Ontology based Information Management for Industrial Applications

Markus Germann, Constantin Rieder and Klaus Peter Scherer
Institute for Automation and Applied Informatics, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, Eggenstein-Leopoldshafen, Germany

Keywords: Ontology Development, Knowledge Graph, Collaboration, Heterogeneous Consistent Knowledge, Semantic Annotation, Intelligent Reasoning, Semantic Wiki, Ontology Learning.

Abstract: For industrial applications, intelligent systems are available, helpful and necessary to support the complex human expert decisions and also the design based construction processes, especially when complex constraints for the process behaviour are given. Normally, such an intelligent support system consists of a knowledge based module, which is responsible for the real assistance power, representing the user specified information, the reasoning explanation part and the logical reasoning process itself. The interview based acquisition and generation of the complex expert knowledge itself is very crucial because of differing correlations between the complex parameters. So, in this project intelligent Wiki based methods are researched and developed for a quality improvement of an ontology based information system concerning electronic 3D print processes.

1 PROBLEM AND PURPOSE

The establishing guide lines and standards for quality assurance in machine based manufacturing processes, especially in the context of print processes (for example 3D printing), requires enormous efforts. Many areas of machine based manufacturing already utilize software systems leveraging knowledge management technologies to make complex heterogeneous relationships accessible towards both the construction engineer as well as the quality assurance personal (Kamsu-Foguem and Noyes, 2013). The aim is to achieve a methodically consistent integrated information management from the design stage through the manufacturing process up to the quality control (Song et al., 2016; Al-Safi and Vyatkin, 2007). In this proposal a software-based intelligent assistance and knowledge system is conceptualized, which supports the human engineer on his acquisition of knowledge, the information inquiry up to the quality control in the sense of purposeful criteria validation. So the assistance system is also a support system for the complex human expert decisions. For this, subject specific detailed knowledge has to be represented in a consistent manner and structured in the partial knowledge domains. A possible approach to reach this goal can be achieved exploiting the advantages of knowledge graphs (Banerjee et al., 2017; Kamsu-Foguem and Abanda, 2015). The success of a high performed support for knowledge acquisition depends also on special knowledge acquisition structures. Furthermore there's need for easy-to-use graphical access to inquire and check the semantics between the individual knowledge contents. With these goals an enhancement of the semantic ontology network is performed.

Since the knowledge in many existing information systems is stored in a decentralized and non well structured manner and because of that the results are often not consistent, a user encounters a variety of difficulties by searching and generating information in the typical classical (Wiki) information systems. The difficulties are:

- Information overflow: Information, which is irrelevant for finding a solution in the particular use case.
- Incomplete information: Missing feature descriptions and necessary details.
- Redundant information: The consequences are a reduced fault tolerance and problems when incremental changes, i.e. a higher vulnerability to errors.
- Reliable information: Often unverified knowledge and fuzzy statements can't modelled and integrated in the knowledge domain.
- Incorrect information: In the real context contradictions are given to other knowledge contents.

Germann, M., Rieder, C. and Scherer, K.
Ontology based Information Management for Industrial Applications.
DOI: 10.5220/0009095607730779
In *Proceedings of the 12th International Conference on Agents and Artificial Intelligence (ICAART 2020) - Volume 2*, pages 773-779
ISBN: 978-989-758-395-7; ISSN: 2184-433X

- Disjoint storage of data: This fact leads to an access with potential inconsistencies.
- Semantic embedding: Usually not easy accessible because there exists no ontology network with semantic relations.

Consequently there is a need to research and develop an extendable, easy to handle information management system, based on a consistent ontology network with reasoned correlations which takes into account the disadvantages of the above mentioned criteria. One real application scenario is the complex 3D print process with focus on printed electronics, which is established at the Institute of Automation and Computer Science (IAI) in the Karlsruhe Institute of Technology (KIT). The following sections 2 and 3 outline the approach of this application scenario and the methodology that is used. Section 4 exemplifies further details regarding the structuring of the knowledge. A concrete use case in which the approach is applied and the models are tested is explicated in section 5.

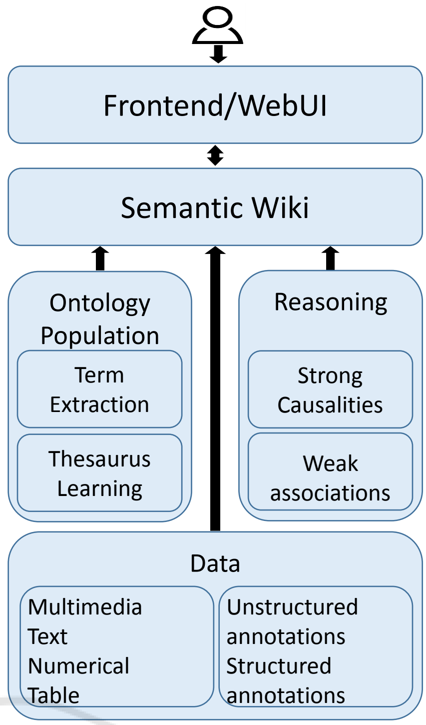

Figure 1: Conceptual overview.

2 INNOVATIVE APPROACH

In contradiction to classical existing information management systems, which often use a wiki structure, in this proposal a semantic wiki with intelligent reasoning methods is required for strong problem solving capabilities for the development and creation of the new knowledge. Important research aspects are the effective linking of heterogeneous knowledge elements provided by the system, which can range from semi-structured data (texts, images, videos) to highly formalized models and rules. Furthermore tools have to be developed and must be available to simplify capturing and changing heterogeneous knowledge elements. Ideally, the knowledge should be edited directly by the domain experts and so the continuous development of the knowledge base is to be driven forward. The following Figure 1 shows the architecture of a reason based wiki extension and the interface between data, semantics and the user.

2.1 Knowledge Structuring

On the first level a frame based information system is performed with all features of the domain ontology. The descriptive layer for the interested information categories is a concept based network representation with a refinement from class to subclass along the relation “subconcept”. For a successful user access, useful graphical representations of the hierarchical knowledge structure exist. For example, Figure 2

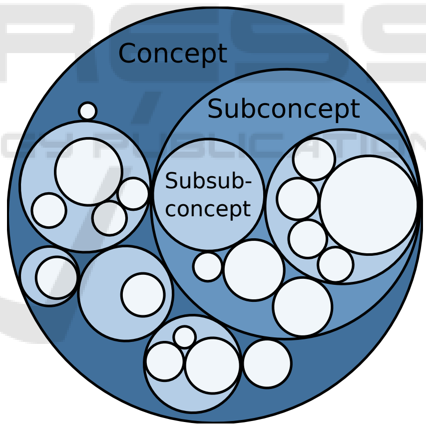

Figure 2: Circle-Packing visualization of the concept hierarchy.

shows a hierarchical representation in a bubble manner, called Circle Packing. The whole ontology consists of the declarative part of the semantics, the concept in this knowledge based approach, the sources (publications, authors and so on) and multimedia representations (pictures, tables, and movies) of the concept functionalities. On the next layer the concept of the semantic dependencies are subdivided into two types of relations: The knowledge can be correlated by so called weak links, i. e. semantic associations between the different concepts. It is a suggestion for the human user, also in regard to the semantic neighbored knowledge domain when focusing on a concept. But there exist no strong logical dependencies between the two knowledge items. The human expert can be guided from one interest of point to another in an intelligent manner along the linked correlation. An additional type of relation is performed by a stronger relation like a rule in a rule based approach. If the premises of the first domain are given, then the second knowledge items result as a strong causal conclusion from the preconditions.

2.2 Knowledge Formalization

Additional to a well structured knowledge domain, the formalization aspect is important for a correct reasoning process. Formalized methods are also responsible for an efficient generation of new knowledge. One important aim is to generate a system expandable and consistent in the knowledge domains up from the starting point. This fact includes a user friendly architecture and component development. In the area of data management, this concerns the access to file systems and databases. The subjects of knowledge acquisition and the use of knowledge are to be considered as separately architectured components. In the following diagram (Figure 3), the aspects of the formalization of knowledge as a continuum with the intelligent reasoning process are presented.

The architecture of the gained innovative approach is represented by the following three components.

- Wiki knowledge which different aspects
- Intelligent request and user navigation
- Formalized consistent knowledge continuum

Figure 3 summarizes these main components in further detail.
With the use of such semantic Wiki concepts the following advantages have been established:

- Knowledge management: Easy and consistent handling of the knowledge concepts and the relationships between them.
- Ontology engineering: Integrated comprehensive state description with semantic network models.
- Flexibility: Case based driven updates in the knowledge domain by comfortable and useful knowledge acquisition methods.
- Reasoning: Strong causality in the sense of predicate logic second order and additional weak associations as weak links.
- Query languages: Easy user accessibility to the knowledge concepts distributed in the network structure.

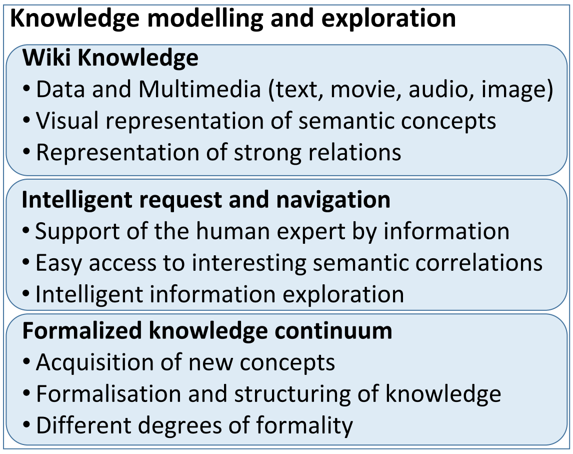

Figure 3: Composition of the target features for acquiring and modelling of knowledge.

Based on these networking and standardized ontology concepts, enormous advantages are expected for the information management performance concerning users and the process developers as domain experts. This results also in an intelligent human decision support system for the given industrial application (here the 3D print domain as use case).

3 ADVANCED KNOWLEDGE REPRESENTATIONS

A Wiki is a web-based system used for collaborative development and maintenance of content. A semantic wiki extends the flexibility of a conventional wiki when editing texts by the creation of ontologies (concepts and their semantic linking) (Baumeister et al., 2011). In this work a high performed concept for a semantic wiki for the representation and structured use of 3D print processes (expert knowledge) with ontology based methods shall be conceptualized. Besides the semantic linking of multimedia contents (texts and images), the system should also be able to process strong problem solving knowledge in the sense of a reasoning process for a required functionality, e.g. as rules or references.
The knowledge will be available directly from the Wiki, so that decisions can be automatically supported immediately after the creation of the knowledge base. Consequently images, explanatory texts or videos can be made available directly next to formalized rules for human construction requests within the print process. The semantic wiki system KnowWE[1]

[1]Website of KnowWE, visited 2019-11-07: https://www.d3web.de/Wiki.jsp?page=KnowWE

("Knowledge Wiki Environment") is in representation mode similar to the well known free encyclopedia Wikipedia, but there are additional features: there are semantic links between the contents, i.e. specialized articles can be placed in certain relationships to other and they can be evaluated according to the resulting ontology (the graph system). The ontology network to be developed is to be modelled with the help of this software in order to provide an intelligent information management, based on the use case of the 3D print process.
Each fact (knowledge concept), i.e. each technical term, is assigned to an article that can be integrated into any content such as textual explanations, images or other media contents (see Figure 4). The information concepts can be associated with each other via different relations (partially in the sense of predicates). Reversely, these n-digit relations (linking of n concepts via predicates) can read and electronically processed. The corresponding visualizations are also realized in this manner. A visualization of the knowledge base can be accessed and regarded from any concept. The combination of the given data structures and the visualization with functions such as Overview, Zoom, Details-on-Demand enables a fast user controlled data exploration (Shneiderman, 1996). As an effect, the user can get a very fast overview of the context of a certain term, fact or circumstance very efficiently. The user can navigate through the knowledge base textually from article to article like in a classical Wiki system, or he can use the visualization if necessary to profit from the advantage of the graphical illustration with direct access to the relationships via the network structure (Figure 5). The visualizations can also extended to the view design profiles of complex products or processes like presented in (Keivanpour and Kadi, 2018). An example of the textual and graphical representation can be seen in Figure 4.

4 ONTOLOGY & INFORMATION BASED MANAGEMENT

An intelligent use of the existing information can be supported by defining an ontology. The ontology can then provide the following features:

- Terminology for the description of content.
- Axioms that define terms used by other terms.
- For certain statements automatic conclusions can be performed (e.g. transitivity).
- Unconventional conclusions are possible (making implicit information explicit).

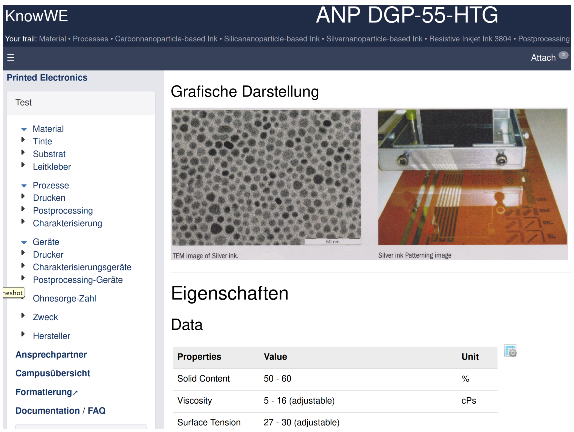

Figure 4: Wiki representation with hierarchical class structure, a feature list and images.

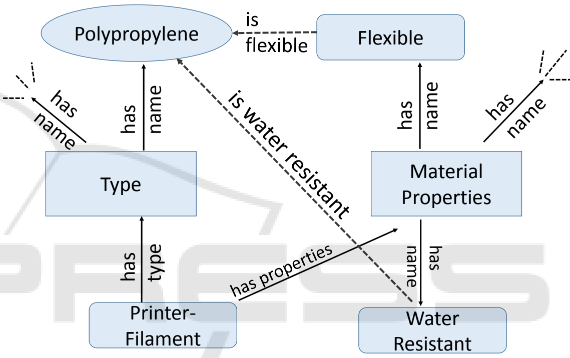

Figure 5: Polypropylene is both flexible and water-repellent.

Furthermore, the architecture of a 3D printing ontology can be used to create a consistent information model with the following representative properties:

- Definition and Classification of the individual elements and components (of substrates and filaments).
- Relations between the defined elements represented by semantic associations.
- Links to describe elements using their elementary characteristics.

With regard to the development of an ontology for 3D printing materials various aspects must be considered. Figure 5 shows the possibility of classifying materials according to different types. Another possibility is the categorisation according to the properties of materials (Figure 6). Annotated elements in the ontology can be considered in relationship with each other. For instance, the material "Polypropylene" is both flexible and water repellent. In Figure 5 (see above) the logical extension of a classical wiki is shown. Free described relations between the different concepts (from different partial hierarchical trees) can used for logical reasoning. The propylene has properties from different class structures an the user has the possibility to ask for feature combinations, which is not possible in classical wikis.

4.1 Ontology Concepts and Relations

In order to build a semantic net and provide the users more expressive types of knowledge, more additional relation types can be defined for example:

performsProcess:
A relation that represents the possibility of any class or individual to perform any specific or type of processes.

fulfillsPurpose:
This relationship represents the fulfilling of a certain purpose by a class or individual by another.

compatibleWith:
For instance one substrate can be compatible with a specific ink type or not.

The resulting ontology is represented in RDF(S). In cooperation with the 3D print experts the requirements for further relations and concepts have to be identified. In conclusion the following useful aspects were regarded:

- Obtain an overview of the 3D print knowledge base by reducing the complexity.
- Obtain an overview of the processes and dependencies between the procedure steps.
- Browsing through the entire knowledge base to identify interesting spots.
- Retrieve detailed information on special relations between concepts and procedure steps on demand.
- Help the user to find quickly the category of a concept inclusive the sub-concepts.

By defining an ontology, the existing knowledge can be classified. This can be restrictive because often the several users use different terminologies. The users must formulate their own ontology of terms, so these can linked with each other. On this way, the contained concepts can directly mapped if all possible designations or labels are entered. If for example, any user searches for "Polypropylene", the entries with "PP" are also taken into account (Figure 7).
The look-up of information can be extended. In case a substrate with several properties is required, it will be simplified by using an ontology. The following

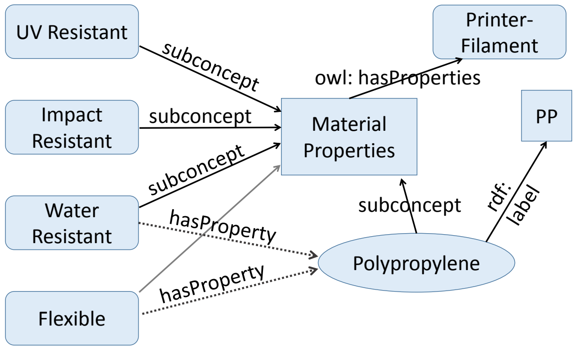

Figure 6: Property assoziations.

example illustrates this fact. The search for a material that is both flexible and waterproof would deliver polypropylene as a result (see Figure 6). In an ontology, these properties were defined and implicitly interlinked for PP.

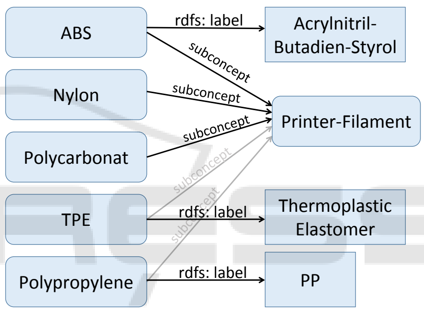

Figure 7: Typical labeling concept for the printing domain.

4.2 Self Learning Methods for Ontologies

In industrial applications and more specifically in print technologies, semantic information systems are in progress but there is a lack of solution approaches covering the necessary and permanent maintenance of the knowledge. This is shown in Figure 8.
This consistent maintenance has to be carried out for structured data (measurements, results, digital patterns) as well as for textual information like reports, design steps and guidelines. There are two essential problems concerning the learning models:

- The semantic approaches use highly specialized knowledge and the established knowledge is given only by a few experts.
- The currently used methods are only available for small data sets and it is a big challenge to process different corpora concerning other document structures, different terms or word variations.

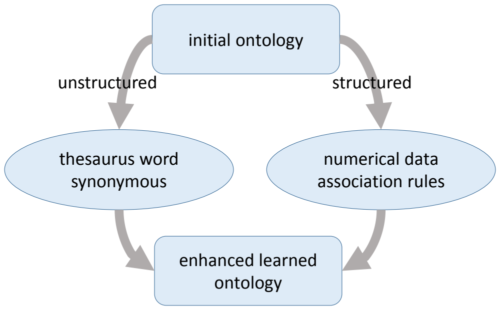

Figure 8: Enhancing an ontology by learning.

Therefore an innovative objective for intelligent information processing is the research and development of self learning semantic information systems (Furth and Baumeister, 2014; Karthikeyan and Karthikeyani, 2015). These learning methods must be integrated in the ontology network. In this context, the construction and the support of the knowledge base is the central point. And the methods must be supported by knowledge engineering tools. Additional to the established knowledge representations like RDF(s) and OWL there exist also tools like KnowWE, Onto studio, Protégé and semantic Media Wiki, but none of these tools serves for the maintenance of the knowledge base. The focused self learning system should be powerful to reprocess the concepts of the knowledge base by modern knowledge engineering methods. This means especially delete, add, reprocess and confirm of concepts of the ontology. The functions will lean on basic data base operations Create, Read, Update and Delete.

5 USE CASE AND A FIRST APPLICATION SCENARIO

Since 3D printing technologies has gained a high popularity by becoming accessible for a broad range of users, a lot of experiments have been conducted on the materials that can be used. This includes, but is not limited to, ink types, substrates and printing systems of varying character (e.g. thermal ink-jet or piezo printing systems). On top of that scientific projects aiming for specific use cases of printing technologies have been under development. Among them some target the purpose of printing electric circuits with electrically conductive ink. This kind of scientific research leads in the past time to a vast amount of information, knowledge and experiences gained in the process. The knowledge has been collected, sorted and ordered by many scientific researches and organizations and therefore been stored decentralized and heterogeneously. We propose a system that enables the collaborative sharing of the knowledge to make it accessible to all participating parties and enrich the knowledge collected leveraging automated ontology-based reasoning methods utilizing semantic annotations of the retrieved data. This is an effective assistance power for communicating with the domain experts.

6 CONCLUSION AND OUTLOOK

The ontology based information model with gained application to the complex 3D print process as a use case is regarded and developed at the Karlsruhe Institute of technology (KIT). So, the heterogeneous knowledge of an industrial process (here the complex 3D print process) can be modelled in a consistent logical network with the power of intelligent reasoning processes. This is supported by a formalized, computer based communication process. The knowledge, hidden in structured tables or lists can be used for logical reasoning processes and to extend the ontology network and the knowledge domain. The computer based representation and visualization for the print knowledge is suitable and necessary for a high performed communication of the experts because they can learn concepts and relations in a semantic network and they can enhance the printing development steps. That means an effective assistance power for communicating with the domain experts. So, for the use case of 3D print processes in terms of intelligent human experiments can be enhanced by a formalized, computer based (intelligent) information management system.

In order to verify the approach for this application scenario both performance and user acceptance have to be tested and the results need to be analyzed for possible improvements. Another consequence of these tests can be a follow-up fine tuning of the models as well as an enrichment or advancement to facilitate the usage in other industrial applications. With the model growing and fine adjustment it could be possible to detect the stable invariants of such an ontology development.

ACKNOWLEDGEMENT

The work presented in this article is supported and financed by Zentrales Innovationsprogramm Mittelstand (ZIM) of the German Federal Ministry of Economics and Energy. The authors would like to thank the project management organization AiF in Berlin for their cooperation, organization and budgeting.

REFERENCES

Adrian, B. (2012). *Information Extraction on the Semantic Web*. doctoralthesis, Technische Universität Kaiserslautern.

Al-Safi, Y. and Vyatkin, V. (2007). An ontology-based reconfiguration agent for intelligent mechatronic systems. In Mařík, V., Vyatkin, V., and Colombo, A. W., editors, *Holonic and Multi-Agent Systems for Manufacturing*, pages 114–126, Berlin, Heidelberg. Springer Berlin Heidelberg.

Banerjee, A., Dalal, R., Mittal, S., and Joshi, K. P. (2017). Generating digital twin models using knowledge graphs for industrial production lines. In *Workshop on Industrial Knowledge Graphs, co-located with the 9th International ACM Web Science Conference 2017*, Troy, NY, USA.

Baumeister, J., Reutelshoefer, J., and Puppe, F. (2011). Engineering intelligent systems on the knowledge formalization continuum. *International Journal of Applied Mathematics and Computer Science*, 21(1):27–39.

Benjamins, V. R., Fensel, D., and Gómez-Pérez, A. (1998). Knowledge management through ontologies. In Reimer, U., editor, *PAKM 98, Practical Aspects of Knowledge Management, Proceedings of the Second International Conference, Basel, Switzerland, October 29-30, 1998*, volume 13 of *CEUR Workshop Proceedings*. CEUR-WS.org.

Buitelaar, P., Cimiano, P., and Magnini, B. (2005). *Ontology Learning from Text: Methods, Evaluation and Applications*. IOS Press.

Furth, S. and Baumeister, J. (2014). TELESUP-Textual Self-Learning Support Systems. In *Proceedings of the LWA 2014, FGWM Workshop, RWTH Aachen University, Aachen, Germany*, volume 1226, pages 277–286.

Kamsu-Foguem, B. and Abanda, F. H. (2015). Experience modeling with graphs encoded knowledge for construction industry. *Computers in Industry*, 70:79 – 88.

Kamsu-Foguem, B. and Noyes, D. (2013). Graph-based reasoning in collaborative knowledge management for industrial maintenance. *Computers in Industry*, 64(8):998 – 1013.

Karthikeyan, K. and Karthikeyani, V. (2015). Ontology based concept hierarchy extraction of web data. *Indian Journal of Science and Technology*, 8(6):536.

Keivanpour, S. and Kadi, D. A. (2018). Strategic eco-design map of the complex products: toward visualisation of the design for environment. *International Journal of Production Research*, 56(24):7296–7312.

Schaffert, S., Bry, F., Baumeister, J., and Kiesel, M. (2007). Semantic wiki. *Informatik-Spektrum*, 30(6):434–439.

Shneiderman, B. (1996). The eyes have it: a task by data type taxonomy for information visualizations. In *Proceedings of the 1996 IEEE Symposium on Visual Languages*, VL '96, pages 336–343, Boulder, CO, USA. IEEE Comput. Soc. Press.

Song, H., Wang, H., Liu, T., Zhang, Q., and Gao, B. (2016). The design and development of manufacturing process knowledge base system based on ontology. In Luo, Y., editor, *Cooperative Design, Visualization, and Engineering - 13th International Conference, CDVE 2016, Sydney, NSW, Australia, October 24-27, 2016, Proceedings*, volume 9929 of *Lecture Notes in Computer Science*, pages 9–16.

Studer, R., Benjamins, V., and Fensel, D. (1998). Knowledge engineering: Principles and methods. *Data & Knowledge Engineering*, 25(1-2):161–197.