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# How to support System Engineering with Knowledge in the context of sustainability

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**Abstract** Sustainability has emerged as a critical item in the world's agenda. Several studies show the planet's environment (Holocene) is under threat. The lack of general consensus on the definition of "Sustainability", and more importantly, the scarcity of proper techniques to understand the impact the system's design on the environment are key challenges to be addressed by the community.

In this paper, we propose an ontology that enables system engineers to precisely identify the impact of different system components on sustainability. We evaluate our proposal by answering typical questions related to system engineering and sustainability.

**Keywords:** *Sustainable development, system engineering, ontology.*

## I. INTRODUCTION

Sustainability has emerged as a topic that gives birth to considerable discussions and research works. Moreover, sustainability has become a core point of public and private policies of many organizations and governments. Indeed, the stability of the planet's environment known as Holocene is now under threat.

The engineering of socio-technical systems maybe a difficult task even without considering sustainability during the analysis and design. There are very few approaches nowadays that try to fill the gap to address these challenges. It is more the case for complex systems. Complex systems, repeatedly denoted as system of systems, frequently involve a great number of parts composed of several technologies co-existing to deliver services. The technical point of view on these systems has been studied through different approaches. However, technical success alone cannot ensure sustainability [Cameron et al, 2008]. Obviously adding sustainability challenges on top of technical points of view does not simplify systems engineering.

One of the challenges raised by sustainability is the lack of a global and consensual comprehension of what is sustainability and how it may impact systems engineering.

This paper presents the definition of a core ontology for system design relating system components to sustainability objectives. This approach allows to semantically reveal the impact of the system's design on sustainability.

Ontologies have been designed since 1993 as explicit formal specifications of a set of terms that define a given domain and the relations that exist among them. Ontologies have now moved from the domain of Artificial Intelligence, more specifically Knowledge Engineering, and are used for a wide range of applications.

This paper proposes an to define a formalized conceptualization of design in system engineering linked to sustainability. Section II presents the approach that was followed to design the ontology. Section III defines the main ontology elements. Section IV evaluates the proposed ontology with some questions the ontology should answer. Eventually section V concludes.

## II. APPROACH

An Ontology is a formal description of a specific domain in terms of objects and their properties, relationships, constraints, and behaviors. As in [Gruninger et al, 94], we are interested in a formal and rigorous approach that provides a coherent and useful representation of knowledge.

Our goal is to provide an ontology of design in a sustainable context that should be accepted, understood, and shared by engineers involved in system engineering projects integrating sustainability during the analysis and design phases. Engineers should use a common terminology with accepted meanings for terms so that they can collaborate within system engineering projects and better satisfy requirements and achieve a higher level of sustainability.

To produce an ontology and define the meaning of important concepts we have followed the methodology described in [Noy et al] which is illustrated in figure 1. The chosen ontology language is OWL [Hitzler et al, 2012] as it is a well-known ontology language and is supported by many tools for ontologies manipulations and reasoning such as Protégé [Protégé, 20]. Protégé was used for ontology editing and manipulations.

The ontology uses a form of logic (Descriptive Logic) which gives a precise and unambiguous semantics for each term. The precision and unambiguity avoid possible conflicts and different interpretations by different engineers.

Moreover, in addition to the definition of terms a set of axioms capture the definitions and constraints on the conceptualization to allow the use of reasoners and automatic deduction from the captured knowledge. The axioms allow our system to answer design relevant questions using not only information explicitly represented in the object model, but also what can be deduced from it. The axioms also allow integrity checking of the design knowledge, i.e. detecting invalid data in the knowledge base, and avoiding updates introducing conflicts among the data and the object model of design.

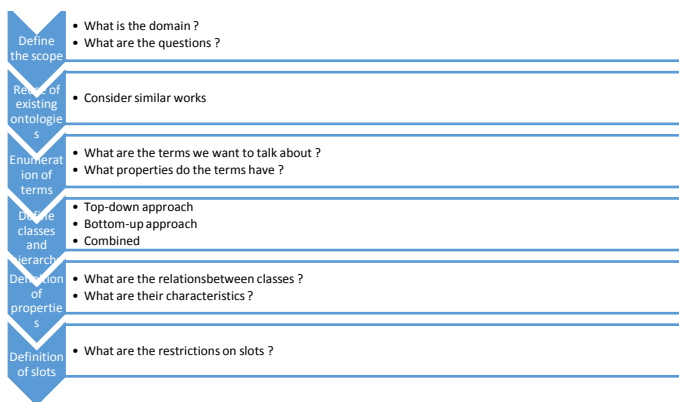


Figure 1. Ontology design process

### III. ONTOLOGY DEFINITION

*In this section, we introduce our ontology for sustainability in Systems Engineering design.*

#### A. Ontology scope

The targeted domain is the one of system engineering and design. A focus on sustainability is added to take these elements into account. Ontology aims to answer the following questions:

- (1) What are the impacts on the environment of a specific part of a system?
- (2) What are the system requirements linked to a specific sustainability goal?
- (3) What are the reasons related to the design problem that justify a given design object definition?

#### B. Existing ontologies

Other ontologies have been proposed either for design or sustainability. For sustainability, as it is an important topic recently identified by many communities there are recent research works that contribute to the domain [Deliyska et al, 20; Ivanova et al, 21; Konys, 18; Macris et al, 06; UNEP, 14; UNEP, 20]. Among these contributions the Sustainable Development Goals Interface Ontology (SDGIO) gathers many advantages. First, it offers a comprehensive view of sustainability goals, targets and indicators. It is composed of more than 900 classes and 150 object properties relationships for example. Second, this ontology assembles a great community of users. Finally, this ontology is freely accessible and is well documented.

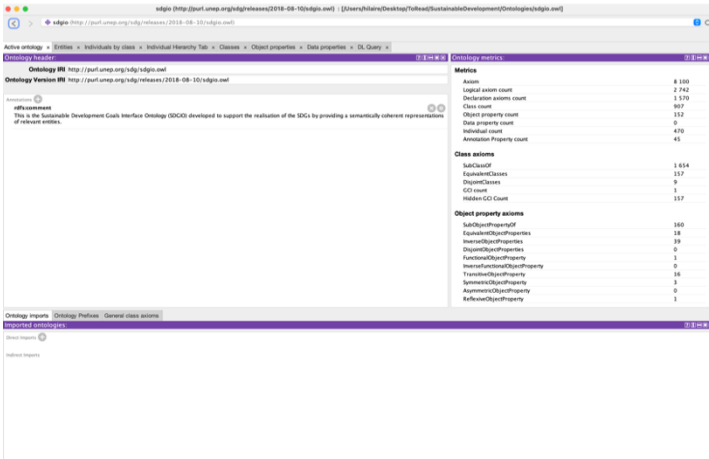
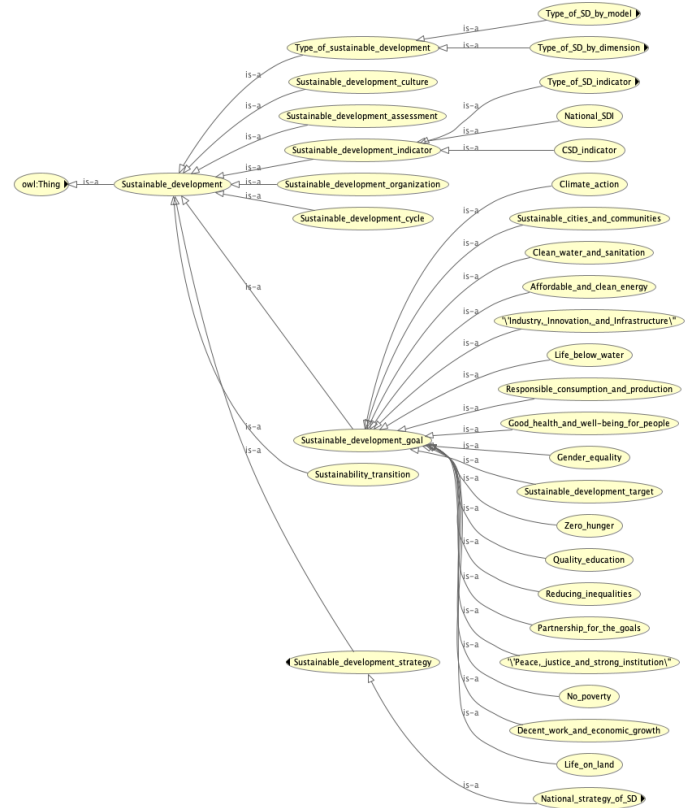


Figure 2. SDGIO Ontology



Another important pillar of the presented work is the Common Ontology for Sustainable Development (COSD) [Ivanova et al, 21]. An excerpt of this latter ontology is shown in figure 3. More specifically, it is focused on sustainable development.

In terms of design, [Gruninger et al, 94] proposes an ontology with a focus on requirements and their evolutions during the design process. [Monticolo et al, 07] defines an ontology related to design and management of project memories. This latter ontology was defined to help system engineers during their projects.

The conceptualization proposed in this paper results from the synthesis of [Gruninger et al, 94], [Hilaire et al, 03] and [Monticolo et al, 07].

### C. Ontology Overview

In the design domain, key elements are defined such as requirements, the functions, features of the system-to-be, components of the system-to-be and parameters. Closely related are the specific terms of each concerned domains that can be structured within glossaries and units used. The analysis of a system usually begins with the elicitation of requirements that are further refined down to system components that satisfy these requirements. Requirements are a kind of constraint that can concern functionalities, structure, physical properties, etc. The refinement of a requirement produces more concrete

requirements (less abstract), simpler or more detailed. The decomposition of requirements helps to define at least one solution for a given context. Several decompositions may be necessary to obtain a final set of requirements that allow to specify a solution. Traceability of requirements (link between a requirement and sub-requirements derived from it) is a critical feature of this process.

A system can be seen as composed by sub-systems/components. These sub-systems are called “parts”. The system-to-be as a whole is considered as a part that can be composed by other parts. Parts that are not composed are called *primitive parts*. The composition relation defines the structure of the system-to-be in terms of components. This relationship associates a part to another (sub-)part

A feature is a generic element that define a characteristic. Among all possible features one can distinguish GeometricFeature, FunctionalFeature, ColorFeature, etc. A part may have several associated features.

During design it is common to define parameters for sub-systems that is in our case parts. A parameter is thus defined for a given part. Moreover, it is basically related to a given measure weight for example and should use some unit for its value.

The design process is obviously a sequence of choices and decisions. It results in the evolution of several elements of design into other design elements. This evolution process that should result in final specification traces the design rationale. It is useful to keep all these refinements (derivation decisions) in order to understand these different choices and allow for possible modifications if a requirement change for example. A derivation is logically defined by two elements, one derived from the other. Following a similar idea, it is also useful to identify the creation date of a design element. In other words, for each design element one should know when it was defined first.

#### D. Definition of classes and hierarchy

The OWL language uses the class construct to define concepts. Classes describe concepts in the domain represented. A class can have subclasses that represent concepts that are more specific than the superclass. This relation called SubClassOf defines a hierarchy of specialization from the more general concepts called Thing in OWL that denotes all possible individuals to Nothing.

The figure 4 illustrates some of the classes identified from the enumerated terms and their specialization relations.

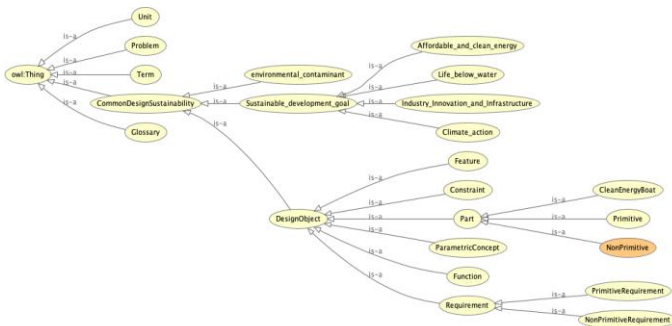


Figure 4. Class hierarchy

A class DesignObject is introduced to generalize all concepts directly related to design. Among these concepts: Requirement which can be either Primitive (non-decomposed) or NonPrimitive, Part, ParametricConcept and Feature. Apart these DesignObject Unit denotes the different units used within a system engineering project. Glossary and Term conceptualize the domain specific glossaries and terms respectively.

The concept Sustainable\_development\_goal and environmental\_contaminant come respectively from the COSD and SDGIO ontologies already cited and discussed. In the

figure 4 there is only a limited number of concepts for the sake of simplicity.

By relating known and accepted ontologies (i.e. COSD and SDGIO) we can semantically link the System Engineering (COSD) and the sustainability goals (SDGIO).

#### E. Definition of classes properties

The definition of concepts does not allow to answer the question identified in section III A. These definitions should be completed with some of the terms identified in section III C in order to define relations between classes.

The relation of composition between Part was identified as one possible definition of the structure of the system-to-be. This relation named componentOf (which has an inverse relation hasComponent) associates a Part to another Part. This relationship is Irreflexive (a Part cannot be component of itself), Asymmetric. If a Part x is component of a Part y, then y cannot be component of x. Eventually, componentOf is a transitive relationship. It means that if a Part x is component of a Part y and y is component of another Part z then x is component of z.

The design rationale or derivation of DesignObject is represented by the derivedFrom relationship that relates a DesignObject to another DesignObject. This relationship should be irreflexive, asymmetric and transitive. The date of definition of a DesignObject is defined by the data relation creationTime which associates a date to a DesignObject. This relationship is functional as for a DesignObject there is only one definition date possible.

The elements of Part type can be associated to any number of Feature. The hasFeature relationship is thus defined from Part to Feature.

The parameters, identified in section III C, are defined by the ParametricConcept class that are subject to three relationships:

- hasUnit that relates a ParametricConcept to a given unit,
- isParameterFor, that relates a ParametricConcept to a Part,
- hasValue, that associates to a given value a parametric concept.

A glossary maybe related to other (sub-)glossaries. This relationship structure a domain terminology in several specific glossaries. This relationship is called isASubGlossaryOf. It is irreflexive, asymmetric and transitive. A term is linked to at least one Glossary. This relationship is named isATermOf. A term is also linked to some DesignObject. This relationship

represents an explanation of this DesignObject and is named explains.

#### F. Definition of slots

Attributes for concepts are defined through properties (also called *slots*) discussed in the previous subsection. Within classes that represent concepts it is possible to define restrictions on slots to define the classes more precisely.

A ParametricConcept is related to single Unit and a single Part. The cardinalities of these slots are thus exactly one for each of them.

A NonPrimitivePart is related to some NonPrimitivePart, at least one.

### IV. EVALUATION

For the evaluation of the proposed ontology we answer the questions stated in section III.A using the DL-query language [Pan et al, 06; Patel-Schneider et al, 06].

#### A. What are the impacts on the environment of a specific part of a system?

The first question aims at the identification of sub-system that have an impact on the environment. The following DL-query is a possible answer.

Part and produces min 1 environmental\_contaminant

The results of the previous query are all parts that are related by the produces relationship with at least one element denoted by the class environmental contaminant (or one of its subclasses). The relation produces and the class environmental

contaminant are reused from the SDGIO ontology. The element Part can be replaced by a specific Part of the System-to-be if more precision is needed.

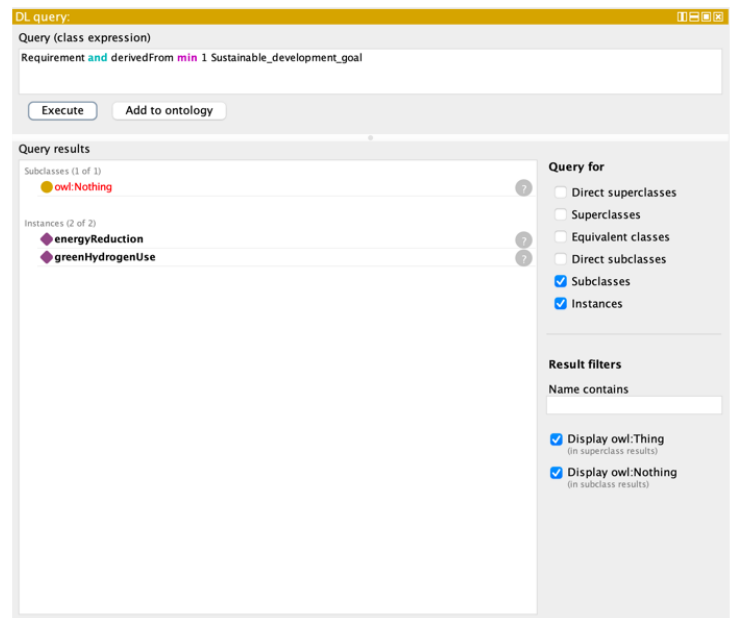
Figure 5. First question DL-query results

An example of execution of such a query is shown in figure 5.

#### B. What are the system requirements linked to a specific sustainability goal?

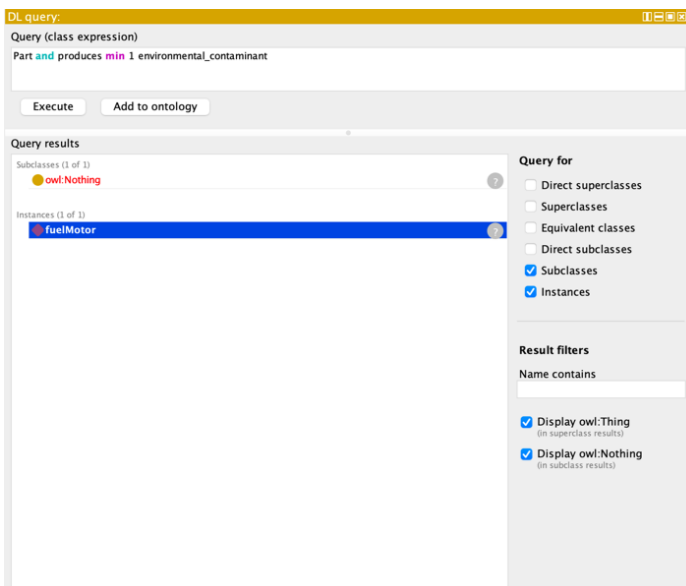
The second question tries to identify requirements linked to sustainable goals and is defined as:

Requirement and derivedFrom min 1 Sustainable\_development\_goal



The previous DL-query produces requirements that are associated by the derivedFrom relationship with at least a Sustainable\_development\_goal. This latter class comes from the SDGIO ontology. If specific goals are targeted one can replace the general class Sustainable\_development\_goal by a more specific one.

Figure 6. Second question DL-query results

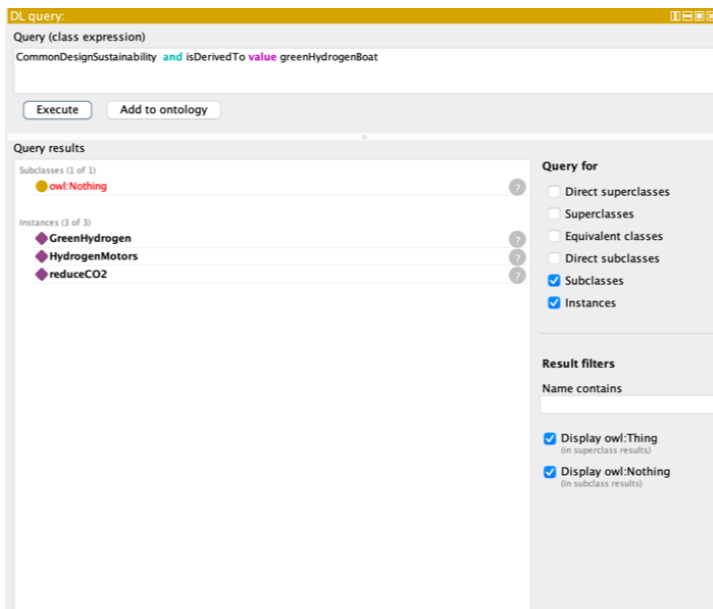


C. *What are the reasons related to the design problem that justify a given design object definition?*

Eventually, the third question of section III A targets the DesignObjects the DesignObjects that precede it definition.

DesignObject and isDerivedTo SystemOfInterest

The answer consists in all DesignObjects whatever their types (sub-classes of DesignObject) that are linked by the isDerivedTo the specific targeted system (SystemOfInterest).



An example with a specific system called greenHydrogenBoat is given in figure 7.

Figure 7. Third question DL-query results

## V. CONCLUSION AND PERSPECTIVES

This paper introduced an ontology that support system engineering within a sustainability context. This ontology is defined using the OWL language and the protégé software. This ontology allows:

- a conceptualization of both system engineering and sustainability aspects,
- a common ground to discuss for a same system both of design and sustainability features,

- the expression of relationships between these elements.

This ontology enables to clearly and formally define a common vocabulary and comprehension related to the cited domains and is supported by reasoning mechanism that can help system engineers.

Some examples, under the form of questions asked to the ontology, are shown to exemplify different usages for specific situations.

The following works will consider supplementary case studies to evaluate the defined ontology and possible evolutions of concepts and relations. We also plan to use this ontology with intelligent assistant such as agents for supporting design processes as described in [Lin et al, 15]. The idea is to automatize the reasoning and support system engineers facing sustainability challenges.

## REFERENCES

- [Cameron et al, 2008] Cameron, Bruce G., et al. "Value flow mapping: Using networks to inform stakeholder analysis." *Acta Astronautica* 62.4-5 (2008): 324-333.
- [Deliyska et al, 20] Deliyska, Boryana & Todorov, Vladislav & Ivanova, Adelina. (2020). Common Ontology of Sustainable Development. *International Journal of Information Systems and Social Change*. 11. 55-69. 10.4018/IJISSC.2020100104.
- [Gruninger et al, 94] Gruninger, M., and Fox, M.S., (1994), "The Design and Evaluation of Ontologies for Enterprise Engineering", Workshop on Implemented Ontologies, European Conference on Artificial Intelligence (ECAI) 1994, Amsterdam, NL. [http://www.ie.utoronto.ca/EIL/public/onto\\_ecai94.ps](http://www.ie.utoronto.ca/EIL/public/onto_ecai94.ps)
- [Hilaire et al, 03] Hilaire, Vincent, Abder Koukam, and Pablo Gruer. "A mechanism for dynamic role playing." *Agent Technologies, Infrastructures, Tools, and Applications for E-Services: NODE 2002 Agent-Related Workshops Erfurt, Germany, October 7–10, 2002 Revised Papers* 4. Springer Berlin Heidelberg, 2003.
- [Hitzler, 12] Pascal Hitzler, Markus Krötzsch, Bijan Parsia, Peter F. Patel-Schneider, Sebastian Rudolph "OWL 2 Web Ontology Language: Primer (Second Edition)", W3C Recommendation, 11 December 2012, <http://www.w3.org/TR/2012/REC-owl2-primer-20121211/>. Latest version available at <http://www.w3.org/TR/owl2-primer/>
- [Ivanova et al, 21] Adelina Ivanova, Boryana Deliyska, Vladislav Todorov; Domain ontology of social sustainable development. *AIP Conf. Proc.* 8 March 2021; 2333 (1): 110006. <https://doi.org/10.1063/5.0042253>
- [Konys, 18] Konys, A. (2018). "An Ontology-Based Knowledge Modelling for a Sustainability Assessment Domain" *Sustainability* 10, no. 2: 300. <https://doi.org/10.3390/su10020300>
- [Lin et al, 15] Yishuai Lin, Philippe Descamps, Nicolas Gaud, Vincent Hilaire, Abderrafiaa Koukam: Multi-Agent System for intelligent Scrum project management. *Integr. Comput. Aided Eng.* 22(3): 281-296 (2015)



- [Macris et al, 06] Macris, A M., Georgakellos D A., (2006) A new teaching tool in education for sustainable development: ontology-based knowledge networks for environmental training, *Journal of Cleaner Production*, Volume 14, Issues 9–11, Pages 855-867, ISSN 0959-6526, <https://doi.org/10.1016/j.jclepro.2005.12.009>.
- [Monticolo et al, 07] Davy MONTICOLO, Vincent HILAIRE, Abderrafiaa KOUKAM, Samuel GOMES, (2007) ONTODESIGN; a Domain Ontology for Building and Exploiting Project Memories in Mechanical Design Projects, 2nd International Conference in Knowledge Management in Organizations (KMO-7), Lecce, Italy, Springer.
- [Noy et al, 01] Noy, N.F. and McGuinness, D. (2001) “Ontology Development 101: A Guide to Creating Your First Ontology.” Stanford Knowledge Systems Laboratory. [http://protege.stanford.edu/publications/ontology\\_development/ontology101.pdf](http://protege.stanford.edu/publications/ontology_development/ontology101.pdf)
- [Pan et al, 06] Pan, J.Z., Horrocks, I.: Owl-eu : Adding customized datatypes into owl. *J.WebSem.*4(1) (2006)29–39
- [Patel-Schneider et al, 06] Patel-Schneider, P., Hayes, P., Horrocks, I.: Web Ontology Language (OWL) Abstract Syntax and Semantics. <http://www.w3.org/TR/owl-semantics>, February 2003.
- [Protégé, 20] Protégé Desktop, Stanford University, available at <https://protege.stanford.edu/products.php#desktop-protege>, (2020)
- [UNEP, 14] UNEP, (2014) Design and development of integrated indicators for the Sustainable Development Goals Report: Senior Expert Meeting 3- 5 December 2014, Gland, Switzerland.
- [UNEP, 20] UNEP, (2020) “The Sustainable Development Goals Interface Ontology (SDGIO)”, <https://github.com/SDG-InterfaceOntology/sdgio>