution. Still, many of the principles are quite naturally fulfilled simply by the fact that the ontology language to be used, i.e. OWL, is based on Web standards, and use URIs as unique identifiers. Below, the four principles are however discussed one by one, in relation to the ontologies, and then finally, a more technical plan is outlined for how the ontologies will actually be published.

3.4.1 Findability and Accessibility

The ontology network being developed in this project can be viewed partly as a metadata schema for describing actual data to be shared in the circular economy, hence, rich metadata is at the heart of this project, and one of our project goals. In addition, the ontologies produced in WP3 will be represented using the W3C standard OWL[22], use URIs as identifiers, and will be published using a persistent URI service, i.e. the w3id service[23], while the source files will be available both from an open source service (GitHub), and registered in indexing services such as LOV[24] and the ODP portal[25], to be even more easily findable.

[21] https://global-standard.org/
[22] https://www.w3.org/OWL/
[23] https://w3id.org/
[24] https://lov.linkeddata.es/
[25] http://ontologydesignpatterns.org/

The use of the ontologies in the open data sharing platform developed in parallel will also support two findability aspects, namely persistent identifiers and indexing of actual circularity data. Regarding accessibility, both data and ontologies should be retrievable through their persistent identifiers, and metadata will be available even if data is restricted or no longer available (e.g. through LOV and other indexing services, as mentioned above).

3.4.2 Interoperability

Interoperability of data includes requirements on metadata to use shared vocabularies and languages for knowledge representation, as well as these vocabularies themselves following FAIR principles, and containing links to related metadata and vocabularies. These aspects are really at the core of this project, since the main aim of the project is to increase semantic interoperability of data through ontology-based data documentation in the CE setting.

In order to ensure interoperability of the ontologies themselves, the ontologies will be based on W3C standards (e.g. represented in OWL), linked to standard ontologies, such as PROV-O, and aligned with other relevant industry standards, and following the standards recommended by the EOSC. Parts of this deliverable reports on our recent survey of related ontologies and standards, in order to ensure semantic interoperability.

3.4.3 Reusability

Reusability, is again the ultimate goal and challenge of this project, i.e. to make data more reusable and more useful for the CE. By developing the core of the ontology network in a modular ad extensible fashion we will ensure reusability across industry domains, i.e. the possibility to specialise the ontologies for any industry domain in the future, and by developing such specialisation for three specific industry use cases we will exemplify and evaluate the reusability of the ontologies for effective data documentation in concrete usage scenarios. In addition, reusability is about provenance, licensing and standardisation. The ontology network will make use of the W3C standard PROV-O to express provenance attributes over the data, and ontologies themselves. We will use open licences for the ontologies produced, e.g. MIT or CC-by. Further, standardisation is an issue that is also treated in the project through a specific WP2 task. The latter will ensure that the results are aligned to existing industry standards in our use case domains, as well as to applicable technological standards, e.g. Web standards, and standards for data modelling and knowledge representation. Further, we will investigate the potential of our core ontologies to be developed into a standard set of ontologies for CE, in the context of our standardisation plan developed by WP2 (T2.4).

3.4.4 Publishing Pipeline

The development of the envisioned ontology network will entail multiple inter-dependent ontologies, several of which will go though multiple development iterations. In order to keep track of such changes, we plan on using a GitHub[26] repository to handle versioning and to create new releases. Proper ontology versioning ensures both consistency and predictability over time, since any reference to a specific version of the ontology will remain valid.

The w3id service will be used to provide permanent identifiers for the ontologies, all of which will be aligned with the ontology releases. This provides a way of decoupling the identifiers used from any specific domain name or publishing platform, thus providing resilience in the long term, and the identifiers can be redirected as needed. Additionally, the w3id service can be used to support some aspects of content negotiation, allowing the ontologies to be made available according to the requirements of the user (e.g. RDF/XML files when access by an application, human-readable documentation when accessed via a browser).

[26] https://github.com/

Documentation is an important aspect when it comes to making ontologies both accessible and understandable. However, creating such documentation can be both labor intensive and time-consuming. In order to streamline this process, the project will leverage pyLODE[27] for generating web-friendly documentation directly from the ontology files, thus removing the need for manually creating such content. Additionally, we will employ OWL2VOWL[28] and WebVOWL[29] to generate interactive visualizations, providing an easy to understand overview of each ontology. These tools are all available open-source under the MIT licence and will be combined into a pipeline that allows ontology documentation to be generated automatically, ensuring that the documentation always remains up to date.

[27] https://github.com/RDFLib/pyLODE
[28] https://github.com/VisualDataWeb/OWL2VOWL
[29] https://github.com/VisualDataWeb/WebVOWL

4 Preliminary Result #1 – Overview of Existing Ontologies and Standards

In this chapter, we present the result of surveying existing ontologies and standards, where the survey is conducted according to the methodology presented in Section 3.3.2. We introduce general level ontologies (Section 4.1, Section 4.2 and Section 4.3), use case specific ontologies (Section 4.4) and standards (Section 4.5), respectively. We categorise the collected ontologies into ontologies related to (1) Circular Economy and Sustainability, (2) Manufacturing, Logistics and Products, (3) Materials, (4) Construction, (5) Electronics, and (6) Textiles. We list 44 downloadable ontologies in Table 4 and Table 6, as the main result of the survey, and provide a catalogue to keep track of these ontologies and ontology-related work in a public repository[30]. In Section 4.6, we then briefly discuss how these ontologies can contribute to the CE domain and what challenges should be noted.

4.1 Ontologies related to Circular Economy and Sustainability

In Table 4, we have assigned labels CE and SU to ontologies related to Circular Economy or Sustainability, respectively, according to the domains presented in Table 1. Note that some ontologies are assigned more than one label since they relate to several domains.

First of all we note that not many core ontologies for CE can be found. Most target very specific use case in specific industry domains. However, in [63] two ontologies have been established to facilitate material circulation within the circular economy context by developing the Circular Materials and Activities Ontology (CAMO) and Circular Exchange Ontology (CEO). Both ontologies have definitions related to resource, product and activity which are common in the context of circular economy. CEO reuses existing ontologies such as GeoSPARQL[31], having a focus on the construction domain. CAMO categorises specific materials, products and activities for circular economy. The usage of CEO and CAMO is furthermore investigated in [64] for representing textile data. As far as our survey can determine, these are the existing ontologies closest to what we are developing in Onto-DESIDE.

In addition, there are a few more ontologies that deal with CE, targeting more specific use cases. For instance, the Building Circularity Assessment Ontology (BCAO) [46] focuses on the construction industry and links data and information from different manufacturer products to support decision making while considering circularity. Nevertheless, the scope of many of the general topics of this ontology overlaps with our focus. For instance, in BCAO a product is made of materials which are produced by an organisation, which are also core notions in Onto-DESIDE. Further, BiOnto [4] from the BIOVOICES[32] project, aims to build a shared and common terminology in the domain of bioeconomy so that multiple and different stakeholders can provide information according to the ontology. Then the BONSAI-core ontology [22, 23] focuses on representing activities in product life cycles in which each activity involves input and output flows as well as participating flow objects. For instance, a flow object, coal, within a flow can be an input flow of an electricity production activity and such an activity produces electricity. The aim of the BONSAI project is to support product comparisons and decisions by representing product footprints. The above ontologies cover specific aspects that also appear in our requirements analysis. For instance, the focus on specific use cases such as construction and some circular concerns such as product life cycles. However, our requirements of ontologies in this project have an overall slightly different focus than those of the above ontologies (introduced in Chapter 5). For instance, one of the central modules in the ontology network is supposed to model domain knowledge for circular value networks and such a module is intended to be connected to and used by other modules in the ontology network modelling general domains or domains of specific industry use cases (i.e. construction, electronics and textiles).

[30] https://github.com/LiUSemWeb/Circular-Economy-Ontology-Catalogue
[31] http://www.geosparql.org
[32] https://www.biovoices.eu/about-us/the-scope-/

Table 4: Characteristics of Relevant General Ontologies.

id	Ontology name	Domain
1	AMO (Additive Manufacturing Ontology) [45]	MAN, PR, MAT
2	BCAO (Building Circularity Assessment Ontology) [46]	CE
3	BiOnto (An Ontology for Sustainable Bioeconomy and Bioproducts) [4]	CE, SU
4	BONSAI-core (Big Open Network for Sustainability Assessment Information core ontology) [23]	PR, SU
5	BPO (Building Product Ontology) [73]	PR
6	BUILDMAT (Building Material Ontology) [8]	MAT
7	BWMD-Domain ontology [50]	MAN, MAT
8	CAMO (Circular Materials and Activities Ontology) [63]	CE, MAT
9	CEO (Circular Exchange Ontology) [63]	CE
10	CHAMP (Coordinated Holistic Alignment of Manufacturing Processes) [67]	MAN, PR
11	COMPOSITION (Collaborative Manufacturing Services Ontology) [12]	MAN, LO
12	ENVO (Environment Ontology) [9]	SU
13	GPO (General Process Ontology) [24]	MAN, LO
14	GRACE ontology [38]	MAN, PR
15	IMAMO (Industrial MAintenance Management Ontology) [32]	LO
16	IOF-core ontology [17]	MAN, MAT
17	ManuService ontology [42]	MAN, PR, LO
18	MASON (MAnufacturing's Semantics ONtology) [39]	MAN
19	MATONTO (MatOnto Ontology) [11]	MAT
20	MDO (Materials Design Ontology) [41]	MAT
21	MPO (Material Properties Ontology) [58]	MAT
22	MSDL (Manufacturing Service Description Language) [2]	MAN
23	MSO-OFM (Manufacturing System Ontology / Ontologies for manufacturing and logistics) [47]	MAN, LO
24	NMRRVOCAB (Materials Data Vocabulary) [44]	MAT
25	PRONTO (Product Ontology) [70]	PR
26	PSS (Product Service System) [43]	PR, MAN
27	ROMAIN (Reference Ontology for Industrial Maintenance) [31]	LO
28	SAREF (Smart Appliances REFerence ontology) [15]	General
29	SAREF4ENER (an extension of SAREF for the energy domain) [14]	SU
30	SAREF4ENVI (an extension of SAREF for the environment domain) [57]	SU
31	SAREF4INMA (an extension of SAREF for the industry and manufacturing domains) [16]	MAN
32	SDGIO (Sustainable Development Goals Interface Ontology) [65]	SU
33	SCONTO (Supply Chain Ontology) [71]	LO
34	SCOR (Supply Chain Operation Reference) [53]	LO
35	UNSPSC (Universal Standard Products and Services Classification) [60]	PR
36	VERONTO (VERsioning ONTOlogy) [72]	MAN, PR
37	Z-BRE4K [75]	MAN

Table 5: Ontology Metrics of General Ontologies.

Ontology	Class #	Object Property #	Data Property #	Individual #	Language	Reused ontologies
AMO	293	19	5	139	OWL	BFO, Common Core Ontologies, CHAMP
BCAO	37	19	17	0	OWL	–
BiOnto	780	64	5	0	OWL	–
BONSAI-core	13	13	0	0	OWL	Units of Measure, schema.org, SKOS, Time
BPO	25	22	6	0	OWL	GoodRelations, schema.org, FOAF, SEAS
BUILDMAT	27	56	7	12	OWL	QUDT
BWMD-Domain	772	24	11	0	OWL	BFO, OBO
CAMO	86	17	1	0	OWL	–
CEO	11	18	0	0	OWL	SKOS, Time, PlaceReferenceTheory, GeoSPARQL, SpatioTemporalFeature
CHAMP	2001	253	11	154	OWL	–
COMPOSITION	317	82	71	118	OWL	MSDL, GoodRelations, MASON, schema.org
ENVO	6566	135	1	44	OWL, OBO	BFO, ChEBI, OBO
GPO	106	12	0	0	OWL	EMMO, SKOS
GRACE	21	28	33	45	OWL	–
IMANO	109	4	6	3	OWL	–
IOF-core	93	103	0	0	OWL	BFO, SKOS
ManuService	105	33	183	69	OWL	–
MASON	246	37	18	102	OWL	SWRL
MATONTO	848	83	13	131	OWL	BFO, SKOS, Snap
MDO	37	32	32	2	OWL	QUDT, PROV-O
MPO	140	13	8	0	OWL	SAREF
MSDL	664	641	5	2926	OWL	BFO, OBO-GO, OBO-RO
MSO-OFM	109	57	116	0	OWL	–
NMRVOCAB	3	0	0	994	OWL, SKOS	SKOS
PRONTO	38	31	0	0	OWL	–
PSS	202	6891	0	1	OWL	Common Core Ontologies, BFO, IOF-core
ROMAIN	1056	171	17	357	OWL	BFO, Common Core Ontologies
SAREF	113	63	31	55	OWL	Time
SAREF4ENVR	147	52	45	30	OWL	SAREF
SAREF4ENVI	31	24	12	24	OWL	SAREF
SAREF4INMA	35	24	11	0	OWL	SAREF
SDGIO	907	152	0	470	OWL, OBO	ENVO, ChEBI, BFO, PCO, DOID, SWRL, OBO, UBERON
SCONTO	201	57	0	0	OWL	–
SCOR	285	5	249	224	OWL	schema.org, Ordered List Ontology
UNSPSC	16506	0	0	16500	OWL	–
VERONTO	26	38	9	0	OWL	–
Z-BRE4K	56	53	26	0	OWL	–

Moving towards the sustainability topic, the Environment Ontology (ENVO) [9] specifies a number of essential environment types that could be useful for annotating biological data. For instance, a central concept in ENVO is environmental system with sub-concepts biome and habitat. Although, these are not core concepts in our set of requirements, representing environmental impact and effects may at some point be necessary, e.g. to asses impact of certain steps in a value network. Smart Appliances REFerence ontology (SAREF) [15] has a focus on the smart appliances domain, modelling concepts such as device, measurement, service, property and function. SAREF4ENVI [57] extends SAREF to describe different physical objects, devices and their characteristics, in an environment setting. SAREF4ENER [14] extends SAREF to represent energy management such as energy efficiency optimization and describes, e.g. specific power sequences. Both these SAREF extensions may be relevant for describing setups in ciruclar value networks.

A bit more general, the Sustainable Development Goals Interface Ontology (SDGIO) [65] intends to represent knowledge related to the sustainable development goals[33] as well as their targets and indicators. SDGIO reuses a number of existing ontologies from different domains such as ENVO [9] in the environment domain.In our ontologies we will need to describe goals of a circular value networks, which in turn may relate to the general sustainable developmen goals.

4.2 Ontologies related to Manufacturing, Product, and Logistics

In a circular value network, a resource can be realized in different states. These states can be identified as particles (materials), parts (components) and products (finished goods) [7]. Operations in terms of manufacturing and logistics can happen in all these three states of resources. For instance, different components need to be assembled into products by manufacturing. A well-designed logistics system can then optimize the management of products in their life cycle by, for instance, reducing the distribution, redistribution and monitoring maintenance cost. Thus, the domains of *Manufacturing*, *Products*, and *Logistics* as presented in Table 1, are tightly connected and we discuss the ontologies for all these domains in this section. We use the labels MAN, PR, LO, respectively. Among the collected ontologies shown in Table 4, there are 22 ontologies for these domains. Some of them are assigned with more than one label since they capture knowledge in more than one domain.

First of all, taking the manufacturing domain as an example, several ontologies model different manufacturing processes. For instance, AMO (Additive Manufacturing Ontology) [45] focuses on modelling different manufacturing processes relevant to additive products as well as their physics-based models. BWMD-Domain ontology [50] contains definitions of different manufacturing processes such as casting and coating. MAnufacturing's Semantics ONtology (MASON) [39] concerns what resources (e.g. human resource and material resource), entities (e.g. assembly entity) and operations (e.g. manufacturing operation and logistic operation) are involved within the manufacturing domain. Particularly, it distinguishes different manufacturing processes or operations by taking into account if such an operation results in a loss of volume or not. Collaborative Manufacturing Services Ontology (COMPOSITION) [12] concerns collaborative manufacturing services that include human operations, logistic operations and manufacturing operations by reusing MASON. Manufacturing Service Description Language (MSDL) [2] focuses on manufacturing services in the mechanical machines. Manufacturing acts are categorised as shaping processes and non-shaping processes based on whether they alter the shape of the input material or not. Overall we note that there are many detailed models of manufacturing processes, whereas this project will mainly be concerned with creating alignments and bridge different viewpoints, rather than creating new detailed ontologies in this area.

In addition to modelling different manufacturing processes, several ontologies focus on modelling relevant concepts and/or relationships that relate to such processes. The IOF-core ontology [17] includes common terms and concepts across multiple domains of industry. For instance, in the manufacturing domain, IOF-core describes that a manufacturing process has a machine or person participation, as well as a material entity as input. General Process Ontology (GPO) [24] focuses on modelling processes such as measurement

[33] https://sdgs.un.org/goals

processes taking materials as input and providing information as output, or manufacturing processes having materials entities as both input and output. SAREF4INMA [16] extends SAREF to capture knowledge in the manufacturing domain. For instance, it contains the item and batch concepts to describe factory production, as well as general concepts such as production equipment and factory. Manufacturing System Ontology / Ontologies for manufacturing and logistics (MSO-OFM) [47] models manufacturing and logistics systems by addressing some main aspects such as physical and technological aspects. The physical aspect captures the characteristics of a manufacturing and logistics system in terms of workers, production facilities, equipment and devices. The technological aspect models processes such as how products are processed within the manufacturing and logistics system. Z-BRE4K [75] is an ontology providing annotations and descriptions to represent manufacturing system performance. Similarly as noted before, many ontlogies model processes and participation of resources in them, and in Onto-DESIDE we will therefore mainly be concerned with generalising over these, and creating appropriate alignments and bridges between these efforts.

Among the ontologies introduced above, we find that several ontologies also concern the logistics domains (e.g. COMPOSITION, GPO, MSO-OFM). There are also ontologies focusing on the logistics domain specifically such as IMAMO, ROMAIN, SCONTO and SCOR. IMAMO and ROMAIN focus on modelling domain knowledge for maintenance in the context of logistics domain. Industrial Maintenance Management Ontology (IMAMO) [32] contains general concepts such as equipment, maintenance task and maintenance strategy which makes it possible to increase semantic interoperability among different applications requiring maintenances within the same industrial environment. Reference Ontology for Industrial Maintenance (ROMAIN) [31] extends the material entity within BFO with a new concept maintainable item as well as relevant concepts such as maintenance strategy, plan and action. SCONTO and SCOR focus on modelling domain knowledge for supply chain in the context of logistics domain. Supply Chain Operation Reference (SCOR) [53] provides vocabularies to represent the supply chain operations reference standard. For instance, it models different processes in a supply chain system such as deliver, plan and return processes. Supply Chain Ontology (SCONTO) [71] defines supply chain related entities in three dimensions in terms of structures of supply chain systems, processes and resources involved in supply chains. For instance, a supply chain system includes specific markets and organisations as well as areas such as logistics, production and sales. Similar to SCOR, the process part also includes deliver, plan and return. Resources can be financial resources, human resources and material resources. Hence, also for supply-chain modelling and logistics several ontologies exist, for various domains, whereby our role will be mainly to bridge different viewpoints, and make sure CE aspects are appropriately covered.

Additionally, some ontologies specifically focus on representing knowledge for the product domain. Building Product Ontology (BPO) [73] has a focus on building products modelling, for instance, how different components of a product can be assembled. Product Ontology (PRONTO) [70] captures production information in two ways. The abstraction hierarchy level considers a product at three different levels of abstraction: as a product, as a member of a variant set (similar products with certain constraints), and as a member of a family (similar products). The structural level considers the components at each abstraction level. Universal Standard Products and Services Classification (UNSPSC) [60] has detailed classifications on product and services in the scope of global marketplace.

As mentioned before, some ontologies are labeled with more than one domain since they capture knowledge from multiple domains. Some of them have been introduced above (e.g. AMO, BONSAI-core, BWMD-Domain Ontology, COMPOSITION, GPO, IOF-core ontology, MSO-OFM). We introduce the others below. ManuService ontology [42] is modelled in a general level (with MAN, PR and LO labels), focusing on a model for the cloud-based service provision in a cloud-based manufacturing environment. It contains concepts related to product specification (e.g. price specification), quality constraints (e.g. design capability and production capability) and different machines for manufacturing processes.

In addition, several ontologies focus on both the manufacturing and product domains. Coordinated Holistic Alignment of Manufacturing Processes (CHAMP) [67] represents knowledge of product life cycles, aiming at integrating data within different industrial organisations, as well as across them. It uses a number of existing ontologies such as BFO [3] and the Common Core Ontologies[34]. GRACE ontology [38] focuses on describing the knowledge for multi-agent systems that integrate processes and quality control in production lines in distributed manufacturing systems. It contains concept definitions such as product and resource. Product Service System (PSS) [43] represents domain knowledge that relates to different aspects of products and product service systems (pss) such as the provider for a product or a pss, and different resources needed for a pss (e.g. manufacturing resources, business resource, hardware and software resources). VERsioning ONTOlogy (VERONTO) [72] is an ontology for the representation of temporal events that affect product information over time.

To sum up this section, there are numerous ontologies describing most aspects of manufacturing, products and their components, as well as logistics and supply-chains. In these cases, Onto-DESIDE will mainly focus on (1) making sure that the CE viewpoint is appropriately covered, and if needed complement the existing ontologies with certain specific concepts, and (2) create alignment modules, to bridge the use of a selected set of these ontologies together with our core ontology modules.

4.3 Ontologies related to Materials

The work presented in [34, 40, 35] has investigated existing ontologies related to the materials science domain. The currently on-going EU project OntoCommons conducted a survey of existing ontologies in identified domains of which one domain is materials science and engineering. Three ontologies in these surveys (BWMD-Domain Ontology, MatOnto and MPO) are clearly relevant for our project (in terms of representing materials composition information) and are included in our survey. Additionally, six other ontologies were collected. In Table 4, we have assigned the label MAT to these ontologies.

BWMD-Domain ontology (also labeled MAN), based on BFO, contains definitions of different material structures (e.g. meso structure, micro structure and macro structure) and different engineering material types (e.g. composite material, metallic material, organic material) which can provide general information of materials for the circular economy domain. MATONTO (MatOnto Ontology) [11] models different material properties, e.g. amount of substance, and flexural strength as measured properties. MPO (Material Properties Ontology) [58] has a focus on describing materials and their properties for building components (e.g. layer, layer set), with a detailed taxonomy of materials that relate to a building. Similar to BWMD-Domain ontology and MPO, BUILDMAT [8] also represents materials with a focus on building components, as well as general material properties and material types. MDO (Materials Design Ontology) [41, 35] contains a structure module describing composition information of materials, which is essential in the circular value network context when a recycling operation is taken. The ontologies AMO, CAMO, IOF-Core Ontology were already described earlier as they were also labeled with other domains.

In summary, the materials domain is also a core concern for the Onto-DESIDE ontology network, but again a domain where much work has been done and is ongoing. We will not attempt to remodel all these notions, but reuse as much as possible the existing ontologies. One observation from the CE domain that becomes important is the fact that the notion of "material" itself is quite context-dependent. This means that what is considered a material in one industry domain, is rather considered a product in another, e.g. a fabric is considered a product of a fabric manufacturer, but a material by a fashion brand. Hence, Onto-DESIDE needs to capture this context-dependent notion of materials, components and products, and appropriately align to materials ontologies in the right contexts.

4.4 Use Case Specific Ontologies

In addition to survey existing ontologies for the domain as we introduced in the previous sections, we search ontologies that are related to the three use cases in the Onto-DESIDE project, which are the Construction,

[34] https://github.com/CommonCoreOntology/CommonCoreOntologies

Table 6: Characteristics of Use Case Specific Ontologies.

id	Ontology name	Domain
1	REC (RealEstateCore) [28]	Construction
2	SEAS (The SEAS Building Ontology) [37]	Construction
3	BOT (Building Topology Ontology) [61]	Construction
4	Building Ontology [10]	Construction
5	SAREF4BLDG [56]	Construction
6	ElectricAppliance ontology [1]	Electronics
7	GeniusTex (Smart Textile Ontology) [21]	Textiles

Table 7: Ontology Metrics of Use Case Specific Ontologies.

Ontology	Class #	Object Property #	Data Property #	Individual #	Language	Reused ontologies
REC	179	99	84	297	OWL, SHACL, DTDL	–
SEAS	102	32	3	5	OWL	Procedure Execution ontology
BOT	10	16	1	5	OWL	schema.org
Building Ontology	46	15	19	0	OWL	BOT
SAREF4BLDG	71	179	83	0	OWL	SAREF
ElectricAppliance	44	20	2	88	OWL	–
GeniusTex	77	63	37	73	OWL	SOSA, Unit of Measure

Electronics and Textiles use cases. These ontologies are shown in Table 6 and Table 7.

There are five ontologies that relate to the construction domain. RealEstateCore (REC) ontologies [28], including different modules such as agent, building, device and lease is developed for property owners to describe data that are generated from interactions within buildings. The SEAS (Smart Energy Aware Systems) Building Ontology [37], including some modules such as zone, building, represents the smart home domain. The building topology ontology (BOT) [61] represents topological related concepts of a building. Building Ontology [10], extending BOT, furthermore describes relationships among topological concepts such as zones, spaces, and building elements. SAREF4BLDG [56] extends SAREF to describe building related concepts such as physical spaces of a building, and different devices that can exist in a building.

In addition, we find ElectricAppliance ontology and GeniusTex ontology that relate to the electronics and textiles domains, respectively. ElectricAppliance ontology [1] has a classification of different electric appliances (e.g. communication, kitchen, entertainment appliances). GeniusTex (Smart Textile Ontology) [21], focusing on smart textiles domain, has different modules to describe relationships among materials, components, and processes related concepts.

Overall, this part of the survey is probably less complete than the other parts, and will be extended when working on ontology extension in the context of WP6. However, still, we may note that also in these domain some specific ontologies already exist, to which alignments might be created.

4.5 Standards for Ontology Development

In order to develop high-quality and complete ontologies, it is also necessary to take the corresponding standards (i.e. ISO standards), and EU policies, laws and regulations into account.

We list 50 relevant standards, regulations and polices in Table 8. These standardisation efforts can be categorised into five domains which are (1) circular economy, (2) general domain (e.g. environment, energy, quality management), (3) construction, (4) electronics, and (5) textiles. We also label each work as a work at the international level or at the EU level. In total, we have 16 standardisation efforts in the circular economy domain (12 at the global level and 4 at the EU level). Among these, 7 standards are under development. There are 12 efforts in the general domains, 8 in the construction domain, 2 in the electronics domain and 12 in the textiles domain, respectively.

One use of these resources is as a basis for extracting relevant terms for a specific domain. They also provide context and restrictions for the terms in the ontology. For instance, ISO/DIS 59004 defines key terminology, establishes circular economy principles and provides guidance for circular economy implementation. ISO/TC 297, ISO 50001:2018, and ISO 14001:2015 define the fundamentals and vocabularies regarding different aspects such as waste collection, energy management, and environmental management, respectively.

There are also different types of EU policies, legislation, and regulations. For instance, the EU taxonomy for sustainable activities (regulation (EU) 2020/852) provides a list of terms as well as the criteria for environmentally sustainable economic activities.

Table 8: Relevant Standards, Regulations and Policies.

Name	Domain	Level
ISO/DIS 59004 Circular Economy – Terminology, Principles and Guidance for Implementation[35] (under development)	Circular Economy	Global
ISO/DIS 59010 Circular Economy — Guidance on the transition of business models and value networks[36] (under development)	Circular Economy	Global
ISO/DIS 59020 Circular Economy — Measuring and assessing circularity[37] (under development)	Circular Economy	Global
ISO/CD TR 59031 Circular economy – Performance-based approach – Analysis of cases studies[38] (under development)	Circular Economy	Global
ISO/CD TR 59032.2 Circular economy - Review of business model implementation[39] (under development)	Circular Economy	Global
ISO/CD 59040 Circular Economy — Product Circularity Data Sheet[40] (under development)	Circular Economy	Global
ISO/CD 59014 Secondary materials — Principles, sustainability and traceability requirements[41] (under development)	Circular Economy	Global
ISO 14021:2016 Environmental labels and declarations[42]	Circular Economy	Global
Circular Product Data Protocol[43]	Circular Economy	Global
circular.ID Open Data Standard[44]	Circular Economy	Global
Product Circularity Data Sheet (PCDS)[45]	Circular Economy	Global
GS1 Global Traceability Standard (GTS2)[46]	Circular Economy	Global
EU Environment related policies[47]	Circular Economy	EU

[35] https://www.iso.org/standard/80648.html
[36] https://www.iso.org/standard/80649.html
[37] https://www.iso.org/standard/80650.html
[38] https://www.iso.org/standard/81183.html
[39] https://www.iso.org/standard/83044.html
[40] https://www.iso.org/standard/82339.html
[41] https://www.iso.org/standard/80694.html
[42] https://www.iso.org/standard/66652.html
[43] https://www.circulardataprotocol.org
[44] https://circularity.id
[45] https://pcds.lu/wp-content/uploads/2020/11/MECO_CEDataSet_PCDS_Public-27072020.pdf
[46] https://www.gs1.org/sites/default/files/docs/traceability/GS1_Global_Traceability_Standard_i2.pdf
[47] https://environment.ec.europa.eu/index_en

EU Circular Economy related policies[48]	Circular Economy	EU
EU taxonomy for sustainable activities (**regulation** (EU) 2020/852)[49]	Circular Economy	EU
EU circular raw materials[50]	Circular Economy	EU
ISO/TC 297 Waste collection and transportation management[51]	General Domain	Global
ISO/TC 154 Processes, data elements and documents in commerce, industry and administration[52]	General Domain	Global
ISO 14001:2015 Environmental management system – Requirements with guidance for use[53]	General Domain	Global
ISO 14004:2016 Environmental management systems — General guidelines on implementation[54]	General Domain	Global
ISO 14005:2019 Environmental management systems — Guidelines for a flexible approach to phased implementation[55]	General Domain	Global
Ecodesign requirements[56]	General Domain	EU
ISO 9000:2015 Quality management systems – Fundamentals and vocabulary[57]	General Domain	Global
ISO 9001:2015 Quality management system – Requirements[58]	General Domain	Global
ISO 9004:2018 Quality management — Quality of an organization — Guidance to achieve sustained success[59]	General Domain	Global
ISO 50001:2018 Energy management systems — Requirements with guidance for use[60]	General Domain	Global
ISO 50002:2014 Energy audits — Requirements with guidance for use[61]	General Domain	Global
ISO 50003:2021 Energy management systems — Requirements for bodies providing audit and certification of energy management systems[62]	General Domain	Global
ISO 6707-1:2020 Buildings and civil engineering works — Vocabulary — Part 1: General terms[63]	Construction	Global
ISO 6707-2:2017 Buildings and civil engineering works — Vocabulary — Part 2: Contract and communication terms[64]	Construction	Global
ISO 6707-3:2022 Buildings and civil engineering works — Vocabulary — Part 3: Sustainability terms[65]	Construction	Global
ISO 6707-4:2021 Buildings and civil engineering works — Vocabulary — Part 4: Facility management terms[66]	Construction	Global
ISO 16739-1:2018 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries - Part 1: Data schema[67]	Construction	Global

[48] https://environment.ec.europa.eu/topics/circular-economy_en
[49] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852
[50] https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
[51] https://www.iso.org/committee/5902445.html
[52] https://www.iso.org/committee/53186.html
[53] https://www.iso.org/standard/60857.html
[54] https://www.iso.org/standard/60856.html
[55] https://www.iso.org/standard/72333.html
[56] https://europa.eu/youreurope/business/product-requirements/compliance/ecodesign/index_en.htm
[57] https://www.iso.org/standard/45481.html
[58] https://www.iso.org/standard/62085.html
[59] https://www.iso.org/standard/70397.html
[60] https://www.iso.org/standard/69426.html
[61] https://www.iso.org/standard/60088.html
[62] https://www.iso.org/standard/77575.html
[63] https://www.iso.org/standard/77077.html
[64] https://www.iso.org/standard/70040.html
[65] https://www.iso.org/standard/80456.html
[66] https://www.iso.org/standard/78714.html
[67] https://www.iso.org/standard/70303.html

EU Construction and Demolition Waste Protocol and Guidelines[68]	Construction	EU
Construction Products Regulation (CPR)[69]	Construction	EU
Eurocodes: Standards in construction[70]	Construction	EU
ICS 31 Electronics[71]	Electronics	Global
TL 9000: Quality Management Systems (QMS) for Telecommunications[72]	Electronics	Global
ISO/DIS 5157 Textiles — Environmental aspects — Vocabulary[73] (under development)	Textiles	Global
ISO/DIS 5157 Textiles — Environmental aspects — Vocabulary[74]	Textiles	Global
ISO/CD 19952 Footwear — Vocabulary[75]	Textiles	Global
GOTS (GLOBAL ORGANIC TEXTILE STANDARD) certification[76]	Textiles	Global
Global Recycled Standard (GRS)[77]	Textiles	Global
Recycled Claim Standard (RCS)[78]	Textiles	Global
Trustrace[79]	Textiles	Global
Traceability for Sustainable Garment and Footwear[80]	Textiles	Global
European light industries innovation and technology project[81]	Textiles	EU
EU strategy for sustainable textiles[82]	Textiles	EU
EU strategy for sustainable and circular textiles[83]	Textiles	EU
EU Market Report-Textiles, Apparel, Footwear, and Travel Goods[84]	Textiles	EU

4.6 Discussion

Although there are quite a number of existing ontologies from different cross-industry domains that are relevant to the circular economy domain, we find that there are still some issues to be addressed when we take these ontologies as background resources when developing an ontology network for circular value networks.

The first issue is that many cross-industry domain ontologies use the same or similar terms to represent concepts that may have different meanings in different domains. For instance, many ontologies contain the material, product, resource, and process concepts. The material concept could be a general concept that models different engineering materials (e.g. NMRRVOCAB) or a specific concept that focuses on representing micro-structural information of materials (e.g. MDO). One of the goals of the Onto-DESIDE project is to address both vertical interoperability and horizontal interoperability. The new concepts developed there could be bridge concepts that connect different domain ontologies.

[68] https://single-market-economy.ec.europa.eu/news/eu-construction-and-demolition-waste-protocol-2018-09-18_en
[69] https://single-market-economy.ec.europa.eu/sectors/construction/construction-products-regulation-cpr_en
[70] https://eurocodes.jrc.ec.europa.eu/policies-standards/en-eurocodes-and-related-standards
[71] https://www.iso.org/ics/31/x/
[72] https://isoupdate.com/standards/tl-9000/
[73] https://www.iso.org/standard/80937.html
[74] https://www.iso.org/standard/80937.html
[75] https://www.iso.org/standard/84291.html
[76] https://global-standard.org/certification-and-labelling/certification
[77] https://d2evkimvhatqav.cloudfront.net/documents/global_recycled_standard.pdf
[78] https://textileexchange.org/app/uploads/2021/02/Recycled-Claim-Standard-v2.0.pdf
[79] https://trustrace.com
[80] https://unece.org/trade/traceability-sustainable-garment-and-footwear
[81] https://single-market-economy.ec.europa.eu/sectors/fashion/eliit_en
[82] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en
[83] https://environment.ec.europa.eu/publications/textiles-strategy_en
[84] https://www.trade.gov/textile-and-apparel-market-report-european-union

Further, in contrast to domains such as biology, materials science and industrial manufacturing where many ontologies have been developed and catalogued in public repositories, circular economy is a relatively new domain in terms of focusing on using Semantic Web-based techniques. This means that circular economy ontologies are not as findable and accessible as they could be and thus do not satisfy the FAIR principles well yet. By cataloguing existing ontologies related to circular economy in a github repository, we improve the findability and accessibility for circular economy related ontologies, and intend to maintain this as a future reference resource.

The ontologies collected in our survey are modelled quite differently in terms of the ontology metrics shown in Table 5. All the ontologies have class definitions (for concepts) ranging from three classes (NMRVOCAB) to 16506 classes (UNSPSC). There are only two ontologies (NMRVOCAB and UNSPSC) without object property definitions (for relations). These two ontologies focus on providing taxonomic information. In addition, we see that there are 34 ontologies that contain data property definitions and 26 ontologies that contain individuals. Some ontologies, as shown in Table 5, reuse existing foundational ontologies (e.g. BFO, EMMO[85]) or general level ontologies (e.g. SAREF). The usage of foundational ontologies provides a common ground to enable interoperability among different domains. Ontologies based on the same foundational ontology make certain common ontological commitments. This means that different ontological commitments are made by different ontologies and care should be taken when using these ontologies together in a network.

Overall, this survey provides us with a good foundation for starting our ontology development in Onto-DESIDE. We have identified the areas where ontologies and standards already exist, and where the work will be more related to aligning and bridging different viewpoints, rahter than developing new ontologies. On the other hand, many ontologies are large and monolithic, and thereby do not go well with a modular approach. This may results in decisions to anyway remodel parts of their content, in order to provide "lighter" models, in terms of the level of details or axiomatisation, and thereby ease the reuse of those concepts. However, by still aligning to the original ontologies, this will not be a way of replacing them, but merely allowing a better way to reuse already existing efforts. Still, some CE notions are not appropriately covered yet, and we foresee that our core modules will fill this gap.

[85] https://github.com/emmo-repo/EMMO

5 Preliminary Result #2 – Requirements and Ontology Network Architecture

In this chapter we describe the requirements collected (Section 5.1), and the intended overall architecture of the first version of our ontology network (Section 5.2). Note that this is a draft that will be validated and evaluated in our use case in the coming months, hence, also the set of requirements and the architecture is subject to change in the next version of this deliverable. So although the ontology modules will be made public as soon as they are delivered, they are to be considered as draft versions in this first release, which will be made clear in their documentation. Additionally, we briefly introduce what modules are supposed to be modelled in our ontology network (Section 5.3 and Section 5.4), and the strategy for aligning our ontologies with existing ontologies (Section 5.5).

5.1 Ontology Requirements

One of the core outcomes of WP3 so far is a set of ontological requirements, developed according to the steps outlined in Section 3.2.2. The full set of ontology stories developed so far, can be found in Appendix B, together with a glossary of terms (consisting of 104 core CE terms) also extracted from the same user stories in D2.1. In total there are 55 ontology stories in the initial set[86], directly extracted from D2.1, as presented in Tables 12 to 14. Further there are another set of requirements, with 17 ontology stories, presented in Table 11, which are generalisations of common aspects in the other three tables, put into context by analysing the use case descriptions in D6.1, as well as taking into account emerging standards and terminology, and feedback from our modelling workshop (sketches presented in Appendix A).

Each story is then associated with a number of CQs, as described in Section 3.2.2, in turn potentially complemented by CS and RR (omitted in Tables 12 to 14 for readability reasons). An example of an ontology story directly extracted from D2.1, with related CQs, CS and RR, is provided in Figure 5. An example of a general CE concept story, targeting the concept of a Circular Value Network resource, is provided in Figure 6.

Story CUS0		
Story text	There are several actors involved in a construction use case/circular value flow, each holding some roles in a certain material flow.	
Identified terms	Building, Owner, Building Owner, Manufacturer, Dismantler, Tenderer, Recycler, Deconstruction, Company, Deconstruction Company, Planner, Marketplace	
Origin	D2.1 section 2.1	
CQ	**CS**	**RR**
1. What are the actors involved in this value network?	Each network has at least one actor.	
2. What is the role of this actor in the network?	Each actor involved in a network has to have a role in it. An actor can have several roles. There can be roles where we don't know the actor yet.	If an actor has a role in a value network it is involved in that network.

Figure 5: An example ontology story and its associated requirements, from the set directly extracted from D2.1.

[86] A few user stories from D2.1 remain to be further analysed with the help of domain experts in the project, these are marked in the appendix.

Story – CVN concept: Resource		
Story text	Resources are what is worked on in the circular value network (CVN). Resources are used as inputs but could also be outputs from the network, and its steps. For resources that are part of a circular value network they will be of a certain type (is it a product, part or material). Also, for these resources, their composition is ideally known at some level. Resources can also be used in processing steps, but without being the main focus of the value network, e.g. consumables, cathalysts.	
CQ	**CS**	**RR**
1. Give me information about this resource.		
2. What is the type of a specific resource?	Resources are of a certain type.	
2. What is the composition of a specific resource?	Each resource in an CVN has a a composition, although it may be unknown.	Secondary resources are derived from the composition of the primary resources.
2. Which CVN:s use this resource, for what and in what steps?	Each CVN has at least one resource.	

Figure 6: An example ontology story and its associated requirements, from the set derived from cross-cutting concepts related to CE.

While the identified requirements from D2.1, as presented in Appendix B in Tables 12 to 14, cover all three use cases in detail, for the ontology development in the first project iteration we do not attempt to cover all those requirements. Instead we focus on a core set of modules, to describe the central concepts that have been identified as cross-cutting and relevant for all three use cases. Those are the ontological requirements presented separately in Table 11. Next we discuss the overall architecture, and plan, for those modules in Section 5.2.

5.2 Overall Network Architecture

As noted in the previous section, the requirements analysis has resulted in a quite extensive set of ontological requirements. Many of them are use case-specific, in terms of involving specific concepts of an industry domain. Still, many of them can also be generalised, and we note that there are many parallels between the three project use cases.

In the first project iteration we have therefore focused on identifying the core topics that need to be covered by ontology modules, using the set of initial requirements. An overview of such topics, in the form of an informal conceptual model is displayed in Figure 7. Note that the boxes do not represent single concepts in an ontology, but rather areas, i.e. topics, that should be covered by some ontology module. The dark blue boxes represent modules that are planned for release, in some form, in our first version of the ontology network, i.e. in D3.3. The lines between the boxes represent some common sense relations between the topics, and will in the actual implementation of the ontology network be replaced by formal relations between modules, e.g. in some cases `owl:import`, as well as some other alignments, or specific object properties connecting concepts inside the modules. The light blue box with the text "location" represents an important notion that is present in many of the requirement stories, namely spatial locations of things, e.g. resources or actors. However, for this specific topic, we will not release our own module, but rather rely on reusing standard geographical ontologies, such as W3C standards and the OGC standard GeoSPARQL. Also note that this illustration of a conceptual architecture is not comprehensive, in the sense that there are less central topics that will be included in the ontology network, but not as their own modules but rather as concepts within the displayed modules. Such topics include for instance, the different circular strategies that specify the type of networks, their goals, the subdivision of process into phases and steps, the work and energy required to perform such steps etc.

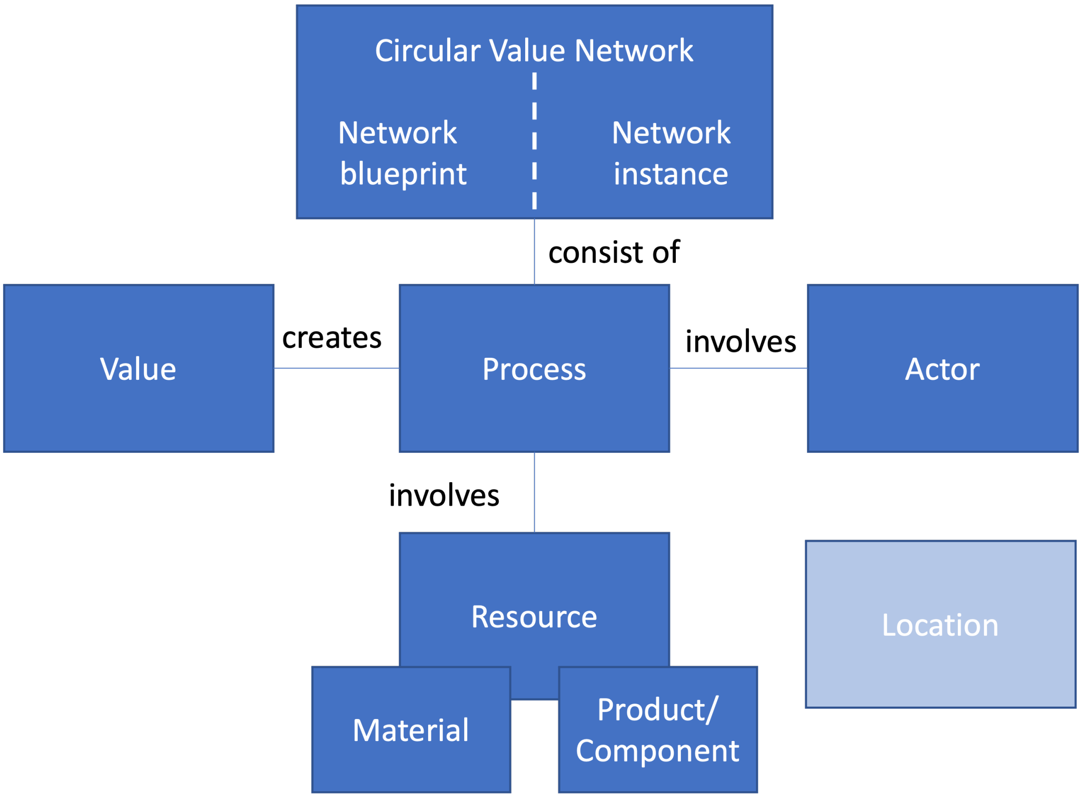

Figure 7: Informal illustration of the core topics of the ontology network.

5.3 Core Cross-Domain Modules

In this section we provide a brief description of the set of core modules that will be created, as generic reusable ontology building blocks, as illustrated in Figure 7. These include:

- Circular Value Network
- Value
- Actor
- Process
- Resource

The result of the first iteration of our requirements analysis process can be seen in Appendix B, in terms of a set of stories, with associated Competency Questions (as well as CS and RR).

5.3.1 Circular Value Network

This module will detail the core concept of the ontology network, i.e. the Circular Value Network itself. The value network works according to a blueprint, which describes the planned setup, with needed roles possible to fill by certain actor types, types of circular strategies targeted (e.g. refurbishment of a product), and relations to typical value propositions and goals. However, we also need to be able to model the concrete instance of the blueprint, i.e. an actual value network where the roles are filled by various actors of the appropriate types, with a specific goal, and specific value proposition in mind.

Our starting point for this module is an analysis of several terminologies, ontologies, and emerging standards, including the emerging standards in ISO 59004, the Circularity Thinking methodology, as well as a generalisation over the project use cases and requirements in D6.1 and D2.1. In Table 11 in Appendix B the detailed set of requirements for this module are represented, but they are additionally supported by several requirements in Tables 12 to 14, marked with topics related to circularity and circular economy.

5.3.2 Value

Although value is a very central concept in the Circular Economy, and closely related to the circular value network through its value proposition, value is also a very hard concept to define. Following the discussions on the value concept that is currently ongoing in other fora, e.g. including standardisation bodies, the concept will for now be left as a "stub" for further definition and extension in later versions of our ontology network. Hence, we reserve a specific module for this concept, but it will not be further detailed in this initial version of the ontology network.

5.3.3 Actor

A circular value network is in essence composed of a set of actors filling certain roles in different phases of the network's flows. Hence, the actors are the ones that actually realise the value network, and perform the work to transform materials, components, and products in the various steps in the value network phases. Similar to the value network itself, also actors will be modelled at two levels, i.e. as actor types that can fill certain typical roles in a network, such as a "recycler" or "manufacturer", and the concrete actors, that are usually organisations, that take on those roles in a specific network instantiation. Actors are also to be related to their capabilities and competencies, which determines if they are able to fulfil a certain role in a network or not.

5.3.4 Process

Each circular value network realises one or more circular value flows, which can be seen as a process of transforming some resource, e.g. from materials, to components, into products, and then potentially back again. Such processes have different phases, e.g. the phase that takes something from materials to components, or the phase of deconstructing a product into its material composition, and each phase can further be subdivided into smaller steps (pieces of work), which can be performed by different actors. Each step may have inputs and outputs, both in terms of resources, but also work, energy, and information, for instance, and may result in some waste. Steps can be performed by actors, i.e. participants in the value network, with the right capabilities. For these aspects, many existing ontologies exist, and this module will mainly act as a bridge, aligning to such existing models for allowing their integration into the network.

5.3.5 Resource

Resources are at the core of the value network, since they are the things that are needed as input and output of each step. Most prominently the resources are the materials, components, and products that the network aims to manage circularly, but resources can also include the additional materials needed for processing, such as consumables or catalysts, the work and investments needed. Similarly to the case of processes, much work already exist in modelling both products and materials, and their relations, hence this module will again mainly be a small general bridge module, to be able to properly align to other ontologies.

5.4 Additional Modules

In addition to the core notions of the CVN itself, that are outlined above. From the ontology stories derived from D2.1, we can find some additional cross-cutting concerns and general concepts that appear in several of the use cases. These include the notion of locations, as well as the more specific types of resources that need to be described, i.e. materials, components, and products.

5.4.1 Location

Location appears in many places in the overall list of requirements in Appendix B. Resources have a specific location at a certain point in time, but can also have a point of origin, and a trace of places where it has been. Similarly for actors, information etc. For certain use cases very specific kinds of location information may be needed, such as that something is located on the second floor of a building in a construction use case setting, or the exact coordinates of a crate of products for pick-up. While in other cases location information such as the country of origin of a certain product or material may suffice. Hence, we need both a generic notion of location, but also a "pluggable" structure where more specific models can be added for specific use cases. Location is also a well-studied, although still challenging, concept to model, where we intend to simply reuse existing standard ontologies, rather than building our own.

From the ODP portal[87] we may reuse the highly generic Place pattern[88], which is a notion of place and location extracted from the DOLCE upper ontology. However, for more specific notions related to positioning, we will rely on W3C and OGC standards, such as the Basic Geo Vocabulary[89] and the GeoSPARQL ontology[90]. In the context of WP6 the project will then further investigate what specific location notions are needed for our three use case.

5.4.2 Material

As shown in Figure 7, Material is an essential topic that is a specific kind of Resource, highly relevant in many CVNs. This was noted during the process of creating the ontology requirements based on user stories in D2.1. As listed in Appendix B, there are a number of material related terms (e.g. Material, Material Composition, Material Type) and most of them are shared by all the three use cases. Therefore, our material module will focus on representing common materials related concepts and relationships, as well as to prepare for the extension with use case specific concepts and relationships (such as concrete concepts for construction materials, fiber for textiles). We will also consider how to represent materials composition for these different materials since they might need to be represented with different structural information (i.e. micro-structural or macro-structural). For the use case specific parts we may then reuse some concepts or relationships from existing use case specific ontologies as presented in Section 4.4 (e.g. Building Ontology, ElectricAppliance ontology, GeniusTex), in the next step of specialising this general module.

5.4.3 Product and part

As we found in the survey of existing ontologies (Section 4.2), product is a common concept that appears in many ontologies from different cross-industry domains. An essential modelling task is to represent products and also parts of a product, i.e. components, if needed. Such a need is central because of different operational processes that happen in the product life cycle, i.e. developing the parts, composing them into a product. As listed in Appendix B, we observe this need in all our use cases as well, and this will be a core module in our

[87] https://ontologydesignpatterns.org/
[88] http://ontologydesignpatterns.org/wiki/Submissions:Place
[89] https://www.w3.org/2003/01/geo/
[90] https://opengeospatial.github.io/ogc-geosparql/geosparql11/index.html

ontology network, again as a specialisation of the resource module mentioned earlier. Where we will take care to also capture the context-dependent nature of these concepts, as discussed earlier, where what one considers a material may be another organisation's product.

5.5 Alignment Strategy

As we have noted in the overview of existing ontologies, earlier in this deliverable, many ontologies exist already and can partly be reused. However, in order to maximise the reuse potential of our ontology network the intention is to prioritise modularisation, minimal ontological commitments in core modules, and separation of concerns, as far as possible. This means that although we will enable the reuse of many existing ontologies, none of them will be directly imported into any of our core modules. Rather, our strategy is to (on purpose) duplicate the necessary concepts into our own modules, so that these are decoupled and reusable without needing external resources. Still, we will then provide alignment modules that import our own modules, and add alignment axioms to them that relate to external ontologies. In this way, we can even provide alternative alignments to mutually incompatible existing ontologies, as long as they are compatible with the minimal commitment in our core modules. Combined with proper documentation and guidelines of what modules, and module configurations, to use in what scenarios, we envision a highly flexible ontology network, but with an extensive library of alignment modules for relating to existing ontologies.

6 Conclusions

In this deliverable we have described the work in WP3 in the first project iteration, leading up to the design of our first set of ontology modules, to be reported in D3.3 later on. This work has mainly consisted of (1) adapting and setting up the methodology for ontology development, alignment, and FAIR publishing, initially targeting mainly the project initiation, scoping, and requirements analysis steps, (2) performing an extensive survey of existing ontologies, as well as policies and standards, that the Onto-DESIDE ontology network needs to take into account, and potentially align to, (3) develop an initial set of ontological requirements, derived from both our own set of project requirements reported in D2.1, contextualised through the use case descriptions in D6.1, as well as policies, emerging standards, and other resources, that lead to the outline of an initial ontology network architecture and a set of initial ontology modules that we will focus on for delivery in D3.3.

Methodology adaptations are related to the highly agile nature of our project, where we need to be able to for instance adapt to both changing scope, and changing external ontologies and other resources (e.g. standards). On the other hand, more focus has been put on developing an ontology architecture suitable for our specific CE setting, with a set of core modules outlined at the outset of the project, and requirements analysis performed in parallel with the development loop. These latter adaptations are intended to reduce the need for refactoring, and ensure that a highly reusable set of core modules (i.e. ODPs) will be built early in the project.

When analysing the existing ontologies, we notice that very few have treated the general notion of CE and CVN. The few that have are not published according to FAIR principles, and can therefore mainly be used as inspiration but potentially not in direct alignments. Or they have focused on industry-specific scenarios rather than general aspects. In particular, the main notion that is missing in related CE ontologies is the CVN itself. We note that this is an essential concept to model, if we are to be able to create a digital representation of that network, i.e. describe a digital twin of a value network to allow a certain degree of automation when discovering, setting up and executing new CVNs. Hence, this has been a core focus when developing the ontological requirements, and such modules will be a central part of our ontology network. Then we will also create a number of additional modules in the initial version of the network, that represent and further detail the core concepts related to the circular value network, such as actors, processes, resources (including materials, components, and products). We note that the notion of value is also central, but quite elusive and unexplored in terms of its meaning and use in the value network, hence, we set a placeholder for further development regarding the value concept, but at this point do not define and detail it further.

Several parts of the results reported in this deliverable still needs to be validated with domain experts and end users, within the project, including our set of ontological requirements. Such validation will be performed as part of completing the first project iteration. Next steps for the work in WP3 will also include the concrete modelling of the outlined modules, which will result in the release of D3.3. This work will also be validated against the research data to be produced in WP6 in the next few months, and then evaluated in the context of the use cases together with the overall platform, to complete the first project iteration. During this work, also the methodology will be further detailed, so that the tailored version of XD covers all methodology steps, e.g. also testing, integration, release, and so on. Additionally, the set of ontological requirements should not be seen as fixed at this point, but rather we will allow this set to evolve during the project, in order to take into account new insights from the project use cases, other ongoing projects and initiatives, as well as to properly align to emerging standards.

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Appendices

A Workshop: Concepts of a Circular Value Network

The following figures were sketched by the workshop participants when asked to create an informal conceptual model of a CVN, with its most important concepts. Note that not all groups had time to finish the sketch, hence the lack of relations to some concepts is not to be interpreted as that they are not actually related to anything. These sketches were used to make an initial validation of the coverage of the CVN ontology stories and terminology. Further validation will be preformed in the next period.

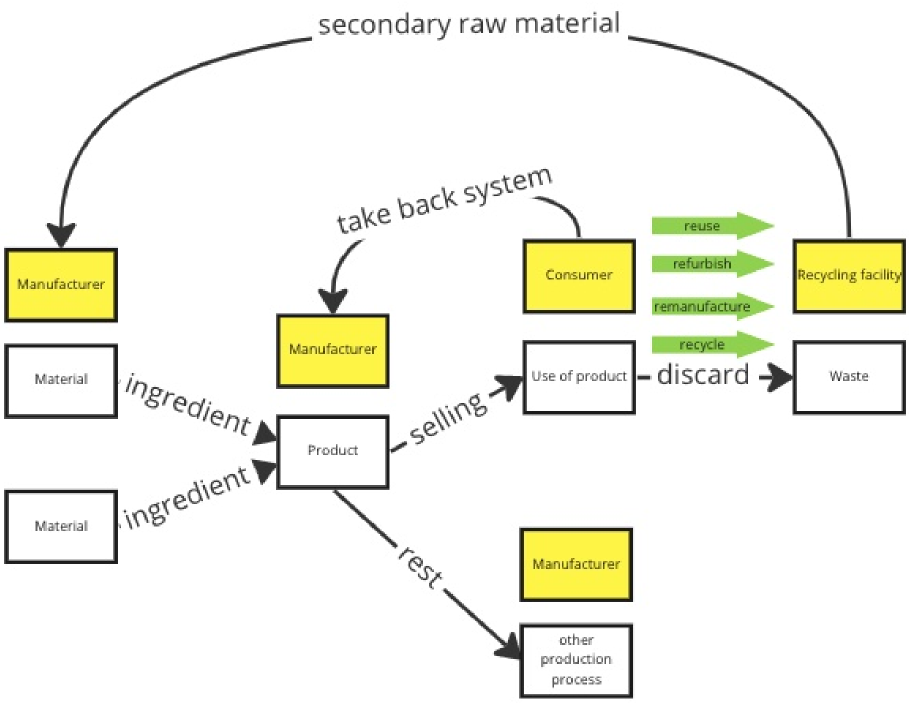

Figure 8: Sketch made by the first group (cleaned up in terms of visual representation, no content changes).

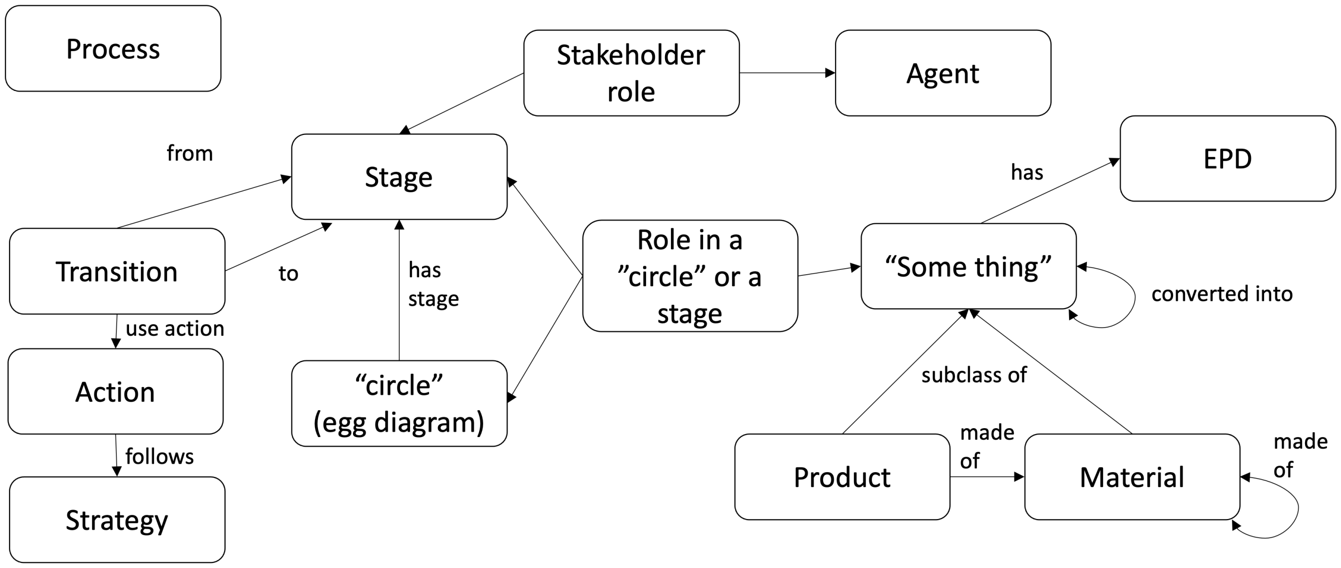

Figure 9: Sketch made by the first group (cleaned up in terms of visual representation, no content changes).

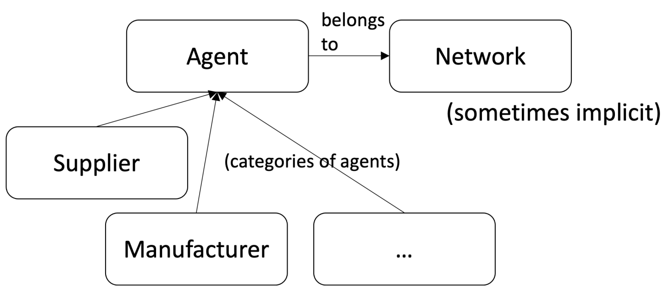

Figure 10: Sketch made by the first group (cleaned up in terms of visual representation, no content changes).

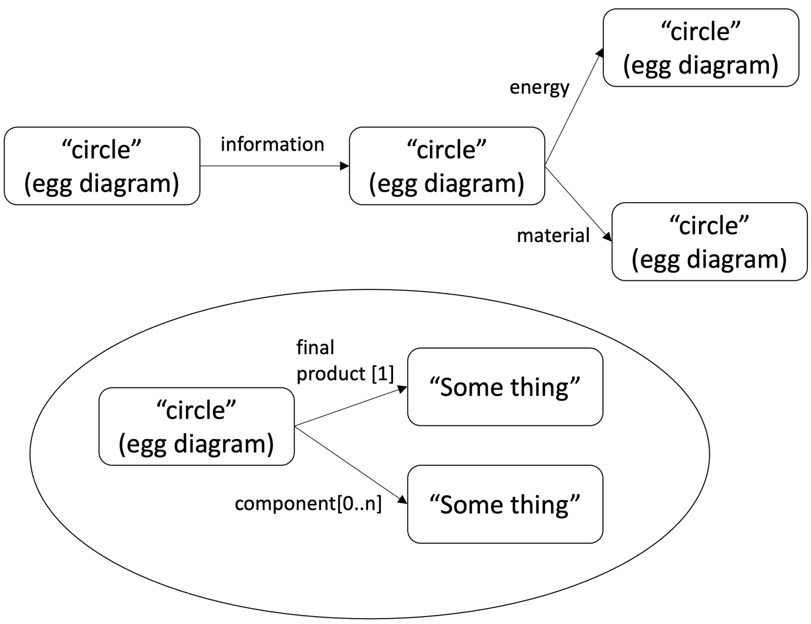

Figure 11: Sketch made by the first group (cleaned up in terms of visual representation, no content changes).

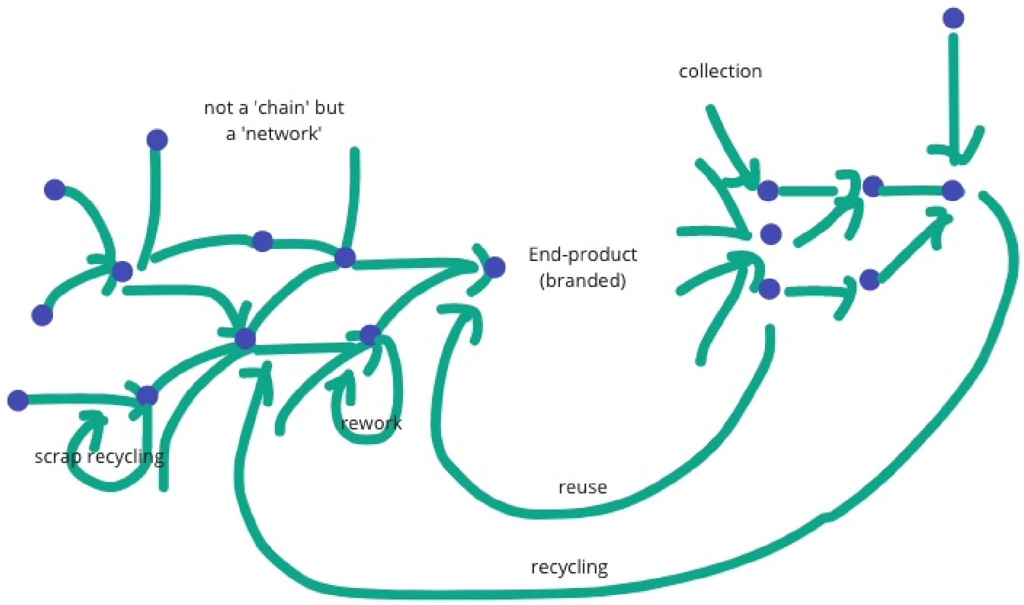

Figure 12: Sketch made by the second group (cleaned up in terms of visual representation, no content changes).

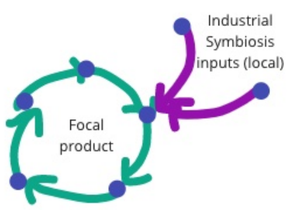

Figure 13: Sketch made by the second group (cleaned up in terms of visual representation, no content changes).

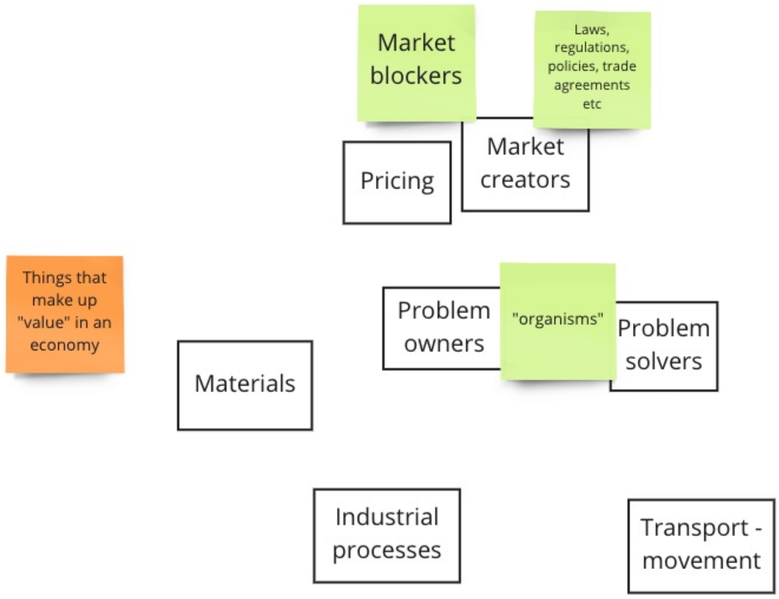

Figure 14: Sketch made by the second group (cleaned up in terms of visual representation, no content changes).

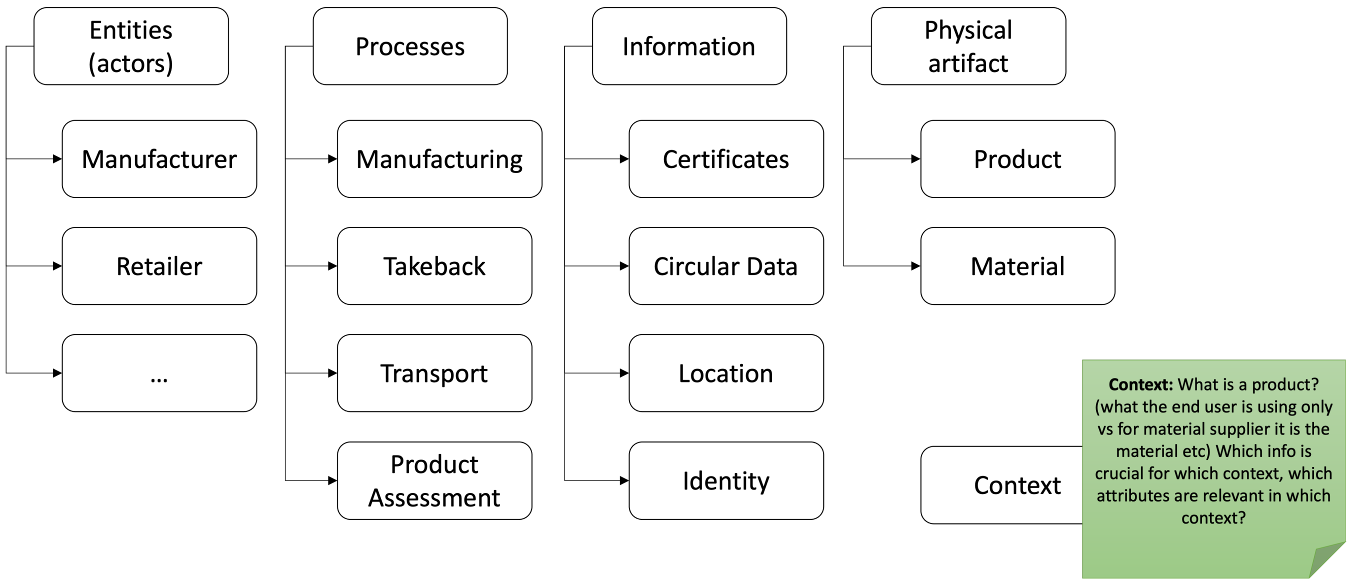

Figure 15: Sketch made by the third group (cleaned up in terms of visual representation, no content changes).

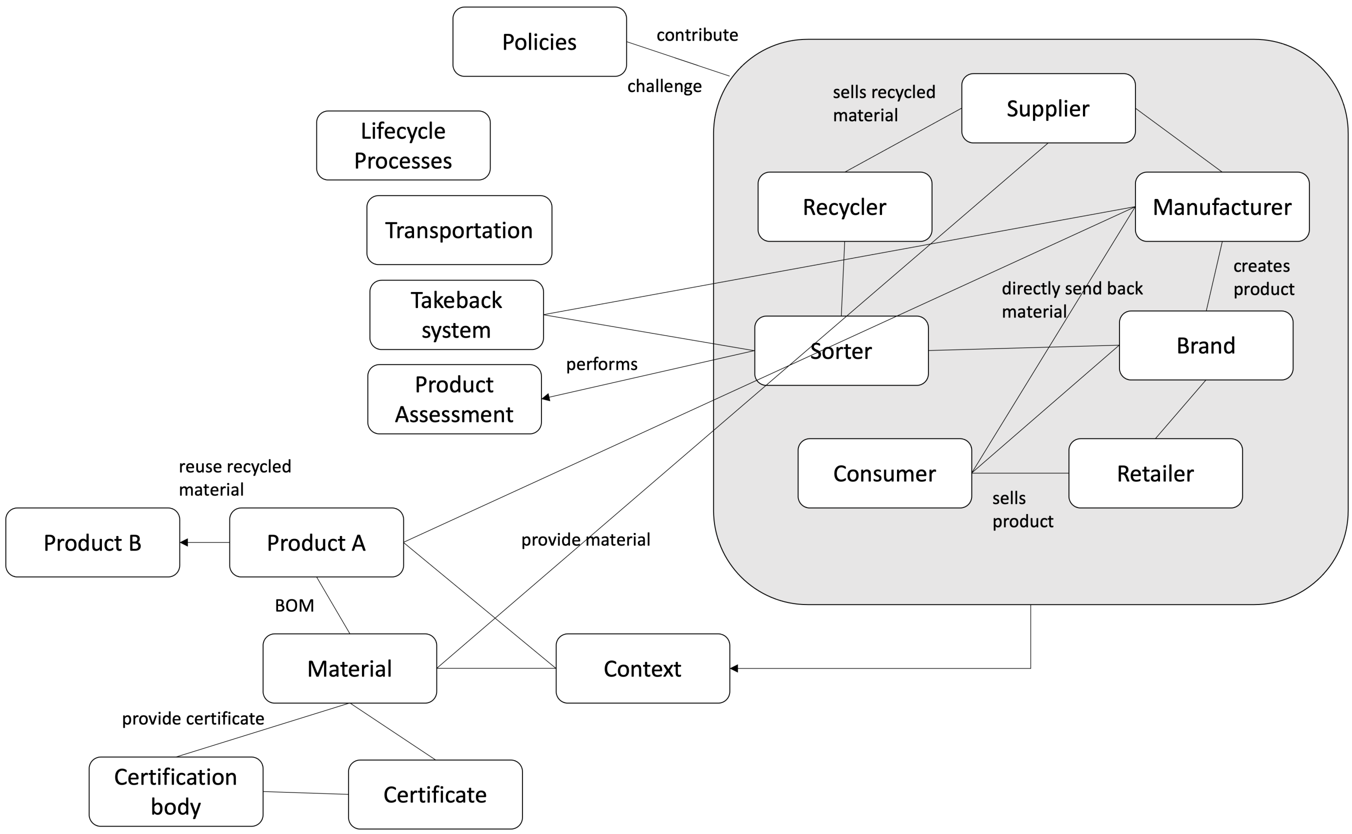

Figure 16: Sketch made by the third group (cleaned up in terms of visual representation, no content changes).

B Glossary of Terms and Ontology Requirements

The following set of terms have been deemed independent of either of the three use cases, i.e. not domain specific to any of the industry domains, they occur more than once in the user stories in D2.1, and have therefore been extracted as the glossary of terms to be covered by the ontologies. Some terms have been merged, which is indicated in parenthesis.

Table 9: Glossary of terms that occur more than once in the user stories in D2.1

Access and Assembly	Assembly Method	Biodegradability	Brand (Brand Name, Label)
Carbon Footprint	Certificate (Certificate Number)	Chemical Composition	Circular Product
Claim	Collector	Color	Company
Compliance (Comply)	Compliance Schema	Component	Composition
Contribution	Correct Way	Cost	Country (Country of Origin)
Cultivated Condition	Customer	Design	Dismantle (Dismantling)
Dismantler	Dispose Guidance	Efficient	End-of-life Scenario
Environmentally Sound Decision	Final product	Financially Sound Decision	Greenwashing
Handle	Hazardous Substance	Improve	Inform
Information	Input	Inventory	Legislation
Location	Manufacturer	Market	Marketplace
Material	Material Composition	Material Content	Material Inventory
Material Name	Material Origin	Material Property	Material Type
Performance	Plan	Planner	Platform
Price	Process	Produced Condition	Product
Product Color	Product Data (Product Information)	Product Name	Product Size
Product Type	Production	Production Process	Proof
Property	Provenance	Quality	Quantity
Raw Material	Recycle	Recycled Content (Recycled Material Content)	Recycled Material
Recycler	Recycling	Refurbish (Refurbishment)	Regulation
Repair	Reuse	Service	Sorter
Stakeholder	Standard	Substance	Supplier
Supply Chain	Supply Chain Stakeholder	Sustainability (Sustainable)	Sustainability Claim
Sustainability Parameter	Sustainable Material	Sustainable Product	Take-back-system
Tender	Tenderer	Transformation Actor	Trustful Data
Upload	User	Variation	

We additionally present the 10 most frequent terms (in order of frequency, from 73 times down to 10), as an indication that these should probably be present in the core ontologies to be created:

Table 10: The 10 most frequent terms.

Product (73)	Material (64)	Sustainability (17)	Information (16)
Composition (14)	Quality (13)	Manufacturer (12)	Production (11)
Supplier (11)	Brand (10)		

Table 11: Ontological requirements for modelling Circular Value Networks

Concept	Story	CQs	CS	RR
Circular Value Network	A circular value network consists of one or many actors that are working together towards a common goal. A circular value network holds a value proposition of achieving beneficial outcomes that the actors involved in the network would not be able to achieve in solitude. To reach this goal actors make use of inputs in the form of competencies and resources according to a specified logic. The circular value network outputs are the value proposition in it self, but also the possible secondary values in products, materials or competencies that could be useful in other contexts.	1. What are the actors involved in this circular value network? 2. What is the goal of this CVN? 3. What are the resources involved in this CVN, i.e. used, processed, produced etc? 4. What are the inputs to this CVN? 5. What are the outputs of this CVN? 6. What is the type of this CVN? What ciruclar strategies are addressed?	Each CVN has at least one type/strategy, one process and one actor involved. It also has a goal and a value proposition, but they may be implicit or unknown. Each CVN could have one or more inputs and one or more outputs.	Involvement of actors can be derived based on their involvement in certain processes (phases, steps) of the network. Same for resources.
Process	A circular value network has some process which outlines work done by different actors in this network.	1. What are the processes of the network? 2. What are the phases of a process? 3. What are the actors involved in the process? 4. What are the inputs of a process? 5. what are the outputs of a process? 5. What CVN:s are this process used in?	A process is used in one or more CVN:s, although the CVN may be implicit in the data.	
Value proposition	The value proposition that a circular value network holds is the value the network can generate and which motivates its existence. It could be in the form of business value as in monetary terms, but also in the form of environmental, sustainability and performance values.	1. What are the value propositions of this CVN? 2. What is the value type (e.g. business, energy) of the value proposition? 3. What is the value of the network to a specific actor or stakeholder? 4. What is the overall aggregated value of a certain type, of the CVN? - To be discussed further with domain experts.	Each CVN has a value proposition, although it may be unknown. Each value proposition has one or more values. Each value is of a certain type. Each value proposition could have a calculation which outlines how value is calculated.	Value calculated/aggregated from the processes and actors involved.
Resource	Resources are what is worked on in the circular value network. Resources are used as inputs but could also be outputs from the network, and its processes, steps etc. For resources that are part of a circular value network they will be of a certain type (is it a product, component or material). Also, for these resources, their composition is ideally known at some level. Resources can also be used in processing steps, but without being the main focus of the value network, e.g. consumables, catalysts.	1. Give me information about this resource. 2. What is the type of a specific resource? 3. What is the composition of a specific resource? 4. Which CVN:s use this resource, for what and in what processing steps?	Each CVN has at least one resource, each resource in an CVN has a type and a composition, although it may be unknown.	Secondary resources are inferred from the composition of the primary resources.

Phase	Each circular value network include phases that divide up the process (flow) into certain phases that are part of that specific value network. Each phase in turn may include steps, i.e. pieces of work that are performed in that phase.	1. What is the current phase (in terms of time) of this specific resource in this specific CVN? 2. What actors are involved in this phase? 3. What are the steps of this specific phase? 4. What is the order of phases (and steps) in the current CVN? What comes before and after the current phase, or step? 5. What are the competencies needed in this specific phase?	Each CVN has at least one phase. Phases have an order in which they are performed. Each phase has at least one step, although this may be implicit. Steps have an order in which they are performed.	A phase consists of one or several steps, anything happening in these steps also happen in the phase.
Work	Work is done as part of a phase in a circular value network. Each piece of work requires certain competencies, information, input, output and actors to be completed. Each piece of work has input in the form of resources, and produces some output. Work has dependencies so that the input of one piece of work may be the output of a previous piece of work.	1. What is this piece of work? 2. Which phases are this work used in? 3. What competencies are needed to do the work? 4. What infrastructure are needed to do the work? 5. What inputs are needed to do the work? 6. What outputs are produced as part of the work? 7. What information is needed to do the work? 8. What actors or actor types are needed to do the work? 9. What CVN:s are this work used in?	Each piece of work is part of a phase. Each piece of work requires one or more actors, competencies, and/or information. Each piece of work could require resources and infrastructure. Each piece of work produces an output, this output could be in the form of rescources or information.	
Actor	Actors collaborate to achieve the value proposition of the circular value network. Each actor is responsible for one or more pieces of work (in a step) and holds one or more competencies to do that work. Also, actors might or might not hold the necessary infrastructure and resources to perform the work. Each actor is of a certain type, and has a role in the network.	1. What are the competencies of a specific actor? 2. What is the infrastructure available to the actor? 3. What is the information held by the actor? 4. What are the resources of the actor? What resources does the actor need? 5. What CVN:s (or CVN types) are the actor able to participate in? 6. What CVN:s are the actor participating in? 7. What is the type of this actor?	Each actor holds one or more competencies and some information.	To be able to participate in a CVN for doing a certain piece of work, implies that the actor holds (or receives) the needed resources, information, infrastructure and competencies.

Competency	For each piece of work an actor does for a certain part of a circular value network there are specific competencies tied to being able to do that work.	1. What is the competency used here? 2. Which work is this competency used in? 3. What actors hold this competency? 4. Which phases or steps are this competency used in? 6. Which CVN:s are this competency used in? 7. For what CVN:s could this competency be used? For what CVN is it needed? 8. For what phases could this competency be used? For which phase is it needed? 9. For what work could this competency be used? For which work is it needed?	Competencies are held by actors. Competencies could be held by one actor, or many actors together. A competency could exist without an actor holding it (specified on the work level).	If an actor performs a piece of work, it must hold the right competencies for that work.
CVN-Type	Each circular value network is of a certain type, i.e related to the circular strategies it realises. The type relates to the type of work done in that value network. Types could for example be refurbish, recycle, remanufacture etc. A generic type is further specified by the kind of products, components and materials that the strategies apply to.	1. What are the types applicable to this CVN? 2. What types are available? 3. What CVN:s apply this type of strategy?	Each CVN has at least one type/strategy applied. A type could exist without a CVN connected to it.	Types could be inferred based on the processes, phases, steps and work done.
Input	Each circular value network has certain inputs that drive the work of that network. Inputs could be in the form of products,, components, and materials, and could also be the outputs coming from another circular value network. Inputs also apply to phases, steps, and work inside the network.	1. What is the input? 2. Which CVN:s use this input? 3. Which phases/steps/work of which CVN:s use this input? 4. What are the resources of the current input?	Inputs are used as inputs to CVN:s but they could also be the output from another CVN.	Inputs and outputs are consumed and produced in the context of doing work, thus it could be aggregated to the phase and CVN level.
Output	Each circular value network has outputs that come from doing the work specified in the network. These outputs could be in the form of products, components, and materials, and also act as inputs for other value networks. Outputs also apply to phases, steps and work inside the network.	1. What is the output? 2. Which CVN:s produce this output? 3. Which phases/steps/work of which CVN:s produce this output? 4. What are the resources of the current output?	Outputs are produced by CVN:s but they could also be used as input to another CVN.	Outputs and inputs are consumed and produced in the context of doing work, thus it could be aggregated to the phase and CVN level.

Information	In each phase in a circular value network there is work done, including decisions being made. This work could require information to be executed.	1. What is the content of the information? 2. For what work is this information needed? 3. For what phases/steps/CVN:s are this information needed? 4. What actors hold this information?	It is not mandatory that a piece of work requires/produces information.	
Infrastructure	In each phase and step in a circular value network there is work done. This work could require infrastructure to be executed.	1. What is the current infrastructure? 2. For what work is this specific infrastructure needed? 3. What actors hold this infrastructure?	It is not mandatory that a piece of work needs infrastructure.	
Calculation	The instructions/algorithms for how to calculate the value (of a specific type) for a specific type of circular value network.	1. What is the calculation/algorithm? 2. What are the input/output values of a calculation, and how can they be connected to other calculations?	Value must have a calculation, but it might be unknown.	
Resource-type	Resources are what is worked on in the circular value network. Resources are used as inputs but could also be outputs from then network. For resources that are part of a circular value network they will be of a certain type.	1. What are the resource types? 2. For which resources is this type used? 3. For which CVN:s is this resource type used? 4. What is the type of this resource?	Resources are of different types, for example, energy, waste, material, component, product. Resources must have a type.	There could be a type hierarchy, where more generic types can be inferred from the hierarchy.
Composition	Resources are what is worked on in the circular value network. Resources are used as inputs but could also be outputs from then network. To be able to use these resources, their composition often needs to be known, e.g. the material composition of a component.	1. What is the composition of this resource? 2. What resources have this composition?	Resources must have a composition, although it may be unknown.	
Value-type	CVN's value propositions are of certain types. They could be in the form of business value, as in monetary terms, but also in the form of environmental, sustainability and performance values.	1. What is this value type? 2. In which value propositions are this value type used? 3. In which CVN:s are this type used?	Value propositions must have a type.	

Table 12: Ontological requirements elicited from construction use-case user stories (CUS)

Origin	Ontology Story	CQs	Relevant topics and ontologies
CUS0: (Introduction text)	There are several actors involved in a construction use case/circular value flow, each holding some roles in a certain material flow.	*C0-1.* What are the actors involved in this value network? *C0-2.* What are the roles of this actor in this network?	Circular Operation; Ontologies circular economy

CUS1: End of life scenarios	Different building materials have different possible end-of-life scenarios. An end-of-life scenario specifies how the material should be handled (e.g. removed from the building, further treatment).	*C1-1.* What is the end-of-life scenarios for this specific building material? *C1-2.* How should the material be handled according to this end-of-life scenario? *C1-3.* What are all the possible end-of-life scenarios of building materials?	Product, Construction, Building Materials, Circular Operation; Ontologies labeled of product, construction, materials, circular economy
CUS2: Material business case	A business case is a scenario of handling materials and the associated costs an potential revenues. A certain actor, such as a building owner, needs information on economic and environmental costs involved in different end-of-life scenarios of materials, in order to assess such material business cases, their economical and environmental soundness, and make a decision on what actions to take.	*C2-1.* What are the business cases of this material? *C2-2.* What are the end-of-life scenarios of this material? *C2-3.* What are the (economic) costs of this end-of-life scenario of this material? *C2-4.* What are the environmental costs of this end-of-life scenario of this material?	Product, Construction, Building Materials, Circular Operation; Ontologies labeled of product, construction, materials, circular economy
CUS3: Inventory	An inventory consists of products (materials) and their quantities and locations, and is produced before dismantling. A product can be resold, refurbished, or enter into a take-back system, after dismantling, by some actors (e.g. building owner, or manufacturer).	*C3-1.* What are the products that are going to be dismantled? *C3-2.* Where are they located and their quantities (or dimensions)? *C3-3.* What materials does a product consist of? *C3-4.* Who is the manufacturer of a certain product? *C3-5.* What take-back-systems are available for a certain product? *C3-6.* Which products does this take-back system cover? *C3-7.* Can this product be resold? *C3-8.* Can this product be refurbished? *C3-9.* What are different operations/process in a take-back-system?	Product, Construction, Circular way of recycling; Ontologies labeled of product, construction, circular economy
CUS4: Rest material from production	The rest materials are remaining materials from the process of manufacturing a product. They can potentially be used in other production processes.	*C4-1.* What are possible ways for offsetting rest materials from production? *C4-2.* What is the product that the materials is used to manufacture? *C4-3.* What is the quantity of a specific remaining material? *C4-4.* What are the business cases of the rest materials? *C4-5.* What processes can this rest material be used as input for? *C4-6.* Are the business cases of the rest materials same as those of the materials used in the manufacturing? *C4-7.* Where is this rest material produced (in the manufacturing process)? *C4-8.* What rest material do I produce? *C4-9.* What is the input of a production process? *C4-10.* What actor needs this input for a production process?	Product, Construction, Building Materials, Circular Operation, Manufacturing; Ontologies labeled of product, construction, materials, circular economy, manufacturing
CUS5: Cost	A cost is caused due to handling a product (e.g. either dismantling or refurbishing). Different costs decide different ways of constructing a take-back system.	*C5-1.* What is the cost of dismantling or refurbishing a specific product? *C5-2.* What are the (economic) costs of a take-back-system for a specific product?	Product, Construction, Circular Operation(dismantle, refurbishment); Ontologies labeled of product, construction, circular economy

CUS6: Market demand	A decision on refurbishing a product may be based on the market demand of refurbished products of this kind. Depending on different market demands, different take-back system may be designed.	*C6-1.* What is the market demand of a specific refurbished product? *C6-2.* Does the refurbished product have the same manufacturer as the original product? *C6-3.* What are the financial properties of this take-back system? *C6-4.* How is this take-back system designed, what does it contain (actors, processes)?	Product, Construction, Manufacturing, Circular Operation(refurbishment); Ontologies labeled of product, construction, manufacturing, circular economy
CUS7: Dismantling	A dismantler requires information about the location of a product within a building that needs to be dismantled, and the location of the building itself. A product has an appropriate procedure for dismantling that should be followed in order for dismantling to have been performed in a correct way.	*C7-1.* What are different ways of dismantling certain (building) products? *C7-2.* What information does the manufacturer provide about the product, on how to dismantle the product? *C7-3.* Where is a building located? *C7-4.* Where is a certain product located within a certain building? *C7-5.* What is the amount of this product within this building? *C7-6.* Was this product dismantled correctly? According to what procedure?	Product, Construction, Building, Circular Operation (dismantling); Ontologies labeled of product, construction, materials, circular economy
CUS8: Tender	A tenderer requires detailed product information for describing an appropriate dismantling method in a deconstruction tender.	*C8-1.* What information of a product is needed for a deconstruction tender? *C8-2.* What is the information about a certain product, needed for this tender? *C8-3.* What is the (preferred?) dismantling method for this product? *C8-4.* Who is the tendered issuing this tender?	Product, Construction, Manufacturing; Ontologies labeled of product, construction, manufacturing
CUS9: Recycling	A building with planned deconstructions may have products that are planned for retrieval of secondary raw material. A recycler requires information about the plan, including the location of the building and the recycler handles the product (at end-of-life scenario) and retrieves certain secondary raw materials.The secondary raw materials can be used in other productions.	*C9-1.* What are different ways of handling a specific product (end-of-life scenario)? *C9-2.* What are different ways of retrieving specific secondary raw materials? *C9-3.* What buildings are planned for deconstruction? *C9-4.* What products within a building are planned for retrieval of secondary raw material?	Product, Construction, Material, Building, Circular way of recycling; Ontologies labeled of product, construction, materials, circular economy
CUS10: Deconstruction	A deconstruction company is responsible for performing a deconstruction. Deconstruction has to be done in a certain way, depending on the products and the building.	*C10-1.* What is the correct/planned way of deconstruction of a product within a building? *C10-2.* What are different ways of deconstruction for a certain product, given certain conditions? *C10-3.* What buildings are planned for deconstruction? *C10-4.* What products within a building are planned for deconstruction?	Product, Construction, Building, Circular Operation; Ontologies labeled of product, construction, circular economy
CUS11: Marketplace	A marketplace requires detailed product information for marketing and selling products.	*C11-1.* What products are available for selling? *C11-2.* What are the properties of a product (composition, dimensions, quantities, pricing)? *C11-3.* Who owns a products and where is it located?	Product, Construction; Ontologies labeled of product, construction

CUS12: Reuse	Planning for a new building by a planner may include reuse of products or materials from previous product. In order to make reuse decisions, product information such as measurements, qualities and quantities need to be known.	*C12-1.* What is the detailed information of a product (e.g. measurement, quality, quantity)? *C12-2.* Does the product or material fit the plan of the new building? *C12-3.* What reused products does this plan contain?	Product, Construction; Ontologies labeled of product, construction
CUS13: Planning	All actors besides building owner require product information when they perform their operations. Also, they require information about manufacturing process and handling methods for a end-of-life scenario of a product.	*C13-1.* What is the cost, time and location of a service? *C13-2.* What is the product on which the service is performed?	Product, Construction, Manufacturing; Ontologies labeled of product, construction, manufacturing
	An actor needs to have accurate product information, on measurements, composition, qualities, quantities, and location of a product, as well as process and handling details, in order to offer and perform the correct handling and services for the product, at a correct cost and the appropriate time and location.	*C13-3.* What is the detailed information of this product's properties (e.g. measurements, composition, qualities and quantities)? *C13-4.* What is the context of this product (e.g. location, quantities)? *C13-5.* What is the previous handling of this product? *C13-6.* What is the correct handling process of this product? *C13-7.* What are the previous services performed on this product? *C13-8.* What is the appropriate/available services for this product? *C13-9.* What is the cost of handling/performing this service on this product? *C13-10.* At what time can this service be performed?	

Table 13: Ontological requirements elicited from electronics and appliances use-case user stories (EUS)

Origin	Ontology Story	CQs	Relevant topics and ontologies materials
EUS1: Provenance/quality and sustainability of raw materials	The brand using a material wants to be able to have proof of the quality characteristics of the material, as well as the sustainability of the material (traceability and circularity) to check against contracts and pricing, as well as to pass this on to the end-user. This can also include material content, carbon footprint data and production process, regulations.	*E1-1.* What are the quality characteristics of this material?	Logistics (supply chain), Electronics, Materials; Ontologies labeled of logistics, electronics, materials
	The end-user buying a product wants to be able to have proof of the quality characteristics of the material, as well as the sustainability of the material (traceability and circularity) to check against claims and pricing. This can also include material content, carbon footprint data and production process, compliance with regulations.	*E1-2.* What is the carbon footprint of this material?	

	A legislator sets requirements on the quality characteristics of materials, their sustainability (traceability and circularity) and may require that there is proof of the underlying data through the supply chain.	*E1-3.* What is the material content?	
	The supplier offering a material needs to have proof of the quality characteristics of the material, its origin, as well as the sustainability of the material (traceability and circularity) to set up contracts and pricing, as well as to pass this on to the brands and end-users. This can also include material content, carbon footprint data and production process. The supplier must be able to check that they and comply to regulations by a legislator.	*E1-4.* Does this material comply with a certain legislation? *E1-5.* Who is assuring that this proof is correct? *E1-6.* Who is the supplier of this material? *E1-7.* Who is an intermediary of this material? *E1-8.* What is the brand that uses this material? *E1-9.* What end users are involved? *E1-10.* What is the supply chain of this product? *E1-11.* To what extent does this product contain recycled material? *E1-12.* Who supplies and ensures the identity of an actor? *E1-13.* What is the pricing of this material based on? *E1-14.* What does this contract require from the parties and the material? *E1-15.* What does this legislation require from the parties and the material?	
EUS2: Production process	A manufacturer of a product needs to understand the composition and origin of the materials, as well as their production processes, to mitigate risks in the supply chain, analyse and improve the supply chain, ensure compliance with regulations etc. Although some stakeholders in the supply chain may be unknown, data origin and proof of validity is important.	*E2-1.* What are the components of this product?	Product, Electronics, Materials, Manufacturing, Logistics (supply chain); Ontologies labeled of product, electronics, materials, manufacturing, logistics
	A product or material has a material composition, a set of production processes to make it, a provenance trace, a set of stakeholder types handling it in the supply chain, and a location where it was produced.	*E2-2.* What are the materials of this component or product?	

	A product is made up of components, which in turn are made up of materials that have a certain properties, and provenance.	*E2-3.* What is the provenance of this product/component/material? *E2-4.* What is the composition of this material? *E2-5.* What is the origin of this material (e.g. stakeholder, location)? *E2-6.* What are the production processes used to make this material/component/product? *E2-7.* What are the supply chain actors (or types of actors) involved in the trace of this material/component/product? *E2-8.* Does this material/component/product comply with certain regulations? *E2-9.* Is a certain actor known? *E2-10.* Who ensures the proof of this data and what is the origin of this data?	
EUS3: Quality and compliance	A manufacturer or brand, of a product needs to assess the sustainability performance of the production, based on a number of factors. The sustainability performance contributes in turn to product quality and compliance of legislation and standards.	*E3-1.* What are the circularity and sustainability scores of a product?	Product, Electronics, Circularity, Sustainability, Stakeholders, Logistics (supply chain);
	A product is to a certain extent sustainable if it is made up of sustainable materials. To assess the sustainability of a material information is needed about its properties, such as monitored materials, compliance to schemes, recycled content, LCA in supply chain, sustainability of production processes, and carbon accounting data. The sustainability of production processes contributes to the sustainability of a product.	*E3-2.* What information is needed to represent the circularity and sustainability scores of a product?	Ontologies labeled of product, electronics, circular economy, logistics
	A compliance schema, such as REACH.	*E3-3.* What are the compliance schemas that my product or material have?	
	Certain materials are considered as monitored materials, based on legislation and standards.	*E3-4.* Does my products require/contain any monitored materials?	
	Recycled material content means to what extent the product contains recycled material, where it comes from, how it has been processed, and what amount.	*E3-5.* What recycled materials does a product have?	
	Carbon accounting data and LCA may be used to assess the carbon footprint of a product.	*E3-6.* What is the carbon footprint of a product?	
	Sustainability of production processes is measured through some ways.	*E3-7.* Is a production process sustainable or not?	
	Claims of carbon neutrality may need to be substantiated by data on carbon footprints of materials, LCA and sustainability of production processes.	*E3-8.* What is the carbon footprint of a material?	

EUS4: Product usage	The end-user of a product wants to know how sustainable their product is, so that they know that the quality they paid for is there, and to avoid green-washing, to act more sustainably and to lower their carbon footprint. This includes material composition, certification of sustainability, and other quality criteria (e.g. made in the EU, sustainably sourced critical materials etc).	*E4-1.* How sustainable is my product (with respect to certain parameters or certifications)?	Product, Electronics, Circular Operation, Circularity, Sustainability; Ontologies labeled of product, electronics, circular economy
	The end-user of a product wants to know how to recycle and refurbish their product, to ensure its optimal performance in all phases of the product life cycle and to act more sustainably and reduce their carbon footprint. This includes dismantling and repair information, material composition, etc.	*E4-2.* How circular is my product (with respect to certain parameters or certifications)? *E4-3.* How should this product be used?	
	To avoid greenwashing and encourage users to buy more sustainable and circular products, accurate sustainability data needs to be provided with the products. This includes product details, e.g. material composition, as well as sustainability parameters such as certifications, quality criteria, and carbon footprint.	*E4-4.* How should this product be used (e.g. to allow optimal performance)? *E4-5.* How should this product be handled (e.g. dismantled, repaired, recycled or refurbished)? *E4-6.* What is the material composition of this product? *E4-7.* What certifications are fulfilled and how? *E4-8.* Who issues these certifications and standards? *E4-9.* Who ensures accuracy of the claims? *E4-10.* Who is the current user/owner of the product? *E4-11.* What is the price of the product?	
EUS5: Product composition	The product is composed of various materials, which has a chemical composition. Some materials may be hazardous substances. Some materials degrade with time.	*E5-1.* What is the material composition of this product?	Product, Electronics, Materials; Ontologies labeled of product, electronics, materials
	Recycling of a product may depend on its material composition, efficiency of recycling.	*E5-2.* What is the chemical composition of this material?	
	For a recycler to recycle a product one needs dismantling information, chemical composition, information on hazardous substances and degradation of materials.	*E5-3.* What hazardous substances does this product/material contain? *E5-4.* What is the degradation properties of this material? *E5-5.* Did the material degrade? *E5-6.* How can I recycle a product with this material composition? *E5-7.* How should this product be dismantled or recycled?	

EUS6: Safety	For a recycler to safely recycle a product they need to know if it contains hazardous materials, and how it can be safely and efficiently recycled. This can be represented in dismantling guidelines, expressed according to compliance schemes, and hazardous substances should be listed in product information.	*E6-1.* What hazardous substances does this product/material contain? *E6-2.* What are the guidelines for dismantling this product? *E6-3.* What is the material composition of this product? *E6-4.* How can this product be safely recycled? *E6-5.* How can this product be efficiently recycled? *E6-6.* How efficient is a recycling method for this product? *E6-7.* What compliance schemes does this product adhere to?	Product, Electronics, Materials; Ontologies labeled of product, electronics, materials

Table 14: Ontological requirements elicited from textiles use-case user stories (TUS)

Origin	Ontology Story	CQs	Relevant topics and ontologies
TUS1: Access to production data	A customer wants to display the material content of the fibers that a supplier provides. This includes types/categories of fibers, type of material, their origin and country of origin of their raw material, their recycled content, certificates, colors, recycling recommendations, biodegradability (certificates), standards and certification compliance.	*T1-1.* What materials does a fibre contain? *T1-2.* What are the properties of and data about that fibre?	Fiber, Material, Customer, Circular Certificate; Ontologies labeled of textiles, materials, circular economy
TUS2: Access to editable and updatable content	The fiber supplier (or transformation actor) will update the fibers that are supplied, sometimes the material content will change without a change of the properties, sometimes also the properties should change. The customers should always get up-to-date information.	*T2-1.* When were material content and/or properties of this fiber changed? *T2-2.* What was the change? *T2-3.* Why did the change happen? Who made the update?	Product, Fiber, Materials, Manufacturing, Performance (circularity, sustainability); Ontologies labeled of product, textiles, materials, manufacturing, circular economy
	A change of fibers' material content and/or properties may be triggered by a change of suppliers. Changes may also affect certificates.	*T2-4.* What were the consequences of the material content change, in terms of fiber properties (e.g. change in colors, performance)? *T2-5.* Give me the latest material content and properties of this fiber.	
TUS3: Integrated product data	A fiber manufacturer or transformation actor will have a library of current and past fibers (products) that they share with others, and should be able to trace the history of those, e.g. when they were uploaded, edited, viewed. Other actors can view the products and contact the manufacturer/transformation actor. The information should also include received certificates, and when they were received.	*T3-1.* What products (fibers) are in my library? *T3-2.* When were they added, updated, and by whom? *T3-3.* What products am I sharing with whom? *T3-4.* Who viewed a product? *T3-5.* Who contacted me when, and about what product?	Product, Fiber, Materials, Manufacturing, Supplier; Ontologies labeled of product, textiles, materials, manufacturing

TUS4: Access to trustful data	Transformation actors will have a library of fibers or materials (products) that they transform. The library including information or data of fibers/materials properties, produced or cultivated conditions.	*T4-1.* What are different produced/cultivated conditions of fibers/materials? *T4-2.* When is a fiber or material (product) going to be removed? *T4-3.* What are different transaction certificates for recycled content? *T4-4.* What substances (products) are included in Restricted Substance List (RSL)? *T4-5.* What compliances do my fibers (products) satisfy?	Fiber, Textile, Materials; Ontologies labeled of textiles, materials
TUS5: Generate material inventory	An inventory should contain basic information to describe a material, such as certificate. This is also for data exchange at the materials level.	*T5-1.* What information of a material is needed to upload to a platform?	Fiber, Textiles, Certificate; Ontologies labeled of textiles, circular economy
TUS6: Sustainability score	A product should be described in terms of sustainability and circularity by scores.	*T6-1.* What are the sustainability and circularity scores of a product?	Product, Performance (circularity, sustainability); Ontologies labeled of product, circular economy
TUS7: Circular materials catalogue	Information is needed to describe circularity of products and materials	*T7-1.* Does a sustainable/circular product need to have all the components satisfying sustainability/circularity?	Product, Textiles, Materials, Performance (circularity, sustainability); Ontologies labeled of product, textiles, materials, circular economy
TUS8: Component data	For a specific product with multiple components, we need to describe how these components are assembled as well as detailed composition of every components, each component should also associated with a number of properties to describe the quality and sustainability.	*T8-1.* What are different assembly methods can be used? *T8-2.* For a specific product, what is the assembly method has been used? *T8-3.* What are the components of a product?	Product, Textiles, Materials, Manufacturing (assembly), Performance (circularity, sustainability); Ontologies labeled of product, textiles, materials, manufacturing, circular economy
TUS9: Certificates	Recycled material is supposed to have certificate or labels. We need to model how to describe materials and certificates.	*T9-1.* Is a material recognized as a recycled material? *T9-2.* What certificates does a material have?	Textiles, Materials, Certificates; Ontologies labeled of textiles, materials, circular economy
TUS10: Materials composition	Similar as the ontology story based on TUS8.	*T10-1.* What resources are used in the assembly process of a fiber and what are the quantities of these resources? *T10-2.* What is the composition of a material? *T10-3.* Has a material been chemically modified? *T10-4.* What properties does a material have?	Product, Textiles, Materials, Fiber, Manufacturing; Ontologies labeled of product, textiles, materials, manufacturing
TUS11: Authentication of data	(Further discussion with domain experts regarding this user story is needed)		
TUS12: Visibility	(Further discussion with domain experts regarding this user story is needed)		
TUS13: Product availability data	(Further discussion with domain experts regarding this user story is needed)		
TUS14: Brand's take back schemes information	A product could be re-manufactured, therefore a take back scheme/program needs to build to specify why and how a product to be sold back for re-manufacturing.	*T14-1.* What are the reasons for a product to be sold back and re-manufactured?	Product, Textiles, Circular Operation (re-manufacturing, reuse); Ontologies labeled of product, textiles, circular economy

TUS15: Repair and reuse guidance	A product can have repair/reuse guide information so that they can re-sold to second-hand market.	*T15-1.* What is the repair/reuse guidance of a product?	Product, Textiles, Circular Operation (repair, reuse); Ontologies labeled of product, textiles, circular economy
TUS16: Sustainability product data	(Further discussion with domain experts regarding this user story is needed)		
TUS17: Verified claims	(Further discussion with domain experts regarding this user story is needed)		
TUS18: Care guidance	Treatment information of product, maybe specific for clothes or shoes should be modeled.	*T18-1.* What are the treatment of a product (e.g. washing guide, care for)?	Textiles, Shoe treatment; Ontologies labeled of textiles
TUS19: User guidance	A (textiles) product should have a guidance regarding how its elements can be replaced.	*T19-1.* What properties or conditions of a (textiles) product to be considered when replacing the product elements?	
TUS20: Take-back data	A (textiles) product should have a guidance regarding how to be disposed.	*T20-1.* What properties or conditions of a (textiles) product to be considered when disposing the product?	
TUS21: Resale product information	A product can be resold when it comes to the end-of-life scenario.	*T21-1.* Who make the decision of reselling products instead of other recycling operations, and based on what conditions?	
TUS22: Material inventory	(Further discussion with domain experts regarding this user story is needed)		
TUS23: Disassembly	In the end-of-life of a product, a disassembly operation can be performed to get different components of a product. As specific disassembly method is needed and a guidance of how to disassemble the product is needed.	*T23-1.* What is the disassembly method of a product? *T23-2.* What is the guidance of of disassembly method?	Product, Textiles, Materials, Circular Operation (disassemble); Ontologies labeled of product, textiles, materials, circular economy