Machine-readable RDF ontologies and vocabularies from the field of industrial manufacturing

Konrad Abicht
k.abicht@gmail.com

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Summary

Introduction: There is currently no verified list of machine-readable, publicly accessible RDF ontologies and vocabularies related to industrial manufacturing. Similar works, such as IndustryPortal, are partly community-driven and have no metadata validation, resulting in inconsistencies between the information on the portal and in the RDF data. Such a list is needed to facilitate access to the ontologies so that interested persons and institutions do not have to search for the facts scattered across the Internet and have a reliable source of information.

Methodology: In the period from **2023-11-01 - 2024-04-03**, an Internet and literature search was carried out and a list of all thematically appropriate and referenced ontologies and vocabularies was created in the form of a CSV file (highly simplified version in the appendix). A range of metadata was recorded for each ontology (e.g. name, short description, project page, version, last modification and license). All ontologies for which there are scientific publications but no publicly accessible RDF data were ignored. Further evaluations can be found at the end of the publication.

Results: As part of the search, **217** ontologies and vocabularies for the subject area of industrial manufacturing (and related subject areas) were found. Only **50** ontologies have complete metadata, for the rest (N=167) at least one metadata could not be determined. **180** ontologies are available under a free or open source license. A dereferenceable ontology URI could be verified for **178** ontologies.

Discussion: The study was only carried out over a period of 5 months. Furthermore, the thematic focus of industrial manufacturing was considered in a broad sense, which may have meant that thematically unsuitable ontologies were also included. There were also errors when reading some RDF files, which made manual evaluation necessary.

Conclusion: The scientific contribution of this work is a manually checked and curated list of ontologies that are (mostly) freely accessible and could therefore potentially be used in your own projects. In addition, there is an evaluation of the research results, which allows conclusions to be drawn about the status of the ontologies under consideration. Due to the freely accessible research data, subsequent investigations can be carried out more easily.

The research data is freely available for public use under the Creative Commons Attribution 4.0 (CC-BY 4.0) license in the following Github repository:

`https://github.com/k00ni/manufacturing-industry-ontology-list`

1 Introduction

The metadata for formal ontologies and vocabularies are currently widely scattered on the Internet. For this reason, a comprehensive search for ontologies for a specific subject area is often tedious and time-consuming. In addition to pages with specifications and scientific publications, various ontology portals must also be consulted for a complete overview. This is a major hurdle for the average domain expert because they often do not have the background knowledge of formal ontologies and semantic web technologies [9].

There is a lack of bridges between formal ontologies, OWL ontologies and the various scientific disciplines. This work aims to contribute such a bridge for the areas of OWL ontologies and industrial manufacturing. As part of an Internet and literature search, all publicly accessible ontologies (and vocabularies) from the field of industrial manufacturing that can be found and are available in RDF were collected. The aim was to create a list consisting of machine-readable ontologies that allow automated processing of the modeled knowledge (e.g. training of an AI or OWL reasoning).

Interested parties can thus select thematically suitable ontologies from the list, download the RDF data and add their own axioms, for example. Up to this point, such testbeds/experiments were only possible to a very limited extent and at great technical expense. In the context of artificial intelligence, the use of curated ontologies can be highly beneficial.

The work is structured as follows: Chapter 2 summarizes the necessary prior knowledge of the reader. Chapter 3 presents related work and projects. The methodology is presented in detail in chapter 4. Chapter 5 analyzes the research results. Chapter 6 contains a brief discussion and Chapter 7 concludes with a summary and outlook.

2 Technical background

This chapter briefly summarizes the necessary prior knowledge for this work.

2.1 Concepts and technologies of the Semantic Web

The Resource Description Framework (RDF)[1] is a model for data exchange on the Internet. RDF extends the link-based structure of the Internet. URLs, URIs and IRIs play an important role in this context. URL stands for Uniform Resource Locator and specifies the address of a resource on the Internet. Every URL can be regarded as a Uniform Resource Identifier (URI). URIs are used to identify abstract or physical resources and may only consist of ASCII characters, which is why Internationalized Resource Identifiers (IRI) were introduced at some point. The term dereferenceability plays an important role in this work. A URL (URI, IRI) is called dereferenceable if it can be called up and a valid response is received (e.g. RDF data for a given ontology IRI). The Web Ontology Language (OWL) is based on RDF and is a W3C specification for formally describing and distributing ontologies.

2.2 Ontologies and Controlled Vocabularies

In the context of this work, the focus was on machine-readable RDF ontologies and vocabularies. Machine-readability is given if the ontology is available in text form (e.g. text file in an RDF notation) and the data can be accessed via a URL. The ontology must also provide a vocabulary to describe the subject area and be based on a logical theory (e.g. in the form of axioms, rules, hierarchies) about the subject area that draws on the vocabulary. In practice, ontologies are sometimes incomplete at this point, which is why the theory only needs to be recognizable to some extent.

These criteria are largely based on Fabian Neuhaus' explanations in [7], with a few additions. **In the context of this work, the term ontology is also used for vocabularies, unless explicitly stated**. The reason for this definition is that it is easier to use in research compared to other, far more vague definitions. Furthermore, the research results show that some authors describe their own work as both an ontology and a vocabulary. For example, Martin Hepp refers to GoodRelations as a standardized vocabulary but uses ontology as a quasi-synonym[2].

[1] https://www.w3.org/RDF/

[2] Quote: "*GoodRelations is a standardized vocabulary (also known as "schema", "data dictionary", or "ontology") for product, price, store, and company data that can [...]*", Source: `https://www.heppnetz.de/ontologies/goodrelations/v1.html`

2.2.1 Types of ontologies

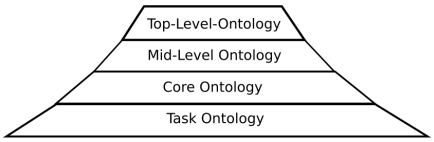

Figure 1: List of ontology types

The research results showed that the ontology authors predominantly categorize their work according to the established four-way division. First come the **Top-Level Ontologies** (synonyms: Upper Ontology, Foundational Ontology). It contains subject-independent content (terms, relations, axioms, etc.) to describe a section of reality. The best known include Suggested Upper Merged Ontology (SUMO), Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) and Basic Formal Ontology (BFO). This is followed by the **Mid-Level Ontology** level, which supplements or modifies the content of the top-level ontology. They have a low thematic reference and serve as a content-related bridge between a top-level ontology and its directly subordinate core or task ontologies. This is followed by the **core ontology** level (synonyms: core ontology, domain ontology). Its content relates more strongly to a specialist area or it supplements the content of other ontologies. The core ontologies are followed by the **Task Ontology** (synonyms: Application Ontology). It generally uses the content of higher-level ontologies and provides its own content for a specific use case.

As a user of the ontologies presented here, you should know the level at which an ontology is located. The level implies the content and any dependencies that play a role in subsequent processing. For example, a core ontology usually adopts the theory of a top-level ontology (including all implications), which can later lead to contradictions with its own axioms if not taken into account.

2.2.2 Ontology Design Pattern (ODP)

Ontology Design Patterns (ODP) are small independent ontologies that model a very limited subject area and have a high degree of reusability and combinability with other ODPs and modeling approaches [4]. There are no restrictions on their design, structure and orientation. The ODPs can also be categorized accordingly in the four categories of ontologies presented.

2.3 License information

The corresponding license was researched for each ontology. It determines the legal framework under which an ontology may be used. As a reader, you should have a rough understanding of the content of free licenses such as the Creative Commons licenses.

3 Related work

No previous work could be found in which a verified list of ontologies from the subject area of industrial manufacturing or industry in general was created. However, there are a few online services and academic publications that relate to similar efforts.

3.1 IndustryPortal

IndustryPortal [1] (`https://industryportal.enit.fr/ontologies`) is an open source platform for the development, publication and maintenance of ontologies in the field of industry, which was developed as part of the OntoCommons project[3]. Among other things, registered users can enter new ontologies and change existing metadata on the platform[4]. No information was found to indicate that such submissions are reviewed.

[3] `https://ontocommons.eu/`
[4] `https://industryportal.github.io/`

The main differences between IndustryPortal and this work lie in the methodology and data scope. It could be demonstrated several times that metadata in IndustryPortal is in some cases incomplete or contradictory to the RDF data. One example is the ontology with the name "Industry 4.0 Knowledge Graph"[5]. This name differs from the name used in the RDF data: "Industrial IoT Architecture Ontology" (dcterms:title as property). It currently contains[6] 109 ontologies for the subject area of industry in the broadest sense. However, this work identified over 217 ontologies in the extended subject area of industrial manufacturing alone. On 03.04.2024 it was determined that for some ontologies the stored RDF data had been changed from RDF/XML to Turtle[7]. The download link is titled "OWL" and therefore says nothing about the RDF notation. However, it is irritating and disrupts implementations if stored links change the syntax of the data over time.

Despite these observations, IndustryPortal is a valuable resource because they provide an infrastructure free of charge that allows long-term improvement of ontologies and associated metadata.

3.2 OntoCommons Ontology Catalogue

The OntoCommons Ontology Catalogue[8] was created as part of the OntoCommons project and is apparently still being maintained. Anyone can use an online form[9] to suggest ontologies for the list. Currently[10] the list contains only 37 ontologies, which focus on the subject areas of industrial manufacturing, materials and construction. The scope and quality of the metadata for each ontology also varies. For some ontologies, no link to the RDF data is provided, which raises the question of why they are mentioned at all[11].

3.3 Scientific publications

Ontologies for Industry 4.0 The publication [5] was included due to the high thematic similarity. The authors first give a brief introduction to the topics of Industry 4.0, Factory 4.0 and Smart Manufacturing and then list relevant challenges in this context, e.g. human-machine communication or data analysis. Later in the paper, the following 4 ontologies are presented in line with these topics:

1. **CORA:** Core Ontology for Robotics and Automation
2. **ROA:** The Ontology for Autonomous Robotics[12].
3. **ORArch**: Ontology for Robotic Architecture
4. **O4I4**: Ontology for Industry 4.0

Unfortunately, the authors did not provide any links to the associated RDF data, which means that the ontologies are not actually within the scope of this work. However, a link to the RDF data of the CORA ontology was found during the research[13].

Where to Publish and Find Ontologies? A Survey of Ontology Libraries The authors of the paper [2] provide an overview of ontology libraries (including Ontology Directory, Ontology Repository, Ontology Archive). This publication is relevant because it lists ontology libraries that can still be used. In addition to metadata such as name, license and the latest version, the associated RDF data is often also provided. The following portals were mentioned and are still considered usable after our own review:

1. BioPortal (`https://bioportal.bioontology.org/`, subject areas: biomedicine)
2. OBO Foundry (`https://obofoundry.org/`, subject areas: biology and biomedicine)

[5] `https://industryportal.enit.fr/ontologies/I40KG`
[6] 28.03.2024
[7] e.g. `https://industryportal.enit.fr/ontologies/OMPD-CMTO`, see OWL download link
[8] `https://data.ontocommons.linkeddata.es/index`
[9] `https://ontocommons.eu/node/146`
[10] 28.03.2024
[11] Example "MPFQ Ontology (Material-Process-Function-Quality)": `https://data.ontocommons.linkeddata.es/vocabulary/MpfqOntology(material-process-function-quality)`
[12] In the associated publication[8], however, the authors abbreviate the ontology as ORA
[13] `https://github.com/srfiorini/IEEE1872-owl`

building	defect	digital twin	factory
industry	machine	manufacturing	product
sensor	supply chain		

Table 1: List of used keywords

3. oeGOV (`http://www.oegov.us/`, subject area: e-Government)
4. Ontology Lookup Service (`https://www.ebi.ac.uk/ols4`, subject areas: Biomedicine)
5. Ontology Design Patterns (`http://ontologydesignpatterns.org/wiki/Main_Page`, many subject areas, see also `http://ontologydesignpatterns.org/wiki/Community:Domain`)
6. ONKI ontology server (`https://onki.fi/en/`, various subject areas)

Ontology libraries, as listed here, are essential for this work. Although they only cover a limited range of topics, they generally offer easy accessibility (e.g. with search functions and lists). My research results confirm the authors' observations, namely that there is often incomplete information on the reuse and licensing of ontologies.

4 Methodology

A literature and internet search was carried out in the period **2023-11-01 - 2024-04-03** and the matching ontologies were collected in a CSV file. The CSV format was chosen because CSV files are easy to parse and are supported in every common programming and scripting language. Due to the limited space available, only a shortened version of the ontology list has been included in the appendix. It contains the name and the corresponding project page or RDF data for each ontology. Please refer to the Github repository mentioned at the beginning for the complete version. Only German- and English-language content was of interest during the entire research.

4.1 Research questions

The following research questions were used as a basis for compiling the list:

1. Which ontologies exist for the field of industrial manufacturing (in the broadest sense)?
2. Which of these ontologies are actively maintained or when was the last documented activity in the project?
3. Which licensing regulations must be observed when using an ontology?

4.2 Thematic delimitation

Industrial manufacturing has a very broad range of topics and many subject areas, such as manufacturing processes, measurement and testing technology and automation, play an important role. In addition, there are a number of trends that are often interdisciplinary in nature and introduce completely new subject areas (e.g. big data in smart manufacturing). It was not easy to create a thematic delimitation in this initial situation. I decided to develop relevant keywords for the search because ontologies are often found in online services that have a keyword-based search. Below is the final list of keywords:

They represent central concepts of industrial manufacturing and related topics / trends. The aim here was to strike a balance between thematic accuracy and manageability. Most online services already had a small number of ontologies, which is why it was often not necessary to search with additional keywords in order to view the entire database.

4.3 Research sources

Ontology development has strong scientific roots, so we started by reviewing scientific publications that present an ontology and its content in more detail. **Google Scholar**[14] was used for the research. **Google Search** was used for the internet search.

4.3.1 Dedicated online services

The following list contains all online services that were used in the search:

1. **AURORAL ontologies** (`https://auroral.iot.linkeddata.es/index.html`) - List of ontologies developed for the AURORAL project (`https://www.auroral.eu/#/`). It includes ontologies on the topic of charging stations and energy consumption.
2. Project page of the **Basic Formal Ontology** (short BFO, `https://basic-formal-ontology.org/users.html`) - List of ontology projects that use the BFO.
3. **BioPortal** - Ontology portal with over 1094 ontologies, primarily from the biomedical subject area[15].
4. **Basic Register of Thesauri, Ontologies & Classifications** (short BARTOC, `https://bartoc.org`) - A website with a connected search engine that lists Knowledge Organization Systems, vocabularies and ontologies. Only OWL ontologies were used. Entries that were not available in German or English were automatically translated and checked.
5. **EU Vocabularies** (`https://op.europa.eu/en/web/eu-vocabularies/controlled-vocabularies`) - A website with ontologies and vocabularies provided by the European Union (or one of its subordinate institutions).
6. **Github** (`https://www.github.com`) - An online service for software development, but very often used as a place for ontology projects.
7. **IndustryPortal** (`https://industryportal.enit.fr/`) - Ontology portal with over 109 ontologies[16] from industry and related subject areas.
8. **Linked Open Vocabularies** (`https://lov.linkeddata.es/dataset/lov/`) - A curated catalog of vocabularies and ontologies for describing data on the Internet.
9. **OntoCommons Ontology Catalogue** (`https://data.ontocommons.linkeddata.es/index`) - Manually curated list of ontologies from the fields of industry, production, materials science, construction and more.
10. **ShowVoc** (`https://showvoc.op.europa.eu/`) - A portal with a list of ontologies, vocabularies and others. Only the ontologies were evaluated.

The search results for each keyword were examined in more detail, insofar as they dealt with an ontology. In the event that there were other types in addition to ontologies and vocabularies, these types were ignored.

4.3.2 Evaluation of namespaces and owl:import

Namespaces and owl:import statements are often used in ontologies. Namespaces are used to abbreviate frequently used URLs. With owl:import statements, you signal that the ontology is dependent on the content of a referenced ontology or that it extends the ontology. In practice, there are various interpretations and implementations[17]. This study is based on the assumption that by using namespaces and owl:import, ontology authors signal that the content of the referenced ontology is relevant in some way.

For this reason, both were also evaluated. Referenced ontologies were checked according to the same criteria and classified accordingly.

[14] `https://scholar.google.com/`
[15] Reviewed on 26.03.2024
[16] Reviewed 26.03.2024.
[17] Good explanations on the topic here: `https://protegewiki.stanford.edu/wiki/How_Owl_Imports_Work`

4.4 Selection criteria for an ontology

An ontology must meet the following minimum criteria for inclusion:

1. The ontology is available as a text file[18]. in an RDF notation (RDF/XML or RDF/Turtle) and can be downloaded via a URL.
2. The ontology provides a vocabulary for describing the subject area and is based on a logical theory (e.g. in the form of axioms, rules, hierarchies) about the subject area that draws on the vocabulary.
3. The contents of the ontology have a direct thematic reference to the listed keywords or the related topics.
4. At least one instance of owl:Ontology can be found in the RDF data or at least one class or property is defined.

All ontologies (along with the associated scientific publications) for which no RDF data was available were ignored. Without the associated RDF data, it cannot be ensured that an ontology is complete. Work derived from this could later lead to unexpected errors and contradictions.

4.5 Captured metadata for an ontology

The following metadata was recorded for each ontology

- **name of ontology** - The name of the ontology that can be found in the RDF data or the associated documentation.
- **Manufacturing Industry related** - The column contains "yes" if the ontology has a direct thematic reference. All ontologies without a thematic reference, but which were referenced, receive "no" in the column.
- **Abbreviation** - The abbreviation of the name of the ontology, if available.
- **Short description** - A short, concise description of the content of the ontology.
- **Project page or publication** - A URL to the project page, if available. Alternatively, a URL to a publication about the ontology or to an ontology portal with further information.
- **Ontology URI** - URI to the ontology. It is usually globally unique.
- **Latest version** - If available, an indication of the latest version of the RDF data. The latest version and the date of the latest documented change are not related and can have completely different time references.
- **Latest activity found** - A date of the most recent and documented change to the RDF data. The change can, but does not have to, coincide with the latest version.
- **RDF/XML file**: A URL to the RDF/XML data of the ontology, if available.
- **RDF/Turtle file**: A URL to the RDF/Turtle data of the ontology, if available.
- **Download location**: Some RDF data do not have a static download link or are part of a ZIP archive. These can be found here.
- **Authors/creators** - A list of names of authors or participating groups/companies. If there is no information on authors, all contributors are listed here.
- **License** - If available, an indication of the license used.

[18]This also includes dynamically generated text files

An evaluation of the content (e.g. quality of the RDF data or licenses used) did not take place. Due to the volume, the list of metadata was limited to the most necessary information. All information in the associated CSV file was created in English to enable the greatest possible accessibility.

When evaluating the metadata, the RDF data was checked first. If this was incomplete, the project page was used if available. If both sources were unsuccessful, an attempt was made to obtain the metadata via the online service that provided data on the ontology. If there was still no information available for a metadata item at the end, "Information not available" was entered in the CSV file.

4.6 Content rework

The content of entries in the CSV file **ontologies.csv** has been adjusted to ensure a minimum level of comprehensibility and comparability:

1. Incomplete or missing information was supplemented with information from ontology portals, provided it was clearly recognizable and appropriate in terms of content.
2. Some ontologies had no information on the authors, only contributors. In this case, all contributors were transferred to the authors/creators field.
3. If no authors and contributors could be determined (e.g. VDI3682), an attempt was made to determine the authors' real names via Git commits.
4. The versions and dates (of the last activity) have been standardized to ensure comparability.

4.7 Programs and technologies used

The following programs and technologies were used as part of the research

- **LibreOffice Calc**[19] - The open source spreadsheet program was mainly used to edit the CSV file with the ontologies.
- **PHP**[20] - Various PHP scripts were developed and used for data research and verification. All PHP scripts were executed under PHP 8.3 in a Docker container[21].
- **VSCode**[22] - All work in the code and certain work on the CSV files was carried out with VSCode.

[19] `https://www.libreoffice.org/`
[20] `https://www.php.net/`
[21] `https://www.docker.com/`
[22] `https://code.visualstudio.com/`

5 Research results

The most important findings are summarized below. The database consisted of the **217** ontologies that have a thematic reference to industrial manufacturing.

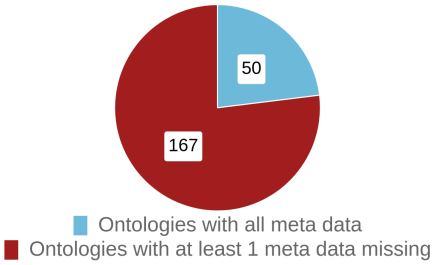

Figure 2

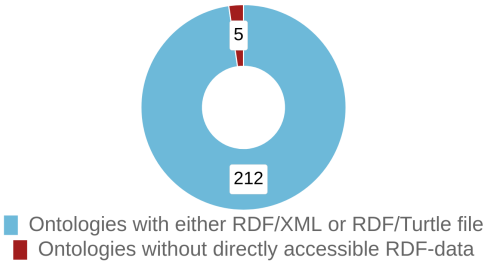

Figure 3

Only **50** of 217 ontologies have complete metadata. For the rest (N=167), there is at least one metadata that is missing the value and therefore contains "Information not available".

212 Ontologies have either an RDF/XML or RDF/Turtle file that can be called up via URL. Only with **5** ontologies, the RDF data is available, but accessing it requires additional effort (e.g. unpacking a ZIP archive). It is not clear why the ontology authors have built in these hurdles for the consumers of their ontology.

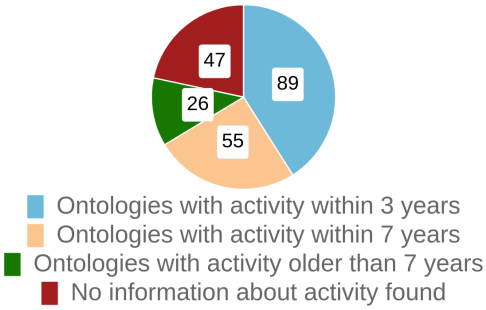

Figure 4

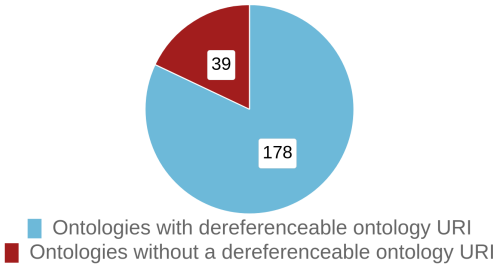

Figure 5

For **89** ontologies, project activity (e.g. Git commit) was detected within the last 3 years. Project activity more than 3 years ago, but within the last 7 years, was detected for **55** ontologies. **26** ontologies had project activity over 7 years ago. No information on the last project activity could be found for **47** ontologies.

178 pieces ontologies have a dereferenceable ontology URI. To check the dereferenceability, an HTTP request was sent and the response evaluated. An ontology URI was considered dereferenceable if the response did not return an error.

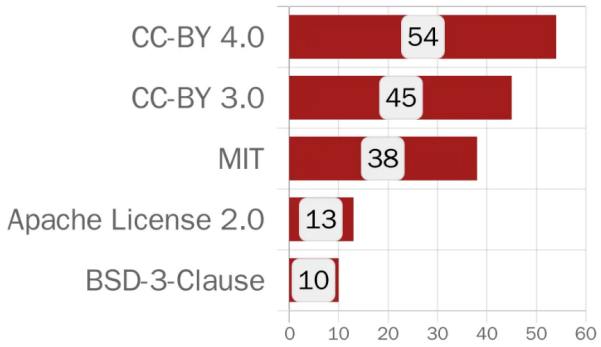

Figure 6: Most used licenses (min. 10 times in use)

180 ontologies used a free or open source license and only **5** ontologies used their own license terms that could not be directly assigned to a known open source license. No information on the license could be found for **32** ontologies. The high proportion of ontologies with a free or open source license is positive because it allows anyone to build their own work on these ontologies without having to worry about licensing costs or legal disputes. However, it should also be mentioned at this point that there are two ontologies that are only available for non-commercial purposes (EEPSA Ontology, Industry 4.0 Knowledge Graph).

All free licenses that were found during the research are listed below:

1. Apache License 2.0[23]
2. BSD License (2- and 3-Clause)[24]
3. Creative Commons Licenses (different types and versions)[25]
4. GNU Public License (different versions Versionen)[26]
5. MIT License[27]
6. OGC Document License Agreement[28]
7. Public Domain Dedication License (PDDL)[29]
8. W3C Document License (2023 version)[30]

Ontologies were found that no longer existed in their original form, e.g. because they had been merged into another ontology. The GoodRelations ontology was merged into schema.org in 2012. Another example is the RealEstateCore ontology: it gave up its OWL ontology in version 4 and then shifted to SHACL and Digital Twin Definition Language serializations[31].

And the Product Types Ontology[32] only provides an RDF data dump with only 1000 of the most frequently queried classes as an ontology.

[23] `https://www.apache.org/licenses/LICENSE-2.0.html`
[24] `https://opensource.org/license/bsd-2-clause`, `https://opensource.org/license/bsd-3-clause`
[25] `https://creativecommons.org/licenses/?lang=en`
[26] `https://www.gnu.org/licenses/licenses.en.html`
[27] `https://opensource.org/license/mit`
[28] `https://www.ogc.org/about-ogc/policies/document-license-agreement/`
[29] `https://opendatacommons.org/licenses/pddl/`
[30] `https://www.w3.org/copyright/document-license-2023/`
[31] See also `https://dev.realestatecore.io/docs/DTDL-or-SHACL` and `https://doc.realestatecore.io/3.3/full.html`
[32] `http://www.productontology.org/`

6 Discussion

The study was carried out over a limited period of 5 months and the ontology list presented does not claim to be complete due to the lack of a list containing all known ontologies. Furthermore, the thematic focus of industrial manufacturing was interpreted broadly, which means that thematically unsuitable ontologies could also be included. For example, ontologies about cars and other products were included because they are manufactured as part of industrial production. At this point, a follow-up investigation with domain experts would be useful. RDF libraries were used in the scripts that could not read all RDF files[33]. In these cases, the files were evaluated manually. The use of metadata outside the ontology, e.g. from an ontology portal, could have led to incorrect information being transferred.

7 Conclusion and future work

The search results show a mixed picture. 217 suitable ontologies were found for the subject area of industrial manufacturing and related subject areas. The last activities identified for each ontology indicate an interest in the subject area over a period of 10 years. It is also positive that some ontologies have a dedicated website with the specification, which provides metadata as well as a list of classes and properties, among other things.

However, it was difficult to obtain the desired metadata for the majority of ontologies. It is remarkable how little attention was paid to the metadata by the ontology authors, even though it is the first thing used in search queries in ontology portals and search engines. The entire research was regularly hampered by unavailable web resources, forcing me to search manually via other online services. This phenomenon is known as "link rot" or "reference rot" and is well documented ([3] [6]). The problem becomes critical when essential web resources from scientific publications are no longer accessible, making the traceability and reproducibility of the work at least more difficult.

This work provides a solid foundation for further research into ontologies in industrial manufacturing. It also allows interested individuals and companies who are not yet so familiar with the RDF environment to access the ontology more easily without having to deal with technical details.

8 Acknowledgments

I would like to thank Paul-Robert Kästner for reviewing and contributing the first ontology entries.

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References

[1] Emna Amdouni et al. "IndustryPortal: a Common Repository for FAIR Ontologies in Industry 4.0". In: *22nd International Semantic Web Conference (ISWC)-Demo & Poster*. 2023.

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9 Appendix

Abbreviated representation of the CSV file with ontologies on the subject of industrial manufacturing:

	Name	Project page, publication or RDF-file
1	3D Modeling Ontology	http://bdi.si.ehu.es/bdi/ontologies/ExtruOnt/docs/
2	Additive Manufacturing and Maintenance Operations Ontology	https://github.com/LA3D/ammo
3	Additive Manufacturing Ontology	https://www.nist.gov/programs-projects/systems-integration-additive-manufacturing
4	Additive Manufacturing and Maintenance Operations Ontology	https://github.com/LA3D/ammo
5	AURORAL Adapters Ontology	https://github.com/oeg-upm/auroral-adapters-ontology
6	AURORAL Cell-Tower Ontology	https://github.com/oeg-upm/auroral-cellTower-ontology
7	AURORAL Energy Ontology	https://github.com/oeg-upm/auroral-energy-ontology
8	AURORAL Logistic Ontology	https://github.com/oeg-upm/auroral-shipmentBiomass-ontology
9	AURORAL Vehicle Charger Ontology	https://github.com/oeg-upm/auroral-VehicleCharger-ontology
10	Automotive Industry Ontology	https://iurianu.rocks/developer/ontology-for-automotive-industry/
11	Battery Interface Ontology	https://www.big-map.eu/dissemination/battinfo
12	Bicycle Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/bicycle.html
13	Brick	https://brickschema.org/
14	Building Automation and Control Network Ontology	https://bacowl.sourceforge.net/intro.html
15	Building Circularity Assessment Ontology	https://github.com/linmor-sys/BCAO
16	Building Element Ontology	https://pi.pauwel.be/voc/buildingelement/index-en.html
17	Building Ontology	https://bimerr.iot.linkeddata.es/def/building/
18	Building Product Ontology	https://www.projekt-scope.de/ontologies/bpo/
19	Building Topology Ontology	https://github.com/w3c-lbd-cg/bot
20	Capability and Skills Ontology based on Industry Standards	https://github.com/CaSkade-Automation/CaSk
21	Capability and Skills Ontology based on Manufacturing	https://github.com/CaSkade-Automation/CaSkMan
22	Car HiFi Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/carhifi.html
23	Car Options Ontology	https://lov.linkeddata.es/dataset/lov/vocabs/coo/versions/2010-10-12.n3
24	Chair Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/chair.html
25	Classification of Business Functions	https://showvoc.op.europa.eu/#/datasets/Classification_of_Business_Functions_%28CBF_1.0%29/metadata
26	Clothing Product Information Ontology	http://www.ebusiness-unibw.org/ontologies/cpi/ns
27	Coffee Machine Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/coffeemachine.html
28	Collaborative Manufacturing Service Ontology	https://zenodo.org/records/3374505
29	Components for ExtruOnt	https://www.semantic-web-journal.net/system/files/swj2217.pdf
30	Computer Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/computer.html
31	Context Aware System Observation Ontology	https://irstea.github.io/caso/OnToology/ontology/caso.owl/documentation/index-en.html
32	Cooker and Oven Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/cookeroven.html
33	core	https://rds.posccaesar.org/ontology/plm/ont/core/
34	Core Ontology for Robotics and Automation	https://github.com/srfiorini/IEEE1872-owl
35	Core Ontology for Robotics and Automation (Bare)	https://github.com/srfiorini/IEEE1872-owl
36	CORAX	https://github.com/srfiorini/IEEE1872-owl
37	Crystallography Domain Ontology	https://github.com/emmo-repo/domain-crystallography
38	CSS Ontology	https://github.com/CaSkade-Automation/CSS
39	DefectOnt	https://github.com/AndreaMazzullo/DefectOnt/
40	Digital Buildings Ontology	https://github.com/google/digitalbuildings/
41	Digital Camera Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/digitalcamera.html
42	Digital Construction Materials	https://data.industryportal.enit.fr/ontologies/DCMATERIALS/submissions/1/download?apikey=019adb70-1d64-41b7-8f6e-8f7e5eb54942
43	Digital Receiver Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/digitalreceiver.html
44	DIN EN 61360 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-DINEN61360
45	DIN EN 62264-2 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-DINEN62264-2
46	DIN 8580 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-DIN8580
47	Dishwasher Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/dishwasher.html
48	Distribution Element Ontology	https://pi.pauwel.be/voc/distributionelement/index-en.html
49	DogOnt: Ontology Modeling for Intelligent Domotic Environments	https://iot-ontologies.github.io/dogont/
50	Domain Mechanical Testing	https://github.com/emmo-repo/domain-mechanical-testing
51	Domain Mechanical Testing Chemistry	https://github.com/emmo-repo/domain-mechanical-testing
52	Dryer Machine Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/dryermachine.html
53	DVD Player and Blu-ray Player Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/blurayplayer.html
54	eClass Products and Services Ontology	http://www.heppnetz.de/projects/eclassowl/
55	EEPSA Ontology	https://iesnaola.github.io/eepsa/EEPSA/index-en.html
56	Elemental Multiperspective Material Ontology	https://emmc.eu/emmo
57	Elemental Multiperspective Material middle-level ontology	https://github.com/emmo-repo/EMMO
58	equipment	https://rds.posccaesar.org/ontology/plm/ont/equipment/
59	ERA Vocabulary	https://showvoc.op.europa.eu/#/datasets/ERA_vocabulary/metadata
60	European Waste Classification for Statistics	https://showvoc.op.europa.eu/#/datasets/ESTAT_European_Waste_Classification_for_Statistics_%28EWC-Stat_Rev.4%29/metadata
61	Extruder Ontology	http://bdi.si.ehu.es/bdi/ontologies/ExtruOnt/docs/
62	Extruder's sensors ontology	http://bdi.si.ehu.es/bdi/ontologies/ExtruOnt/docs/
63	Facility Ontology	https://github.com/oeg-upm/cogito-facility-ontology
64	Fridge and Freezer Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/refrigerator.html
65	Furniture Sector Ontology	https://industryportal.enit.fr/ontologies/FUNSTEP
66	Game Console Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/gameconsole.html
67	Garment Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/garment.html
68	General Process Ontology	https://gitlab.cc-asp.fraunhofer.de/ISC-Public/ISC-Digital/ontology/gpo
69	GRACE Ontology	https://industryportal.enit.fr/ontologies/GRACE
70	Grid2Onto	https://industryportal.enit.fr/ontologies/GRID2ONTO
71	Hair Dryer Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/hairdryer.html
72	Home Hifi Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/homehifi.html
73	IEEE Standard for Autonomous Robotics Ontology	https://github.com/hsu-aut/IndustrialStandard-ODP-IEEE1872-2
74	IFC2X3	https://github.com/buildingsmart-community/ifcOWL
75	IFC2X3_TC1	https://github.com/buildingsmart-community/ifcOWL
76	IFC4	https://github.com/buildingsmart-community/ifcOWL
77	IFC4_ADD1	https://github.com/buildingsmart-community/ifcOWL
78	IFC4_ADD2	https://github.com/buildingsmart-community/ifcOWL
79	Industrial Maintenance Ontology	https://industryportal.enit.fr/ontologies/IMAMO
80	IOF Core Ontology	https://github.com/iofoundry/ontology/
81	International System of Quantities	https://github.com/emmo-repo/EMMO
82	Industrial IoT Architecture Ontology	https://github.com/i40-Tools/StandardsOntology
83	Industrial Ontologies Foundry Supply Chain Reference Ontology	https://spec.industrialontologies.org/iof/ontology/supplychain/SupplyChainReferenceOntology/
84	Industry 40 Knowledge Graph	https://industryportal.enit.fr/ontologies/I40KG
85	IoT Ontology	https://github.com/oeg-upm/cogito-iot-ontology
86	ISO 22400-2 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-ISO22400-2
87	Key Performance Indicator ontology	https://bimerr.iot.linkeddata.es/def/key-performance-indicator/
88	Landline Phones Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/landlinephone.html
89	M3-lite Taxonomy	https://github.com/fiesta-iot/ontology
90	M3 Ontology	http://sensormeasurement.appspot.com/m3#
91	Maintenance Activity Ontology	https://github.com/uwasystemhealth/Paper_Archive_Maintenance_Activity
92	Maintenance Activity Ontology	https://industryportal.enit.fr/ontologies/MNT-ACT
93	Maintenance Reference Ontology	https://spec.industrialontologies.org/iof/ontology/maintenance/Maintenance/
94	Manufacturing	https://github.com/emmo-repo/EMMO
95	Manufacturing Semantics Ontology	https://www.academia.edu/download/30806306/Lemaignan2006.pdf
96	Manufacturing System Ontology	https://github.com/enegri/OFM

	Name	Project page, publication or RDF-file
97	ManuService Ontology	https://industryportal.enit.fr/ontologies/MANUSERVICE
98	Materials	https://github.com/emmo-repo/EMMO
99	Materials Design Ontology	https://github.com/LiUSemWeb/Materials-Design-Ontology
100	Material properties ontology	https://bimerr.iot.linkeddata.es/def/material-properties/
101	Material Science and Engineering Ontology	https://matportal.org/ontologies/MSEO
102	Mechanical Testing Ontology (MTO)	https://industryportal.enit.fr/ontologies/MTO
103	Microstructure domain ontology	https://github.com/emmo-repo/domain-microstructure
104	Microwave Vocabulary	https://ebusiness-unibw.org/ontologies/opdm/microwave.html
105	Mobile Phone Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/mobilephone.html
106	Modem Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/modem.html
107	Molecules And Materials Basic Ontology	https://github.com/daimoners/MAMBO
108	MPS500	https://github.com/hsu-aut/MPS500-Capabilities
109	MPS500 AssembleCylinder	https://github.com/hsu-aut/MPS500-Capabilities
110	MPS500 AssembleThermometer	https://github.com/hsu-aut/MPS500-Capabilities
111	MPS500 CameraModule	https://github.com/hsu-aut/MPS500-Capabilities
112	MPS500 DrillingModule	https://github.com/hsu-aut/MPS500-Capabilities
113	MPS500 PropertyTypes	https://github.com/hsu-aut/MPS500-Capabilities
114	MPS500 RawCylinderSupplyModule	https://github.com/hsu-aut/MPS500-Capabilities
115	MPS500 RawThermometerSupplyModule	https://github.com/hsu-aut/MPS500-Capabilities
116	MPS500 ShippingModule	https://github.com/hsu-aut/MPS500-Capabilities
117	MPS500 StorageModule PutInStorage	https://github.com/hsu-aut/MPS500-Capabilities
118	MPS500 StorageModule RetrieveFromStorage	https://github.com/hsu-aut/MPS500-Capabilities
119	MPS500 Transport Module	https://github.com/hsu-aut/MPS500-Capabilities
120	MSDL (Manufacturing Service Description Language)	https://industryportal.enit.fr/ontologies/MSDL
121	Navigation Device Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/navigation.html
122	Occupancy Profile ontology	https://github.com/oeg-upm/bimerr-occupant-behavior
123	oneM2M Base Ontology	https://git.onem2m.org/MAS/BaseOntology
124	Ontology for Maintenance Procedure Documentation (OMPD) Conditional Maintenance Task Ontology	https://industryportal.enit.fr/ontologies/OMPD-CMTO
125	Ontology for the Battery Value Chain	https://gitlab.cc-asp.fraunhofer.de/ISC-Public/ISC-Digital/ontology/bvco
126	Ontology model for Web of Things	http://iot.linkeddata.es/def/wot/index-en.html
127	Ontology of units of Measure	http://bdi.si.ehu.es/bdi/ontologies/ExtruOnt/docs/
128	OntoSensor Device Ontology	https://mmisw.org/ont/univmemphis/sensor
129	OPC UA Core ontology	https://github.com/OntoUA/ua-nodeset-core-ont
130	OPC UA NodeSet ontology	https://github.com/OntoUA/ua-nodeset-core-ont
131	OPC UA Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-OPC-UA
132	OpenADR ontology	https://albaizq.github.io/OpenADRontology/OnToology/ontology/openADRontology.owl/documentation/index-en.html
133	OpenLink Product Features Ontology	http://www.openlinksw.com/ontology/features#
134	Open Energy Ontology	https://openenergy-platform.org/ontology/
135	PackML StateMachine Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-PackML
136	Paper Vocabulary	https://ebusiness-unibw.org/ontologies/opdm/paper.html
137	PCA 'Part 14' upper ontology	https://rds.posccaesar.org/ontology/lis14/ont/core/
138	Platform Ontology	https://github.com/oeg-upm/cogito-platform-ontology
139	Portable Media Player Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/portablemp.html
140	Position Ontology	https://github.com/srfiorini/IEEE1872-owl
141	Printer Vocabulary	https://ebusiness-unibw.org/ontologies/opdm/printer.html
142	process	https://rds.posccaesar.org/ontology/plm/ont/process/
143	Process Ontology	https://github.com/oeg-upm/cogito-construction-process-ontology
144	Product Ontology	https://github.com/mvegetti/PRONTO/
145	Product Types Ontology	http://www.productontology.org/
146	Product Vocabulary	https://ns.inria.fr/provoc/v1/provoc_v1.html
147	PSS Ontology	https://industryportal.enit.fr/ontologies/PSS
148	RealEstateCore Full	https://github.com/RealEstateCore/rec
149	Reference Generalized Ontological Model	https://github.com/MuhammadYahta/rgom
150	Reified Requirements Ontology	https://data.dnv.com/ontology/requirement-ontology/core/req-ont.html
151	Resistance Spot Welding Ontology	https://github.com/nsai-uio/RSWO
152	RESPOND Ontology	https://respond-project.github.io/RESPOND-Ontology/respond/index-en.html
153	RFID System Configuration Ontology	https://github.com/eleniTsalapati/ONTOLOGIES
154	RIVA InfoModel	https://github.com/hsu-aut/RIVA_InfoModel
155	Resource, Material, Process, Function and Quality (rmpfq) ontology	https://github.com/zhengxiaochen/rmpfq_ontology
156	ROMAIN: Reference Ontology for industrial Maintenance	https://industryportal.enit.fr/ontologies/ROMAIN
157	RPARTS	https://github.com/srfiorini/IEEE1872-owl
158	Safety Ontology	https://github.com/mahsa-teimourikia/Safety-Ontology
159	Safety Ontology	https://github.com/oeg-upm/cogito-safety-ontology
160	SAREF Ontology	https://saref.etsi.org/core/
161	SAREF extension for the Automotive domain	https://saref.etsi.org/saref4auto/
162	SAREF extension for building	https://saref.etsi.org/saref4bldg/
163	SAREF extension for the Energy domain	https://saref.etsi.org/saref4ener/
164	SAREF extension for the electric grid domain	https://saref.etsi.org/saref4grid/
165	SAREF extension for the industry and manufacturing domain	https://saref.etsi.org/saref4inma/
166	SAREF extension for the smart lifts domain	https://saref.etsi.org/saref4lift/
167	SAREF4SYST: an extension of SAREF for typology of systems and their inter-connections	https://saref.etsi.org/saref4syst/
168	SAREF4WATR is an extension of SAREF for Water	https://github.com/oeg-upm/S4WATR
169	SCOPRO (Supply Chain Process Ontology)	https://openreview.net/pdf?id=ricE3prhfH8
170	SCORVoc	https://github.com/vocol/scor
171	SEAS Architecture ontology	https://ci.mines-stetienne.fr/seas/ArchitectureOntology
172	SEAS Building Ontology	https://ci.mines-stetienne.fr/seas/BuildingOntology
173	SEAS Device ontology	https://ci.mines-stetienne.fr/seas/DeviceOntology
174	SEAS Electric Light Source Ontology	https://ci.mines-stetienne.fr/seas/ElectricLightSourceOntology
175	SEAS Electric Power System Ontology	https://ci.mines-stetienne.fr/seas/ElectricPowerSystemOntology
176	SEAS Electric Street Light System Ontology	https://ci.mines-stetienne.fr/seas/StreetLightSystemOntology
177	SEAS Electric Vehicle ontology	https://ci.mines-stetienne.fr/seas/ElectricVehicleOntology
178	SEAS Photovoltaic ontology	https://ci.mines-stetienne.fr/seas/PhotovoltaicOntology
179	SEAS Smart Meter ontology	https://ci.mines-stetienne.fr/seas/SmartMeterOntology
180	SEAS Thermodynamic System ontology	https://ci.mines-stetienne.fr/seas/ThermodynamicSystemOntology
181	Semantic Sensor Network Ontology	https://www.w3.org/TR/vocab-ssn/
182	Semantically Integrated Planning Model	https://industryportal.enit.fr/ontologies/SIMPM
183	Sensor Data ontology	https://bimerr.iot.linkeddata.es/def/sensor-data/
184	Sensor, Observation, Sample and Actuator	https://www.w3.org/TR/vocab-ssn/
185	Sharework Ontology for Human-Robot Collaboration	https://industryportal.enit.fr/ontologies/SOHO
186	Shaver Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/shaver.html
187	Shoe Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/shoe.html
188	Shredder Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/shredder.html
189	SmartHomeWeather	https://paul.staroch.name/en/
190	SmartProducts EADS	https://projects.kmi.open.ac.uk/smartproducts/ontology.html
191	SmartProducts Generic model	https://projects.kmi.open.ac.uk/smartproducts/ontology.html
192	SmartProducts Product model	https://projects.kmi.open.ac.uk/smartproducts/ontology.html
193	Statistical classification of products by activity	https://op.europa.eu/en/web/eu-vocabularies/dataset/-/resource?uri=http://publications.europa.eu/resource/dataset/cpa21
194	Storage Media Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/storagemedia.html
195	Tablet PC Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/tablet.html
196	Television Vocabulary	https://ebusiness-unibw.org/ontologies/opdm/television.html
197	Top Level Ontology of Ontology-based-InformationFlow-Industry-40	https://github.com/ko3n1g/Ontology-based-InformationFlow-Industry-4.0
198	Units of measure (uom)	https://rds.posccaesar.org/ontology/plm/ont/uom/
199	Utility vocabulary of OPDM Category Scheme based on the taxonomy of product types defined by Google	http://www.ebusiness-unibw.org/ontologies/opdm/category/google.owl
200	Vacuum Cleaner Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/vacuum.html
201	VDI 2206 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-VDI2206
202	VDI 2860 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-VDI2860
203	VDI 3682 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-VDI3682
204	VDI 5100 Ontology-Design-Pattern	https://github.com/hsu-aut/IndustrialStandard-ODP-VDI5100
205	VDI VDE NAMUR 2658	https://github.com/hsu-aut/IndustrialStandard-ODP-VDIVDENAMUR2658
206	Vehicle Sales Ontology for Semantic Web-based E-Commerce	https://www.heppnetz.de/ontologies/vso/ns
207	Versioning Ontology	https://data.ontocommons.linkeddata.es/vocabulary/VersioningOntology(veronto)
208	Vicinity core model	http://iot.linkeddata.es/def/core/index-en.html
209	Video Camera Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/videocamera.html
210	Video Projectors Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/videoprojector.html
211	Virtual Asset Representation Ontology	https://fundaciontekniker.github.io/a4blue-ontology/var/index-en.html
212	visualization4ExtruOnt	http://bdi.si.ehu.es/bdi/ontologies/ExtruOnt/docs/
213	Volkswagen Vehicles Ontology	https://www.w3.org/2001/sw/sweo/public/UseCases/Volkswagen/Volkswagen.pdf
214	Washer Machine Vocabulary	http://www.ebusiness-unibw.org/ontologies/opdm/washingmachine.html
215	Waste Categories	https://showvoc.op.europa.eu/#/datasets/ESTAT_Waste_categories/metadata
216	WoT Digital Twin Ontology	https://oeg-upm.github.io/WoT-DT-ontology/OnToology/dt-ontology.ttl/documentation/index-en.html
217	Z-BRE4K semantic model	https://www.z-bre4k.eu/