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RAFAEL VOLTOLINI

COST ESTIMATION IN INITIAL DEVELOPMENT STAGES OF PRODUCTS - AN ONTOLOGICAL APPROACH

DISSERTATION

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COST ESTIMATION IN INITIAL DEVELOPMENT STAGES OF PRODUCTS - AN ONTOLOGICAL APPROACH

Dissertation presented to the MECHANICAL & MATERIALS ENGINEERING POST-GRADUATE PROGRAM of Federal University of Technology - Paraná (UTFPR) in partial fulfillment of the requirements for the degree of Master in Mechanical Engineering - concentration area: Manufacturing Engineer.

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A Dissertação de Mestrado intitulada**: COST ESTIMATION IN INITIAL DEVELOPMENT STAGES OF PRODUCTS - AN ONTOLOGICAL APPROACH**, defendida em sessão pública pelo Candidato **Rafael Voltolini**, no dia 12 de fevereiro de 2019, foi julgada para a obtenção do título de Mestre em Engenharia, área de concentração: Engenharia de Manufatura, e aprovada em sua forma final, pelo Programa de Pós-Graduação em Engenharia Mecânica e de Materiais – PPGEM.

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Madobe kara yagate tobitatsu

Hotobashiru atsui patosu de

Omoide wo uragiru nara

Kono sora wo daite kagayaku

Shounen yo shinwa ni nare

- *Neon Genesis Evangelion*

RESUMO

VOLTOLINI, Rafael. COST ESTIMATION IN INITIAL DEVELOPMENT STAGES OF PRODUCTS - AN ONTOLOGICAL APPROACH. 109 f. Dissertation – MECHANICAL & MATERIALS ENGINEERING POST-GRADUATE PROGRAM, Federal University of Technology - Paraná (UTFPR). Curitiba, 2019.

Estimativas de custos nas fases iniciais de um produto são repletas de incertezas. O projeto conceitual do desenvolvimento de produto é caracterizado pela ausência de dados, sendo os mais críticos os custos. O impacto dos custos nas fases iniciais do projeto é baixo, quando descobertos em fases posteriores representam grandes riscos. Como não existem meios estruturados de obtenção dos custos no projeto na fase conceitual, o reuso de dados de projetos passados é uma alternativa discutida na literatura. Abordagens de gerenciamento de conhecimento podem buscar dados, inexistentes nas fases atuais, em projetos anteriores bem-sucedidos. O uso de ontologia é discutido como uma abordagem na geração de conhecimento armazenado em um banco de dados. A solução proposta busca estimar custos baseada em projetos anteriores. É formulada uma pergunta que descreva a função do produto e configurações. O modelo ontológico busca na base de dados classes, instâncias e propriedades e gera uma estimativa de custos. Os custos do projeto anterior são reutilizados para gerar uma nova estimativa de custos ágil sem necessidade de consultar outros setores da indústria. Este projeto de dissertação segue o framework metodológico Design Science Research para fazer entregas parciais até a entrega do artefato final, um modelo ontológico. Esta proposta possui grande potencial na indústria, considerando que não existem ferramentas que atendam as fases iniciais com a mesma eficiência.

Palavras-chave: Sistemas especialistas; Ontologia; Estimativa de custos; Desenvolvimento de Produtos

ABSTRACT

VOLTOLINI, Rafael. COST ESTIMATION IN INITIAL DEVELOPMENT STAGES OF PRODUCTS - AN ONTOLOGICAL APPROACH. 109 f. Dissertation – MECHANICAL & MATERIALS ENGINEERING POST-GRADUATE PROGRAM, Federal University of Technology - Paraná (UTFPR). Curitiba, 2019.

Cost estimation in the early stages of a product are fraught with uncertainties. The conceptual design of product development is characterized by the absence of data, the most critical being costs. The costs impact in the initial phases of the project is low, when discovered in later stages represent great risks. As there are no structured alternatives to obtaining costs in the conceptual phase, the reuse of data from past projects is an alternative discussed in the literature. Knowledge management approaches can search for data, nonexistent in the current phases, in successful earlier projects. The use of ontology is discussed as an approach in generating knowledge stored in a database. The proposed solution seeks to estimate costs based on previous projects. A query is formulated to describe the product function and settings. The ontological model searches the classes, instances, and properties in the database and generates a cost estimation. The costs of the previous project are reused to generate a new agile cost estimate without the need to consult other industry sectors. This dissertation project follows the methodological framework Design Science Research to make partial deliveries up to the final artifact, an ontological model. This proposal has great potential in the industry, considering there are no tools attending the initial phases with the same efficiency.

Keywords: Expert Systems; Ontology; Cost Estimation; Product Development

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CAD	Computer-Aided Design
DSR	Design Science Research
DFC	Design for Cost
DTC	Design to Cost
ES	Expert System
GQM	Goal, Questions, Metric
KBE	Knowledge-Based Engineering
NPD	New Product Development
OWL	Ontology Web Language
PD	Product Development
RDF	Resource Description Framework

CONTENTS

1 INTRODUCTION

Industry 4.0 manifests the digital front in efficiency improvement. It is characterized by the machine's autonomous work and application data in real time (HERMANN; PENTEK; OTTO, 2016). Humanity is improving human-machine interaction in order to facilitate machine's communication and capacity to reproduce human decisions (HONG; YIN, 2016). Machines should make decisions even under an uncertain context based on available data.

In industrial context, New Product Development (NPD) is a stage full of uncertainty (NAFISI; WIKTORSSON; RÖSIÖ, 2016). The NPD's deliveries increase competitivity and make the product valuable for the company (DERBYSHIRE; GIOVANNETTI, 2017). Even following a structured pattern to generate ideas, human limited capacities reduce the process' efficiency. The iterative process becomes sluggish and old-fashioned, which can produce not convincing results. The NPD needs to be fast and assertive, besides to avoid mistakes committed in the first attempt (NUNES; PEREIRA; ALVES, 2017). The more close to initial phases, the more uncertainty the NPD will have to handle (KIM, 2017).

The decision makings are unclear to the work team (STINGL; GERALDI, 2017). Without information about the customers' necessities, the company becomes stagnant (WEI et al., 2015). Engineers need to use different approaches to find out the products' requirements at the beginning of the process. Different authors warn about one of the most dangerous uncertainties that a project can handle: costs (GOPALAKRISHNAN et al., 2015).

Niazi et al. (2006) explain that the most part of the final costs are defined in the beginning of the project while decisions are been made. Sales specialists need quickly estimate the costs even with insufficient data. The list can contain components, assemblies, product planning, manufacture, customer's requests, among others. The different types of costs distinguish in Direct, Indirect, Fixed, or Variable. Megliorini (2012) describes Direct Costs as what is directly consumed and Indirect Costs what is allocated in determined criteria. Fixed and Variable Costs are related to independence and dependence of the produced quantity, respectively. Every data influence on cost estimate in an unique way. In order to manage this cluster of information, Zhao, Verhagen and Curran (2015) and Mengoni et al. (2016) present alternatives to cost estimate, but they are dependent of customer's requirements to generate a graphical model. In these approaches, the cost estimates are dependent of information not always available and not instantaneous.

The knowledge management is conducted by specialists that need to save all the collected content (PENG et al., 2017). As the quantity of data exponentially increases, the capacity of management needs to follow it. This industry' process maintain the continuous flow in the development called interoperability (BHATT et al., 2017). With machines generating data in real time, the industry must maintain a database with the originated internal knowledge. When the cost estimation is sent to the customer, it contains registers about requirements, technical reports, product's registers, a representation of the customer's perspectives, and his/her necessities (SAVOLAINEN; AHONEN; RICHARDSON, 2012). All this information represents the acquired experience by the specialists. Even in the absence of a professional, the company has the resources to continue the development process (GÜRDÜR; ASPLUND, 2018). Each cost estimation can continue, independently of company situation. This implicit knowledge stored in specialists' mind needs to become explicit so it can be used by the work team (MUTHAMILSELVAN; BALAMURUGAN, 2017).

Zhao, Verhagen and Curran (2015) present the concept of a specialist system as the human experience translated into an artificial language in order to reuse information and to construct knowledge. It means that the company can reuse data under the same domain to create knowledge and to reduce the NPD's stages dependence. All human experience kept in History has been used by industry. It is an opportunity to increase knowledge based on data reuse and to overcome the comprehension about the theme. Even professionals which are not considered specialists can assume a high level of understanding about a determined domain (QUINTANA-AMATE et al., 2017).

The premise is to express natural language into artificial language (CAMBRIA; WHITE, 2014). Questions made in artificial language can be understood by the machines and it can result in knowledge. This condition satisfied, the cost estimate can be based on previous projects, considering any data that the company has, such as customer's satisfaction, configurations of the project, or similarities of the requirements (HOOSHMAND; KÖHLER; KORFF-KRUMM, 2016). Therefore, an opportunity to address the initial stages of product development is recognized. There is a information gap in the conceptual phase where the analysis is complex (PAHL et al., 2007). The customer's requirements can be no more primordial to the cost estimate. The specialist system reproduces the last requirements based on the previous assertives (BAXTER et al., 2008).

Following these premises, NPD later stages are apart from the domain of this research, considering that exist adequate tools to deal with them. This research covers the domain of costs into an industrial environment using artificial language, a language created by humans, to deal with the information gap that other approaches do not answer. Observing this context, this research seeks to answer the following research question: How can one estimate the costs with uncertainties reusing knowledge with an approach of specialist system in NPD?

1.1 GENERAL OBJECTIVE

The general objective of this research is to develop an artifact composed by a specialist system considering an ontological approach. The artifact must be adequate in order to estimate costs in NPD's initial stages and to handle uncertainties of the conceptual project.

The solution proposed in this dissertation should help the developer of products in the initial stages when the client has uncertain requirements. The formal Ontology Web Language (OWL) is used to address the cost domain in the NPD of an overhead crane. The case study is an artificial simulation using the Protégé ontology editor.

1.1.1 SPECIFIC OBJECTIVES

To achieve the proposed general objective, the study should address the following specific objectives:

1. Identification of research opportunities discovered in literature analysis
2. Determination of approaches directed to cost domain
3. Development of the artifact through an ontological approach
4. Demonstration of the industrial context applicability
5. Artifact evaluation according multiple approaches

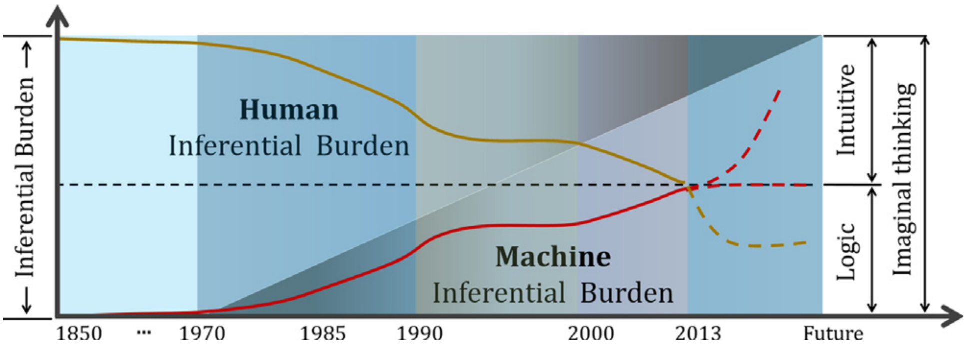
1.2 JUSTIFICATION

Industries are upgrading to accelerate the product development process (SANTOS et al., 2017b). Most of the benefits are in intelligent systems and artificial intelligence. Large companies, like Autodesk (ABANDA; KAMSU-FOGUEM; TAH, 2017) and Dassault Systemes (GE et al., 2017), use semantic language to integrate technologies. In the context of product development, few software alternatives are available.

LeanCOST estimates the costs considering CAD model of the product and the company's industrial process (MENGONI et al., 2016). Computer-Aided Design (CAD) tools as Inventor and SolidWorks are not specific for this purpose, but they have features to support cost management (JIANMEI, 2016). In common, all the features require the three-dimensional model. In the early stages, there is no awareness about an artifact that can assist in cost estimation without the CAD model. Without the requirements definition and with all the uncertainties, the industry needs support to improve the interoperability. Trokanas and Cecelja (2016) emphasize the use of ontology as an alternative to deal with these constraints.

Figure 1 shows that human work on projects is decreasing, in contrast to the functions performed by machines in the process of project automation. Yin et al. (2015) describes that humans and machines are not able to perform individual tasks efficiently, but when they join efforts the result is motivating. With the help of knowledge management technologies such as ontology, humans began to focus on management, optimization, target setting, and decision-making activities, leaving the tedious and repetitive logic work to the digital platforms.

Figure 1: Brief history of automating design



Source: Yin et al. (2015)

The ontological approach is described as an alternative to reuse the knowledge of previous projects and handle lots of information. The cost area is complex in the initial stages and is a challenge for the NPD. There are few studies on this subject. Therefore, an ontological model is proposed to help in cost estimates in the initial phases. The model will assist in complex analysis of data at different levels of expertise.

The relevance of this research is to propose an artifact with benefits in industry and in academia. The ontological approach collaborates with cost estimation in the initial stages before the application of CAD tools. There are no references to dealing with costs at such initial stages, which represents an important step in the scientific community. The research opens up possibilities for future studies using ontology in different case studies, in different domains or even including hybrid approaches.

1.3 RESEARCH STRUCTURE

This research is structured in five chapters. In the first chapter, there is a problem of contextualization that will be investigated, the objectives to be achieved, and the development justification. The research covers the cost domain in the cost estimate of an overhead crane. The following chapter presents the theoretical basis necessary for the understanding of the proposed work. Chapter three describes the methodological aspects with a detailed description of all the steps and a timeline of the research.

Afterward, the results achieved are presented and discussed. The presented cost estimate addresses the industrial context, precisely in the initial stages of the NPD if there is prior knowledge to be reused. Different products and real application of the demonstration are out of scope considering that this research is still an artifact prototype. This is an academic research with a structured ontology simulating a scenario. The ontology works as an initial stage to be completed with instances and classes under the representation of the domain. Finally, chapter five presents the final considerations and conclusions about the research project.

2 THEORETICAL FRAMEWORK

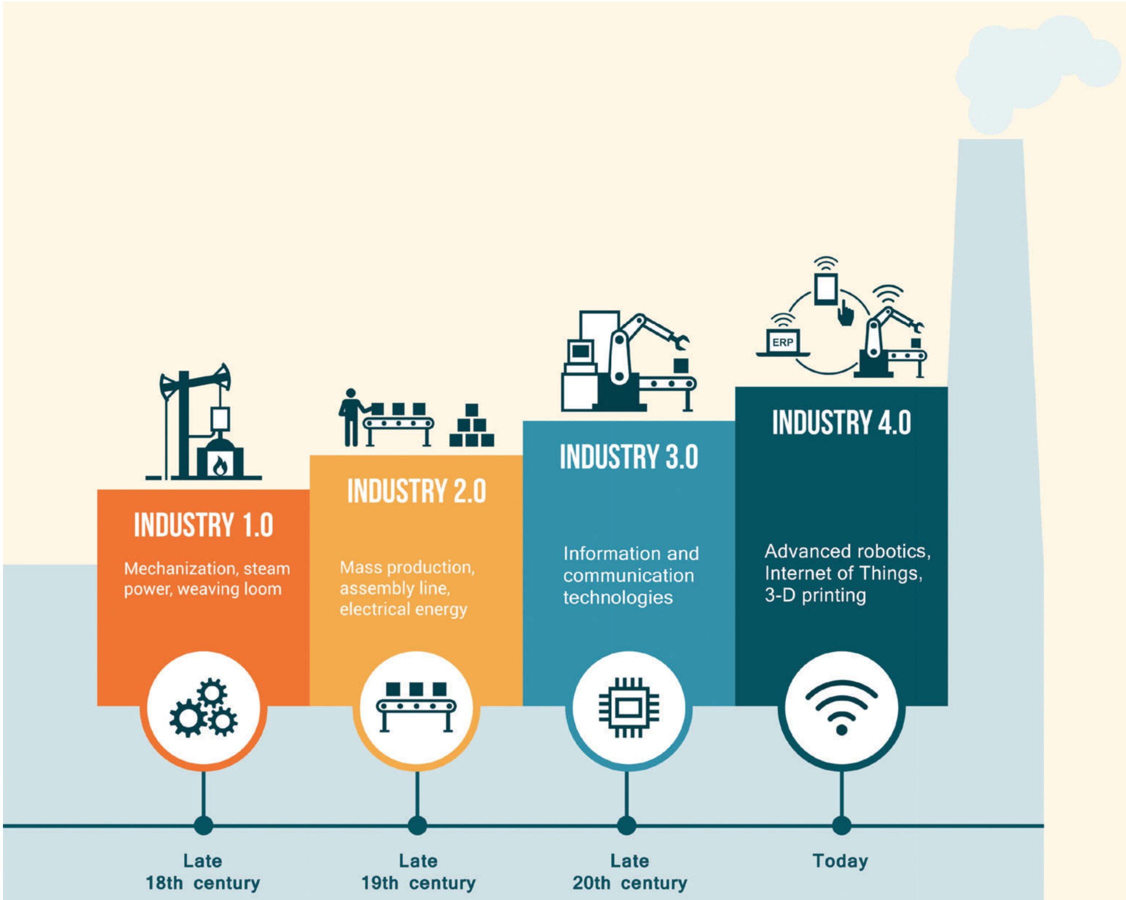
In this chapter, the concepts used in the research are presented. The industrial context presents opportunities to continuously improve the process in the cost domain. Knowledge management is the key to deal with so many information in Product Development (PD). Artificial Intelligence (AI) is highlighted with the ontological approach to deal with uncertainties in the ES developed.

2.1 INDUSTRY 4.0

Hermann, Pentek and Otto (2016) describe Industry 4.0 as a priority on several fronts of research, it cannot be avoided. It enables people, machines, and resources to communicate in a decentralized production process so that humans can make problem-solving decisions as soon as possible. The basic principle is to connect machines to the workflow by intelligent connections in an autonomous production chain. It is intended to collect and apply real-time data with the connection of individual elements in the reduction of complexity of operations while increasing efficiency and reducing the final cost (LÖFFLER; TSCHIESNER, 2013). In the industrial field, the concept arises from the link between semantic web and intelligent solutions such as AI, fuzzy front-end, ontology and other approaches from knowledge management (ZHONG et al., 2017). Yin et al. (2015) indicate ontology-based knowledge management as a solution to intelligent human-machine integration in project automation.

The industrial evolution is presented in Figure 2 until nowadays. Each century is marked by specific changes in the industry. What motivates the evolution is the reduction of costs and process time. In Industry 1.0, the objective was to accelerate the movement, with costs reasons. In Industry 4.0 the target is the optimization of industrial manufacturing (NUNES; PEREIRA; ALVES, 2017). All companies are trying to aggregate technological resources in the process to generate smart products. This era represents a digital evolution due to the tools and approaches used in the technological advancements. Zhong et al. (2017) describe the use of AI in manufacturing systems to solve problems. As the company optimizes itself with digital technologies, the smart factories also include the benefits to higher the quality and reduce PD process.

Figure 2: Industrial revolutions shifts



Source: Adapted from Hallward-Driemeier and Nayyar (2017)

Wortmann, Combemale and Barais (2017) report expectations with model-based systems engineering to reduce costs with the integration of production systems in the industry. The reduction can be in different ways: time reduction (of development, time-to-market) and cost reduction (of development, integration, (re) configuration).

The raised concept of industry 4.0 is directly linked to factories, products, and intelligent services. The link between the fourth industrial revolution and PD is precisely this integration of physical and digital technologies, such as the use of AI tools in PD analyzes. The product launch in the market and the time of development are optimized by identification of problems in a shorter time (SANTOS et al., 2017a).

2.2 INTEROPERABILITY

The manufacture industry is always changing to follow the market needs. Industry 4.0 goes beyond and allow the flexibility and adaptability (PEDONE; MEZGÁR, 2018). It means the industry having the capacity to communicate, sharing data between humans and machines continuously. Even in situations where some intersperses appear the system continues to work. Castañé et al. (2018) described interoperability in the context of ontology to corroborate with intelligent decisions. The approach acts supporting the mechanism influencing the semantic interoperability increasing the abstraction at the same time it connects all structure.

Gürdür and Asplund (2018) develop a review to define interoperability as the ability for the system to work with different systems with less or none efforts from the user. In sharing context, is the ability to exchange and use exchanged data from the network. The network can be internal or networking between companies, with technology and semantic information. Mykkänen and Tuomainen (2008) add the definition of data interoperability as the ability of data to be accessed, reusable and comprehensible by all. It means either human-machine or machine-machine exchanging documents and digital resources.

Experts in your knowledge area, with or without industry and market experience, must deal in an agile and assertive manner with the challenges that unexpectedly appear. Uncertainties and lack of knowledge in the initial stages of a PD may represent a risk for the project, finishing its development at the beginning (KHODAKARAMI; ABDI, 2014). With the use of evolution, the instrument tends to increase the interoperability, making it continuously refined and intelligent, increasing its power of applicability (FORTINEAU; PAVIOT; LAMOURI, 2013). A collaborative approach in engineering is adopted between human and machine working together with. The idea is to aggregate different tools and techniques of analysis and simulation in NPD with computational support and knowledge sharing (BORSATO; PERUZZINI, 2015).

2.3 KNOWLEDGE MANAGEMENT

Chryssolouris et al. (2008) present the knowledge management concept as practices and techniques to identify, represent and share information. It can be characterized as knowledge or expertize used by companies to inform, reuse and transfer knowledge. Pahl et al. (2007) highlight the importance of converting data to information, and then in knowledge.

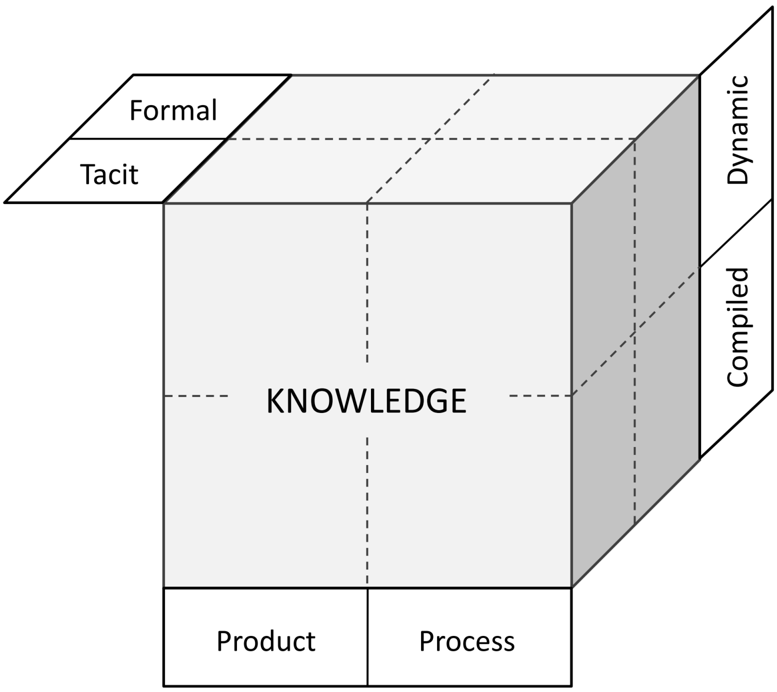
There are different types of knowledge inside the industrial field. All activities that use engineer experience produces knowledge in different disciplines in design process (YOSHIMURA et al., 2006). With so many extents of knowledge, the companies have difficulties to manage all data; it is spent time just searching for it. Papakostas et al. (2010) affirm that 40% of information is identified personally in databases by specialists. All data stored is lost because the user can’t find it appropriately.

The companies, seeking interoperability, are trying to use systems to manage the knowledge. Efthymiou et al. (2015) present the use of ontological approaches to work with knowledge representations and reuse of knowledge. The main objective of using ontologies is to capture, store and reuse knowledge. Past projects have data to be captured and stored in repositories. Reuse of knowledge represents the reasoning of semantic data by the ontology.

In the steps expressed described by Pahl et al. (2007) the engineer is able to establish relations and generate information based on data found in customers' requirements, their creativity, in information sharing and available manufacturing process. Knowledge is acquired by experience and continuous learning throughout the NDP, as the proposals are put into practice (OWEN; HORVÁTH, 2002). For the context of intelligent engineering systems, Sriram and Logcher (2002) describe knowledge as the intelligence being used in problem-solving.

Knowledge can be classified, according to Figure 3, in i) formal vs. tacit, ii) product vs. process e iii) compiled vs. dynamic.

Figure 3: Classification of knowledge



Source: Chandrasegaran et al. (2013)

Owen and Horváth (2002) describe formal knowledge is found in product documents, repositories, product functions, computer algorithms, intelligent knowledge systems, among others. Otherwise, tacit knowledge is expressed as user experience, non-articulated models, or implicit rules. This knowledge is characterized by the intellectual of the designer, unique, which over time evolves and builds the wisdom of that professional. The initiative of the user is the only way to transfer this personal knowledge and if the designer leaves the team all information is lost.

Candlot et al. (2008) define product knowledge as the union of information associated throughout the product life cycle, such as requirements, relations between parts and assemblies, geometries, functions, and design rationale. Process knowledge is the methods used to develop product detailing.

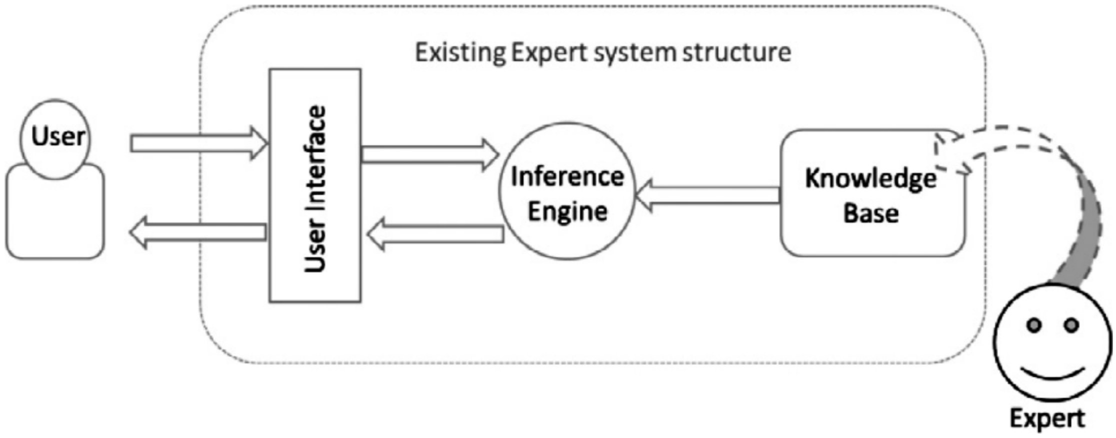
Sriram (1997) characterizes the knowledge compiled as one acquired with experience and explicit into rules. Dynamic knowledge is not covered by compiled knowledge, so it generates additional implicit knowledge. It can be expressed by common sense reasoning, theories of approximation in qualitative form and in terms of compatibility, numerical techniques at a quantitative level.

It is important to differentiate the type of knowledge, explicit and implicit. Alavi and Leidner (2001) describe explicit knowledge appear in reports or manuals. They are already encoded to express the content in a natural language form. Implicit knowledge is mental maps, viewpoints, beliefs and skills developed in a certain domain along the life.

Formalizing the knowledge representation, Candia et al. (2016) describe Knowledge-Based Engineering (KBE) to seek the capture, maintenance, reuse and regeneration of intellectual capital. Zhao, Verhagen and Curran (2015) refer to the use of KBE as the systematic capture and reuse of knowledge. The knowledge reuse objective is to avoid wasting time with activities that already have been done previously, in the same or different project. These repetitive activities increase the project costs and time and exclude creativity in tasks.

Hussain et al. (2015) clarify the use of an ES to solve complex problems. Human knowledge solving problems by rules and data. It comprises, as shown in Figure 4, a knowledge base, inference engine and an interface with the user to solve problems through reasoning based in rules. An expert provides the comprehension about an issue to a knowledge engineer. Then it built an inference engine to deal with complex issues. The user is who uses the system benefit by a framework for example.

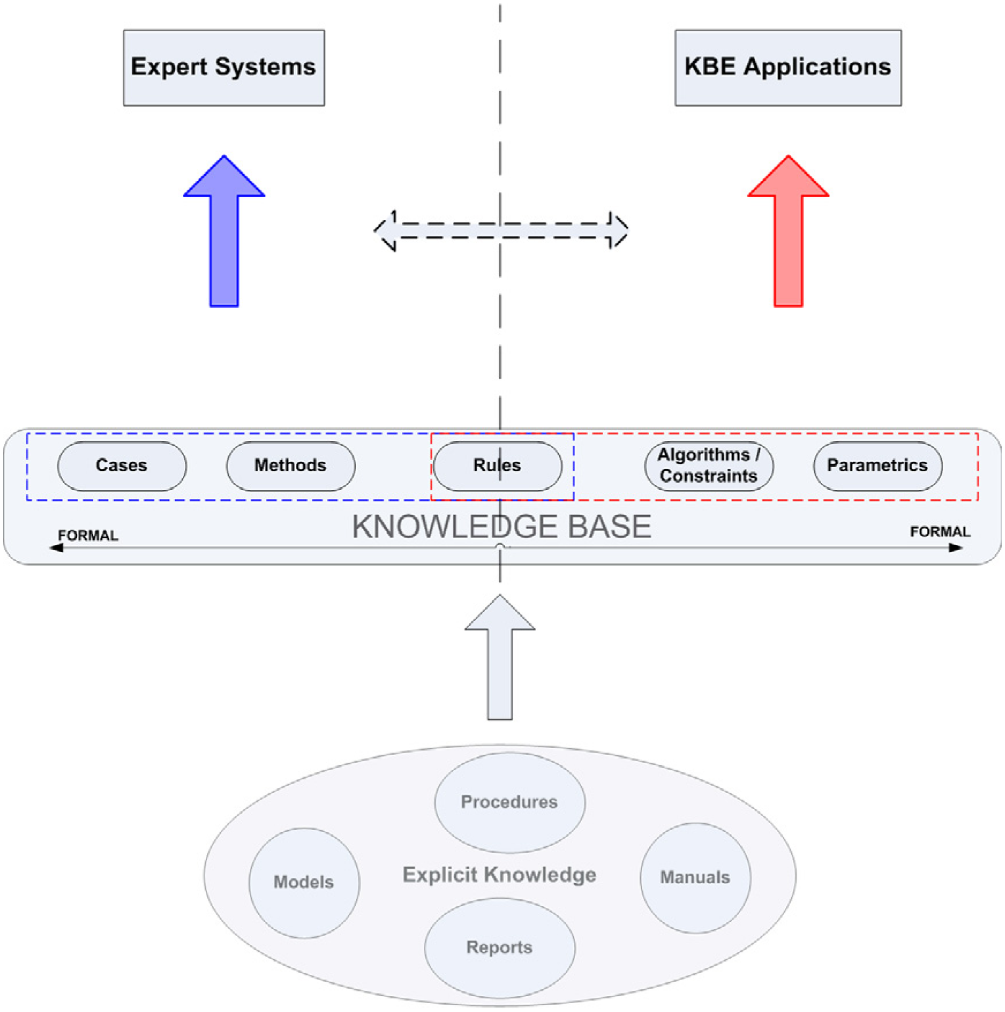
Figure 4: Conventional ES



Source: Hussain et al. (2015)

There are differences between ES and KBE applications as Curran et al. (2010) expose. An ES is used to support the end user based on past information. It is an interaction human-machine to collect explicit knowledge. KBE is specialized in capturing and reuse the engineering knowledge to reduce time and costs. Usually, a dedicated software is used to develop to avoid repetitive tasks and support multidisciplinary integration to be assertive since the first tentative. Figure 5 presents some examples of explicit knowledge feeding the knowledge base. There are some formal alternatives to create an ES and KBE application, they share the basis but evaluate to different approaches. It is important to define what type of knowledge is intended to create and choose the right side.

Figure 5: Knowledge-based systems application



Source: Curran et al. (2010)

In order to avoid loss of information in future projects, Relich (2016) suggests gathering tacit knowledge from experts, storing and generating solutions. Knowledge management is presented described by KBE as a way to manage implicit knowledge and make it explicit for reuse and search for solutions (QUINTANA-AMATE; BERMELL-GARCIA; TIWARI, 2015).

According to Rush and Roy (2000), learning from past cases improves future skills and using AI for the adequacy of modeling, storage, and reuse of data (gathered from the knowledge capture with the goal of solving problems) is considered a proper approach.

2.4 ARTIFICIAL INTELLIGENCE

Russel and Norvig (2010) define AI as the use of computer simulating the human's behavior with intelligence. It is the ability of the artificial agent to achieve goals. Horowitz

(2018) explain AI as ES and production rules allowing the machine, after considering parameters established by a human expert, to deduce behavior or a statement.

In the multidisciplinary context, knowledge can still be expressed by computational techniques involving logic and ontologies, such as the use of AI in research representations (SOWA, 2000). Chandrasegaran et al. (2013) express concepts sketches, principles of solution and ontologies representing a symbolic form of knowledge as representations of knowledge in the initial phases of the project.

2.4.1 ONTOLOGY

An ontology is the explicit specification of a conceptualization, an abstract, simplified view of the world represented (GRUBER, 1993). Since conceptualization is something abstract, could be a simplified form of the world being represented (GENESERETH; NILSSON, 1987). For Borst (1997), ontology is the formal specification of shared conceptualization and collaborates with researchers in defining a vocabulary common to the scientific community within a given domain.

Ontology is an object of AI used as a conceptual tool in knowledge modeling (GIL; MARTIN-BAUTISTA, 2012). It provides a vocabulary and semantics to enable the processing of knowledge within the specified domain. In this way, the concepts are interconnected according to the definitions indicated by the artifact. For AI everything existing in the real world can be represented (GRUBER, 1995).

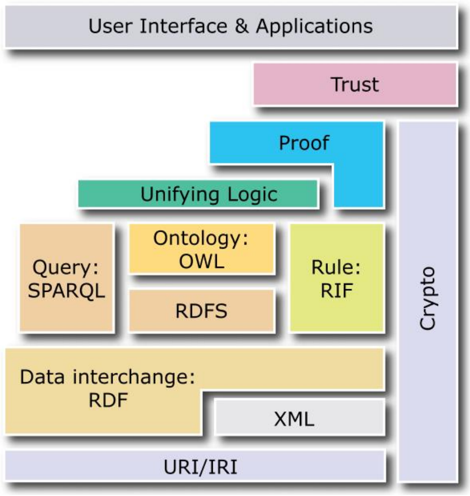
For Monticolo et al. (2014), the ontology provides a vocabulary and semantics that enable processing of knowledge in a given domain and indicates how concepts are connected to each other in a formal way. In this context, ontological approaches are characterized as a form of capturing knowledge, storing, generating solutions and reusing knowledge (SANYA; SHEHAB, 2015). It is a method of making the process flexible and responsive to market demands and customer requirements (EFTHYMIOU et al., 2015).

Noy and McGuinness (2001) define factors to motivate the development of ontologies, they are: i) knowledge sharing, ii) knowledge reuse, iii) making the domain referred explicitly, and iv) knowledge analysis. Noy and McGuinness (2001) also describe ontology as an explicit form of concepts within the domain introduced as classes; properties of concepts (describing functions and attributes); and property constraints. Thus, in order to develop an ontology, it is necessary to define classes, organize their taxonomy (i.e. class hierarchy), define slots (and values for them), and fill those values with instances. Class is the concept description in the domain; to describe a class there are slots presented as properties describing features and attributes of the concept; and instances are the knowledge base defined by the class.

For Pinto and Martins (2004) ontologies promote and facilitate the interoperability between information systems, intelligent processing, information sharing, and knowledge reuse. Several benefits can arise from the use of ontologies in the development of products. Since the formal language is used to express knowledge and be understood by the machine, therefore, natural language cannot be considered.

In practice, the ontology must be formally expressed by a language. The OWL, based on Resource Description Framework (RDF), is the one that stands out (BAADER; HORROCKS; SATTLER, 2009). The RDF language is widely used in the semantic web because of its data model. But it alone does not translate the understood representations of the web, being required other languages like Dublin Core and OWL (PAN, 2009). Figure 6 indicates the layers of the ontology vocabulary (OWL) upon the RDF layer, because OWL provides a greater detail in ontologies, a greater vocabulary in the description of properties and classes, and makes it a more robust and adequate semantic web (MCGUINNES; HARMELEN, 2004).

Figure 6: Semantic web layer cake



Source: Berners-Lee and Fischetti (1999)

Antoniou and Harmelen (2009) describe tools to be used during the development of ontologies to support in OWL language, these ontology editors used could be the Protégé, Swoop, etc. Protégé has been adopted as the default editor because of all tools offered and tutorials available on the web making the user's life easier. Its interface is customizable and supports different formal languages. Its architecture is modular and has several plug-ins that make it capable of integrating other applications (GENNARI et al., 2003). In Protégé ontology editor there are reasoners (i.e., inference machines) who manipulate knowledge in order to result in combinations, conclusions, and thus generate new knowledge (AKERKAR; SAJJA, 2010).

Reasoners can be applied at different stages of development. During the design can be applied to check the concepts, whether they are contradictory or if they actually represent the desired relations (BAADER; HORROCKS; SATTLER, 2009).

Some of the applications that stand out in the use of ontologies are the search systems (queries) that can be used in the semantic web in a collaborative and interactive way with different ontologies (KOLLIA; GLIMM; HORROCKS, 2011). According to Vrandecic (2009), queries are questions of competence that a specialist can submit to a knowledge base related to the domain.

But is important to beware about understanding the difference between a database and an ontology to find the results expected (SIR; BRADAC; FIEDLER, 2015). A database contains data and can extract exactly what contains inside. If the question asks for what is the cost of some object, the answer will be the value, a numeric answer. The statement will be true if what is known is true. Differently, inside the ontology, the answer can be true or can be unknown. It depends if what is questioned is well defined and how the query is made. The ontology returns or a statement or an answer considering that is not possible to affirm based on the semantics available. The ontology can return the right answer, the wrong one and also the statement of missing information in the query. If the approach is abstract as a product development, the answers can vary and.

2.4.1.1 PROTÉGÉ

The ontology editor Protégé is an open-source platform to construct and edit domain models and knowledge-based applications with ontologies being developed at Stanford University. It provides a graphic user interface to define ontologies using the main language OWL (PROTÉGÉ, 2018).

To find information from a databases the RDF data model makes statements about the resources expressions. The triples compound by subject-predicate-object are the main structure. SPARQL it is a semantic query language for databases to retrieve data stored in RDF format.

Presenting the query, the first part is the prefix to declare the scheme used in the query. Then, to consult the content, it are used SELECT, FROM and WHERE. SELECT is used to identify which values will return from the query. FROM to identify the data sources consulted. WHERE means the identification of triples in the RDF basis. The query pattern WHERE specifies what to query for in the underlying dataset. Then, the query modifiers slice, order and rearrange the query results (W3C, 2018).

2.4.2 ONTOLOGY EVALUATION

The ontology evaluation process can be defined as a comparison in the quality of some specific criterion in a particular application (ALM et al., 2013). In this sense, the ontology is understood as a specification in the similarity with the domain, where evaluation is the rule that measures this distance between concept and reality (GÓMEZ-PÉREZ, 2004).

There are several alternatives to evaluate an ontology, to check if it does well what it promises. But Noy and McGuinness (2001) emphasize there is no one correct way to model a domain, each developer will create a different ontology. As the process is iterative, maybe more tentative are necessary to achieve the objective intended. Hlomani and Stacey (2014) define the ontology evaluation as the process to decide the quality in particular criterions. Table 1 bring primary ideas about the ontology evaluation in general context that collaborate with the understanding.

Table 1: Questions in ontology evaluation

Question	Answer
What do an evaluation and assessment mean?	Evaluation means to judge technically and assessment refers to the usability and utility.
What can be evaluated?	A set of definitions, documentation and the environment.
Why evaluate?	To guarantee to end users the correctness and completeness of the ontologies definition, documentation and operation.
What to evaluate against?	A frame of references. It can be a set of competency questions, requirements and the real world.
When to evaluate?	It is an iterative process that should be performed during each phase and between phases of the development. The goal is to detect as soon as possible wrong, incomplete or missed definitions.
How to evaluate?	Using standard techniques.
Who evaluates?	The development team, others development teams, and the end user can evaluate different features of the ontology.
Where to evaluate?	Anywhere, in the lab (technical evaluation) or at the end user location (assessment).

Source: Adapted from Gomez-Perez (1994)

According to Vrandecic (2009), the validation process of the ontology reflects how well it is built, if it actually presents a model of reality. Based on the literature, it establishes criteria that characterize how good the ontology is. Table 2 presents a collapse of important criterions based on the literature.

Table 2: Quality criteria description

Criteria	Quality questions
Accuracy	Do the axioms comply with the expertise of one or more users? Does the ontology capture and represent correctly aspects of the real world?
Adaptability	Does the ontology anticipate its uses? Does it offer a conceptual foundation for a range of anticipated tasks? How does the ontology react to small changes in the axioms? Does the ontology comply with procedures for extension, integration, and adaptation?
Clarity	Does the ontology communicate effectively the intended meaning of the defined terms? Are the definitions objective and independent of context?
Completeness	Is the domain of interest appropriately covered? Are competency questions defined? Can the ontology answer them? Does the ontology include all relevant concepts and their lexical representations?
Computational efficiency	How easy and successful can reasoners process the ontology? How fast can the reasoning services be applied to the ontology?
Conciseness	Does the ontology include irrelevant axioms with regards to the domain to be covered? Does it include redundant axioms?
Consistency	Do the axioms lead to contradictions? Does the translation from the knowledge level to the encoding show a minimal encoding bias? Are any representation choices made purely for the convenience of notation or implementation?
Organizational fitness	Is the ontology easily deployed within the organization? Do ontology-based tools within the organization put constraints upon the ontology? Was the proper process for creating the ontology used? Does it align with other ontologies already in use? Is it well shared among potential stakeholders?

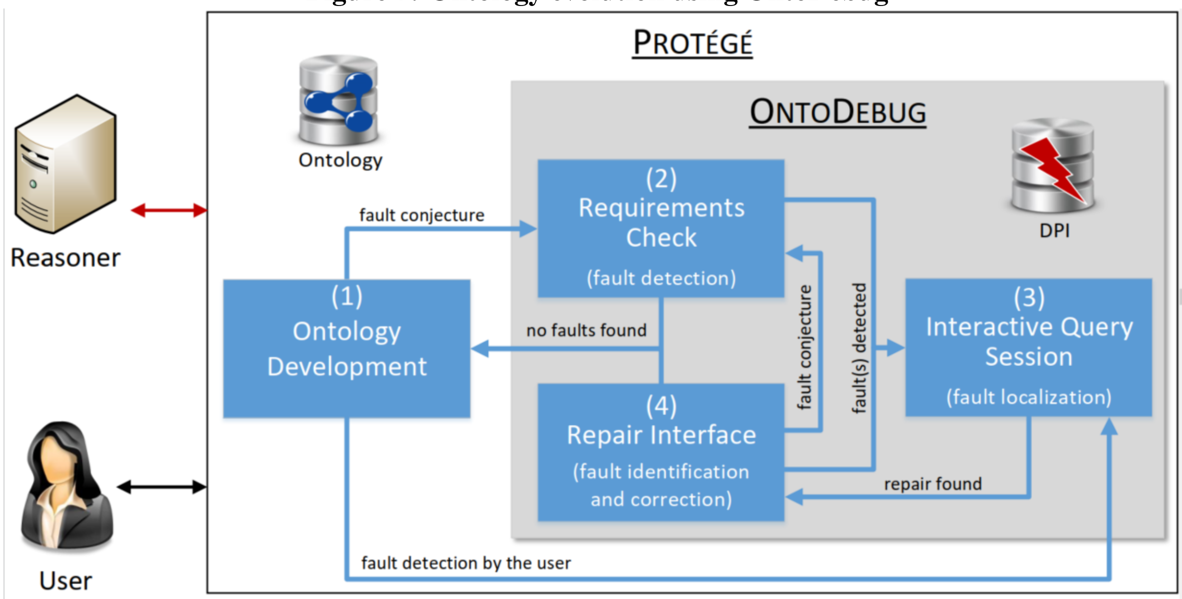
Source: Vrandecic (2009)

After exposing some metrics about what can be evaluated in an ontology, different approaches were adopted to fortify the evaluation and obtain the best result in less time. Poveda-Villalón, Gómez-Pérez and Suárez-Figueroa (2014) show different approaches to evaluate an ontology: a generic quality evaluation framework; evaluation depending on its final use; quality models based on features, criteria, and metrics; and methods for pattern-based evaluation. But independently the choices, it is important to remember a quality is not totally guaranteed because each ontology is different and vary by the ontologist with your own wide range difficulties on the context of use.

2.4.2.1 ONTODEBUG

OntoDebug is a debugger plugin for Protégé. Figure 7 presents the tool stages. The is used during the ontology development and supports the analysis detecting the faults. It allows the fault localization by using queries. The plugin itself allow the user to query and to verify statements. After detected, the repair interface helps in the correction. When a class is not well defined, for example, debugger supports the identification, incoherence and inconsistency with the axioms. The fault can be a misunderstood of the concept and do not describe it correctly.

Figure 7: Ontology evolution using OntoDebug

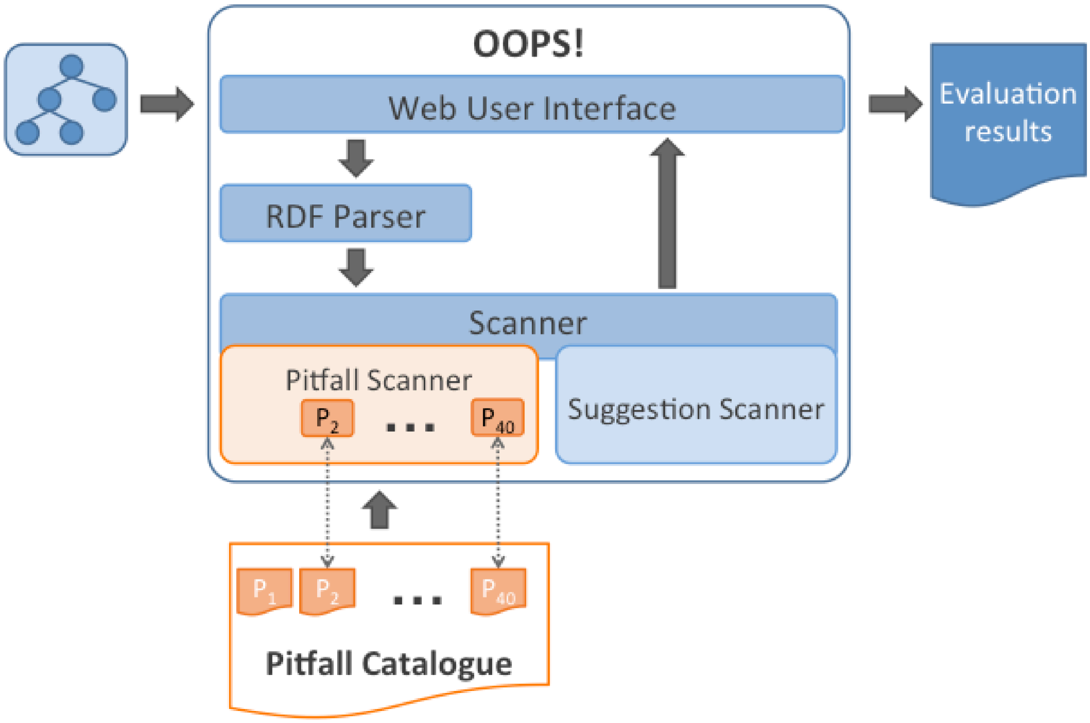


Source: Schekotihin, Rodler and Schmid (2018)

2.4.2.2 OOPS!

OOPS! is an ontology pitfall scanner, a tool to evaluate the ontology for free presented by Poveda-Villalón, Gómez-Pérez and Suárez-Figueroa (2014). It works as systems pointing some errors called pitfalls following the structure represented in Figure 8. It is not a checklist, the developer inserts the RDF code in the website and runs the evaluation. According to the pitfalls incorporated in the tool, the result highlights what have to be changed varying levels as critical, important and minor. In total, exist 40 pitfalls distributed in a structural pattern, lexical content and specific characteristics.

Figure 8: OOPS! architecture



Source: Poveda-Villalón, Gómez-Pérez and Suárez-Figueroa (2014)

2.4.2.3 FOCA

In a structured way, Bandeira et al. (2016) present FOCA, an ontology evaluation methodology. The first stage is the definition of the ontology type, the second step makes use of the GQM approach and, in the third step, the quality of the ontology is calculated. The verification of the ontology type follows according to Guarino (1998) with the following variations: i) Top-level Ontologies (general concepts such as space, time, love, etc., independent of a given problem or domain), ii) Domain Ontologies and Task Ontologies (general domain such as medication, cars, or generic tasks such as diagnosis for medicine) and iii) Application Ontologies (dependent concepts of a given domain and task). In the questions of the GQM approach, developed by Basili (1992), the objectives are defined and refined with the help of questions to extract information from the models. Simultaneously this procedure defines a metric in the interpretation structure. In the quality verification stage, the evaluator checks the questions of the second stage and calculates the corresponding notes, followed by the ontology quality according to the regression model proposed by Ferrari and Cribari-Neto (2004). In order to create the quality criteria for the evaluation, the following authors were considered: Gangemi et al. (2006), Gómez-Pérez (2001), Gruber (1995), Hlomani and Stacey (2014), Obrst et al. (2007) and Vrandecic (2009).

The methodology approaches roles of knowledge representation discussed by Davis, Shrobe and Szolovits (1993) presented in Figure 9. Each question is presented with the justification to clarify.

Figure 9: The GQM justification of FOCA Methodology

Correspondent Role	Question	Justification
Substitute	Q1	This question addresses the document which contains the competency questions, the main terms and the objectives of the ontology.
Substitute	Q2	This question addresses the verification of the coherence between the documentation which contains the competency questions, the main terms and the objectives of the ontology with the model.
Substitute	Q3	This question addresses reusing existing concepts to model the real world.
Ontological Commitments	Q4	This question addresses choosing the best representation for a specific domain.
Ontological Commitments	Q4	This question addresses choosing the best representation for a more abstract domain.
Ontological Commitments	Q6	This question addresses verifying the coherence with the real world.
Intelligent Reasoning	Q7	This question addresses verifying a correct reasoning of ontology
Intelligent Reasoning	Q8	This question addresses verifying a correct reasoning of ontology.
Efficient Computation	Q9	This question addresses a good computational performance (successful).
Efficient Computation	Q10	This question addresses a good computational performance (speed).
Human Expression	Q11	addresses the easy understanding of the modeling.
Human Expression	Q12	This question addresses the easy understanding of modeling.
Human Expression	Q13	This question addresses the easy understanding of the modeling.

Source: Bandeira et al. (2016)

The questions were defined considering the GQM approach and the metrics are based on evaluation criteria proposed by Vrandecic (2009). FOCA born from the relation between the questions, roles (organized in goals) and the GQM structure (representing the criteria in the metric column) as presented in Figure 10.

Figure 10: The GQM goals of FOCA Methodology

Goal	Question	Metric
1. Check if the ontology complies with Substitute.	Q1. Were the competency questions defined?	1. Completeness.
	Q2. Were the competency questions answered?	1. Completeness.
	Q3. Did the ontology reuse other ontologies?	2. Adaptability.
2. Check if the ontology complies Ontological Commitments.	Q4. Did the ontology impose a minimal ontological commitment?	3. Conciseness.
	Q5. Did the ontology impose a maximum ontological commitment?	3. Conciseness.
	Q6. Are the ontology properties coherent with the domain?	4. Consistency.
3. Check if the ontology complies with Intelligent Reasoning	Q7. Are there contradictory axioms?	4. Consistency.
	Q8. Are there redundant axioms?	3. Conciseness.
4. Check if the ontology complies Efficient Computation	Q9. Did the reasoner bring modelling errors?	5. Computational efficiency.
	Q10. Did the reasoner perform quickly?	5. Computational efficiency.
5. Check if the ontology complies with Human Expression.	Q11. Is the documentation consistent with modelling?	6. Clarity.
	Q12. Were the concepts well written?	6. Clarity.
	Q13. Are there annotations in the ontology that show the definitions of the concepts?	6. Clarity.

Source: Bandeira et al. (2016)

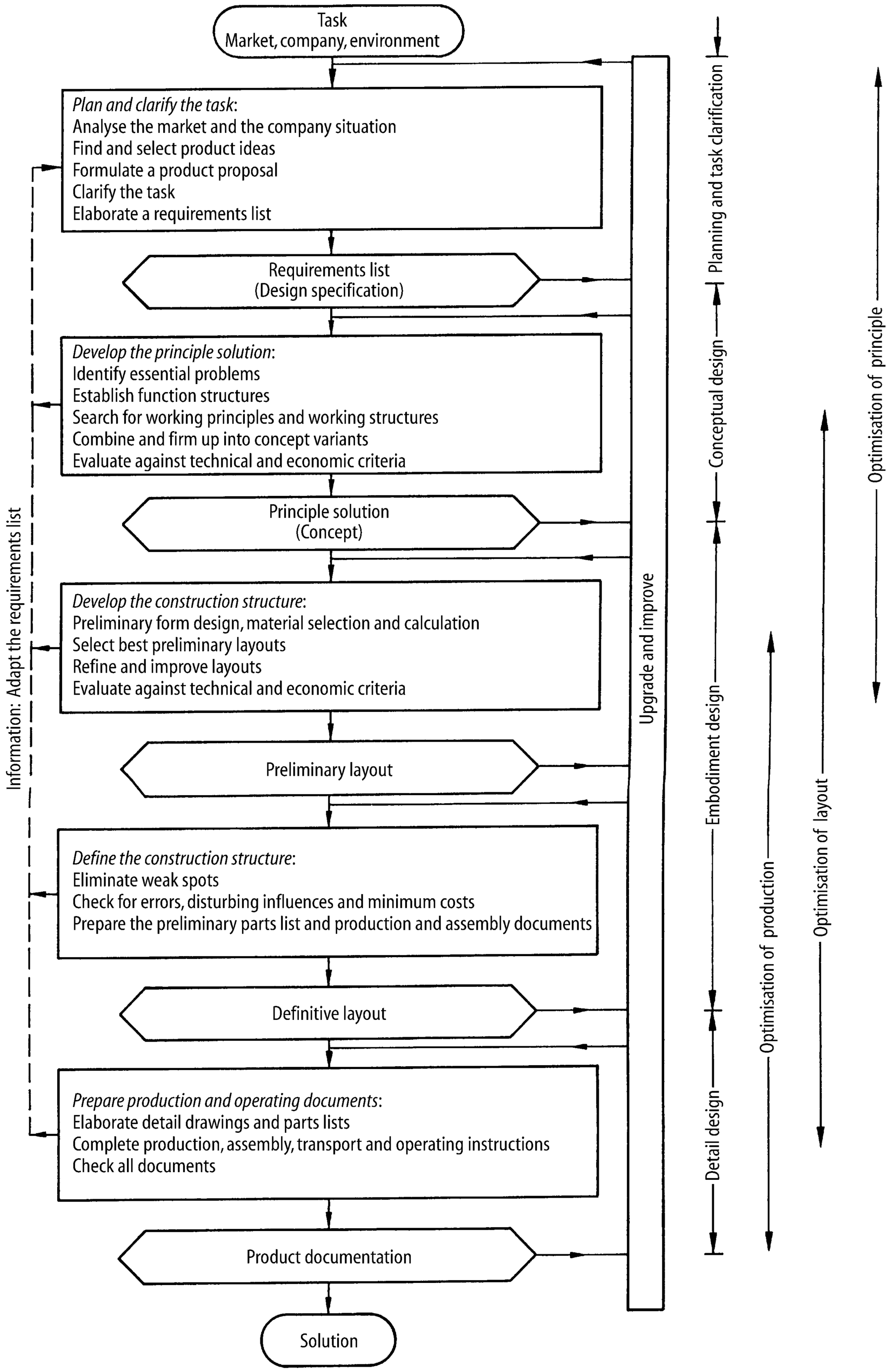
2.5 PRODUCT DEVELOPMENT

The NPD process can be defined as a set of activities aiming to develop the product from the design specifications (ULRICH, 2003). Market needs, the manufacturing process, technological constraints, and other factors are analyzed. The goal is to integrate engineering and industry in a structured way, where the requirements of the project are aimed at reducing costs, improving quality and shorter development time (NAFISI; WIKTORSSON; RÖSIÖ, 2016).

The model proposed by Pahl et al. (2007) is a planning and design process. It can be characterized as interdisciplinary and compound by different phases, where it develops a principle of solution (i.e. a formalization of the mental concept) and seeks to generate a production item. Other alternatives should be considered, such as Ulrich (2003), Cooper (2006) or Rozenfeld et al. (2006), considering that all models present guidelines and proposals for the designer to express their creativity.

The PD can be structured in 4 steps according to the model proposed by Pahl et al. (2007) in Figure 11. First, i) planning and task clarification results in the specification of project information, a document with a list of requirements planned for the given product, considering customer requirements, manufacturing process, and other guidelines relevant to PD. Then, ii) conceptual design is the phase where the main solutions will meet the requirements and origin a raw cost estimation. These solution principles are subjective and can assume many forms. If the goal is to reduce the costs or shorten the delivery time of some task, it is at the conceptual design stage these ideas must be expressed and formalized. The next step, iii) embodiment design, is the constructive form taking shape and can be expressed in a layout which contains information such as functions, forces, spatial orientation, etc. Finally, iv) detail design is the phase where approximations become definitions. The product express shape definitions, dimensions, surface properties, material specifications, production possibilities, technical drawings and etc. At this stage, the cost estimation can be updated due to the high quantity of detailed information.

Figure 11: Steps in the planning and design process



Source: Pahl et al. (2007) page 130

In NPD it is indicated to evaluate the concept of the product to save time and cost in the product quality issue. Starting this analyzes since the beginning manages the costs in the 70 to 80% scale in the initial phases of the project (NIAZI et al., 2006). While the project phase generates only 6% of total development costs (HUNDAL, 1993). All the time invested in initial phases are justified because decisions turn more robust and the wasting of time and money are avoided in the future (BRACEWELL et al., 2009). Tiwari, Jain and Tandon (2016) report customer satisfaction, PD time and product costs as the objectives whose most contribute to the success of the project.

In initial stages of NPD, uncertainties are considered the deficiency to model the process. Xu et al. (2012) explain that to achieve what is intended is necessary to reduce the uncertainty changing the system, reducing the lack of knowledge. It contains fuzziness and randomness. Even in incremental development, where past projects act as a support in knowledge reuse, there are some uncertainties (DERBYSHIRE; GIOVANNETTI, 2017). Success cases bring tips to the development process. The unobserved information, differently, increase the probability to fail. Dayan, Ozer and Almazrouei (2017) expose that project uncertainties occur when is not possible to predict the success rate with so few information.

Chandrasegaran et al. (2013) make clear at the end of the aforementioned process many information is accumulated and can be used in future projects. The reuse of knowledge in the early stages can also help reduce PD time. During the development of the project, a lot of time is wasted by the engineers. Information, in its various articulations, exists and is dispersed by different stages of the NDP. Hou and Ramani (2004) state that more than 75% of a product's development activities are composed of knowledge reuse, whereas Ullman (2002) exposes industry inefficiency by claiming engineers spend 60% of their time looking for this information.

Thus, it is necessary to use an artifact to assist engineers in the initial phases in knowledge management. The use of computational tools in the initial stages of the NDP is complex when the list of functions and requirements do not accurately describe the desired resources, with approximations and incomplete data, which justifies the use of intelligent methods in knowledge management (WANG et al., 2002).

2.5.1 COSTS

Authors such as Ulrich (2003), Clark and Fujimoto (1991) and Pahl et al. (2007) discuss cost approaches in the NPD. But cost management is limited and takes place throughout the process, with measurements in the stages of PD. Thus, there is a need for an artifact in cost management in the early stages of the process.

The concept of cost is the amount, given in monetary units, of resources for some goods or services. For the company, cost means expenditure incurred to produce the product, and for the customer, it means the price (HANSEN; MOWEN, 2006).

According to Pahl et al. (2007), during the manufacturing of the product, the opportunities of reducing costs are scarce and complex. There are presented methods in the identification of costs that can be classified as:

- Comparison with costs: when costs are compared to reference models
- Cost estimation: through the standardization of cost values, after a given time or amount of information, estimates can be based on the databases
- Cost estimates based on regression calculations: through regression calculations and specific parameters, we look for coefficients to generate a function

The cost estimation is the process of estimation monetary resources at the beginning of each project activity. PMI (2013) inform it is based on the information collected in the initial stages and offer support on the identification and alternatives to conclude the project. During the development process, the cost estimation has to be improved to increase the precision. Using an analogous estimation based on past project data the parameters of the actual project can be increased. It requires less effort and time, helping not only the initial stages of cost estimation.

Many approaches and methods for cost estimation have been presented in the literature by Duverlie and Castelain (1999), Niazi et al. (2006), and Rush and Roy (2000). Weustink et al. (2000) defining cost estimation as predicting costs in certain activities before they are carried out. The author exposes two approaches: based on variation and generative cost estimation. Variation-based depends on the similarity between products on the same production line. The generative mode operates in predicting costs based on the manufacturing process. After certain operations, it is possible to determine the cost of the product.

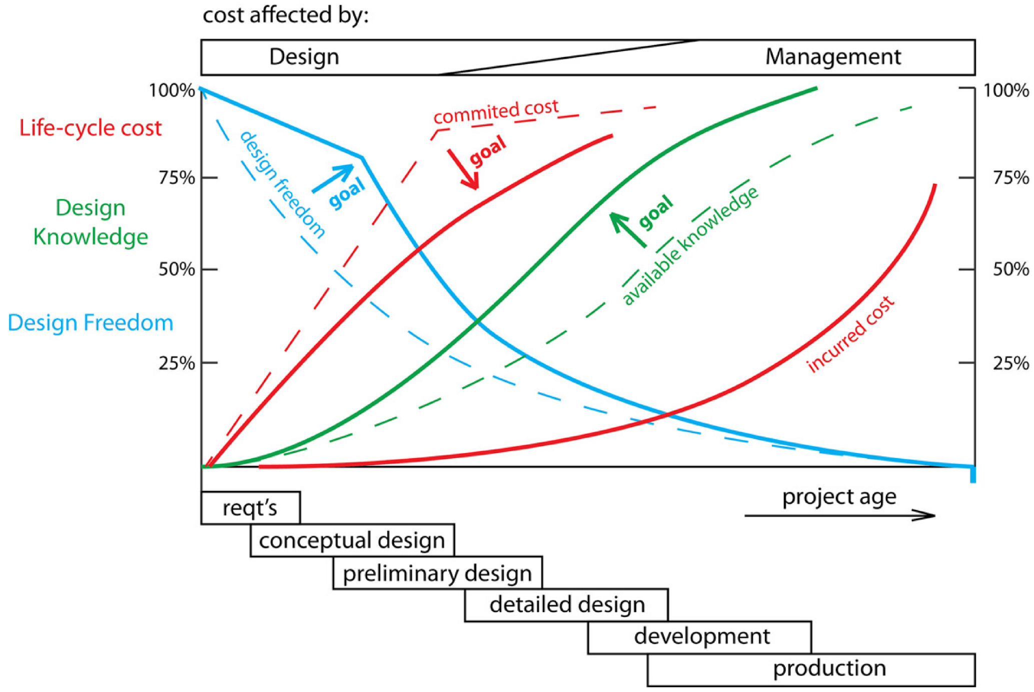
Due to the high number of data, Vargas (2009) describes the causes of failures of the cost management process in PD by the following factors:

- Wrong interpretation of data
- Omission in the scope definition of the project
- Inaccurate or optimistic schedule

- Failure to assess risks
- Poorly defined quality parameters

Rozenfeld et al. (2006) point out that the initial technical decisions are responsible for about 85% of the cost of the final product, which means that later activities exert less influence on the final cost of the product. Nunes, Pereira and Alves (2017) and Santos et al. (2017b) report the importance of advanced technology to increase the potential of PD in a flexible way and affordable costs in the Industry 4.0. Figure 12 compares the incurred costs and the committed costs in the NPD. The costs incurred are relatively low in relation to the final cost, but critical in terms of the final cost of the product. Observing the conceptual design column, the power of decisions on committed costs of the whole project are between 60 and 80%, while the incurred costs do not bring representative impact to the project. The design freedom is higher in conceptual design, but the available knowledge lower. Pahl et al. (2007) state that in the initial stages raw and generic cost estimations are important rather than detailed calculations, which should be left to later stages when more data is available in addition to having CAD modeling tools.

Figure 12: Product life-cycle cost, design knowledge and freedom related to design process



Source: Verhagen et al. (2012)

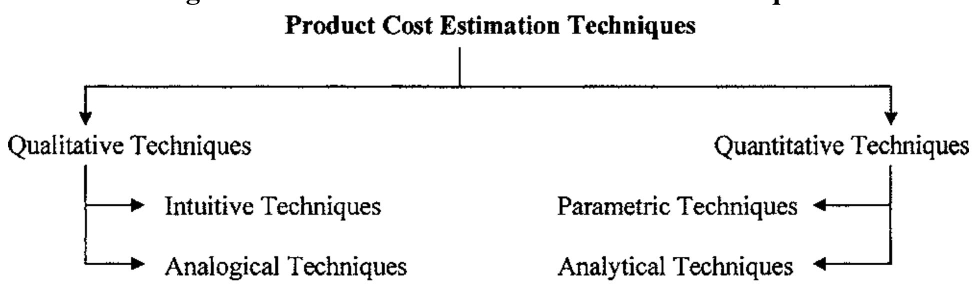
From the models proposed by Pahl et al. (2007) and Ullman (2003), it can be concluded that the costs of the products are mainly influenced by the following features: geometry, material, production and production planning process. The geometry determines the amount of material that will be used and the production process required. The material is certainly one of the most obvious influencers of product costs, as it can account for 50% of the total cost. The production process is responsible for the transformation of the gross item into manufactured and depends on the factors of the company in question, such as operators, tools, equipment. Production planning refers to the logistics that the company adopts, the resources it has and requires detailed knowledge of the process to plan the consequences of the process.

2.5.2 COSTS IN PRODUCT DESIGN

According to Niazi et al. (2006), cost estimations can be classified in qualitative and quantitative terms expressed in Figure 13. Qualitative techniques are based on comparative analyzes between a new product and other ones manufactured in search of similarities. In this category, the intuitive technique is based on previous project experiences and the specialists' knowledge is used systematically. The use of AI and ES (approaches simulating the knowledge of a specialist in a particular area of knowledge) are described as resources for agile and consistent storage of knowledge and are used to reproduce the expert's knowledge and automate the work. The analogical technique is based on known costs gathered from similar products or projects.

Quantitative techniques are based on product design, functions, and the manufacturing process. The first alternative represents costs as functions and variables in parametric technique derived from statistical methodologies. However, this technique requires parameters that are easily identifiable, absent in the development of new products. Analytical techniques decompose the product into elementary units, operations, and cost organization activities, but also require more information difficult to identify in the early stages of development.

Figure 13: Initial classification of the PCE techniques



Source: Niazi et al. (2006)

In this way, the interest in qualitative techniques in estimating costs using specialist systems is highlighted. The research topic is growing in the scientific and industrial community. Jorgensen and Shepperd (2007) present a review of the literature of cost estimating studies in software development. Emphasize that over the years the researchers are most interested in methods of estimation, with 61% of publication in the subject.

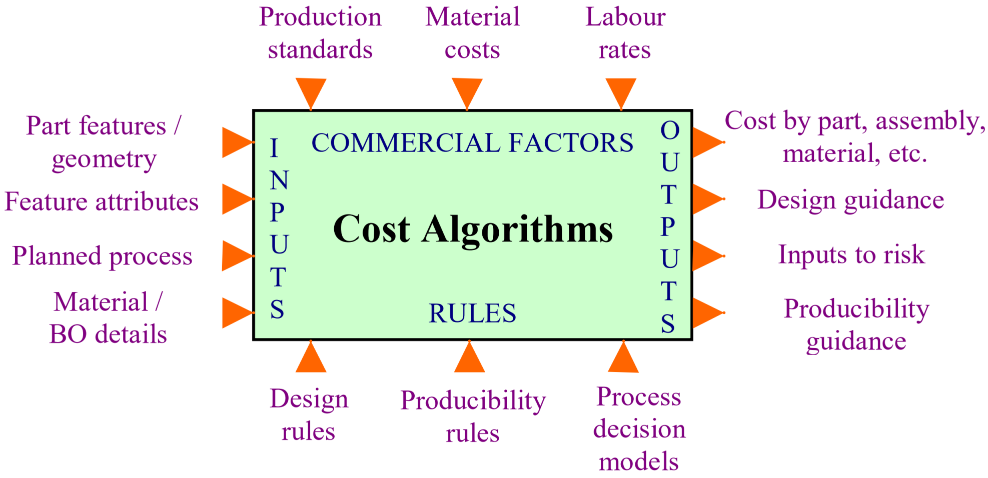
Favi, Germani and Mandolini (2016) present two the well-known ideas: costs of product design are only 10% of the total budget and 80% of all costs of the manufacturing process are decided in phases of the PD process. The challenges lie in how to manage product costs in the early stages considering not much data is available to designers. It is necessary to use approaches that connect the accumulated expert's knowledge in the industry and make researches in order to increase interoperability and efficiency (NUNES; PEREIRA; ALVES, 2017).

Jung (2002) states that estimating manufacturing costs and prediction in the early stages is one of the most important things in a company's competitiveness. In the early stages engineers only rely on preliminary CAD models that can generate errors and numerous iterations to the process. Favi, Germani and Mandolini (2016) describe a DTC approach to be applied at the same time as Design for Manufacturing and Design for Assembly but clarifies that this approach may not be the best choice from a manufacturing and cost point of view. The sooner be applied cost analysis techniques, even from raw data, sooner the engineer will be aware of the costs involved in the process. Throughout the development of an iterative approach can assist in increasing the accuracy of estimates.

Costs can be addressed in the design in two ways, in the context of DTC or Design for Cost (DFC). DTC is the conscious use of engineering process technology to reduce product life-cycle costs. DFC proves functional requirements in the project aiming at a final target cost (SHEHAB; ABDALLA, 2001).

DTC is described by Rush and Roy (2000) as a convergence of the project at an acceptable cost instead of the cost converging to the project. DTC in conceptual design is what determines the choices between cost and performance. Figure 14 presents the DTC model with the inputs and outputs of the artifact to be developed, where the result considers costs as the first importance in the analysis.

Figure 14: DTC model



Source: Rush and Roy (2000)

DFC described by Ehrlenspiel, Kiewert and Lindermann (2007) is the study and development of methods and tools that allow the engineer to calculate costs in the early stages of development through processes involving knowledge.

Mengoni et al. (2016) present LeanCOST as a solution in KBE. The tool is able to analyze the product information from the CAD model and generate a manufacturing process from an internal database with the equipment, processes, and materials available in the company. The LeanCOST application is able to reduce design time by 20% and the accuracy of the cost estimation is around 4%. It presents a strategy for DFC estimating costs based on CAD modeling, detecting the most economically feasible process for the company.

The features presented in the knowledge-based tool are:

- CAD interface module: analysis of the CAD model as its topology in the identification of advanced manufacturing functions
- Allocation Module process: conversion of the identified data into operations by determining the manufacturing process and parameters for each component
- Calculation engineering: automatically calculates manufacturing time based on processes and translates the result into costs
- Report module: manages calculated data and filters according to user needs

2.5.3 CLASSIFICATION OF COSTS

There are different ways to represent costs classified according to the needs. Park (2015) present some statements based on cost behaviors. Fixed cost is the one that remains constant, even if changes occur in the company. If the production volume changes, the fixed costs will not change. Differently, the variable cost changes in proportion the activity change in the company. It has a relationship to the volume of the business.

Megliorini (2012) presents the costs distinguishment as direct and indirect when associated with the products. Direct costs are those which can be easily traceable to a product. Indirect cost is difficult to trace to a single product and has to be apportioned to different products with appropriate measurement techniques. In the context of production, there are fixed costs and variable. Fixed costs are those which the cost is incurred for a period and tends to be unaffected by fluctuations in the levels of activity. They arise with the passage of time and not with production, as rent, insurance, etc.

3 METHODOLOGICAL ASPECTS

In this chapter, the proposed research is characterized and the procedures to be adopted are detailed. It presents the project phases and how the research achieved the objectives.

3.1 RESEARCH CHARACTERIZATION

Simon (1996) describes an approach called Design Science that proposes the construction of artifacts with a certain purpose. The method suggests the elaboration of science in a rigorous and structured way according to the proposed objectives. The artifact is defined as what is created by humanity, something artificial with pre-established properties. Within this scope, March and Smith (1995) define artifact as:

- Constructs: concepts that describe problems within the domain
- Models: representations of how things are
- Methods: steps for the execution of a task
- Instantiations: concretization of an artifact in its environment

According to March and Smith (1995), a model can be assumed as a representation of how things are, it has to capture the structure of reality to represent a thing. A method is the algorithm to execute the task, based on the model. The artifact developed in this research can be characterized as a model due to the representation of the domain overhead crane costs in an ontological approach.

The artifact nature is characterized as prescriptive to seek for a problem solution. Aken (2004) shows that research based on prescriptive approaches differs from descriptive ones by orienting Design Science with a focus on the solution. Descriptive knowledge assists in the construction of research questions and, simultaneously or later, prescriptive knowledge contribute to the investigation of artifacts in the resolution of documented research problems (GREGOR; HEVNER, 2013). In a more advanced stage, based on assumptions, experience or syntheses about certain knowledge, the prescriptive study aims to generate an artifact to support the theme (BLESSING; CHAKRABARTI, 2009). Lee et al. (2014) add that prescriptive analysis can aid with objectives and requirements in activities with mathematical techniques in determining complex decision-making. Therefore, this work characterizes a prescriptive study in the search for the development of an artifact (ontological approach) to support designers.

3.2 METHODOLOGICAL APPROACH

This research is developed based on DSR. DSR is a methodological framework to guide the researcher to present the outcomes in a structured way rigorously. The process describes the artifact designing to solve problems following the structure to construct, evaluate and communicate appropriately according to the objectives (PEFFERS et al., 2007). For the study construction, Hevner and Chatterjee (2010) present a structure which acts as a guide in the conduction of the DSR presented in Table 3:

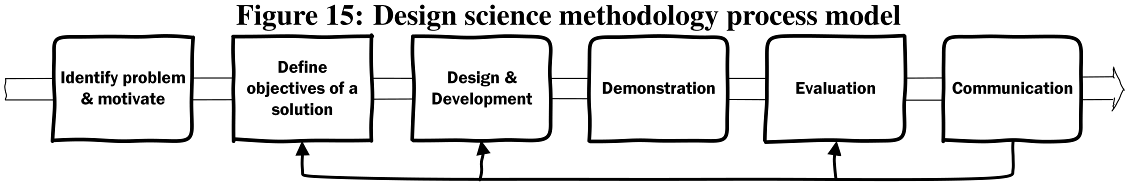
Table 3: DSR Guidelines

Guidelines	Descriptions
Design as an artifact	Research should result in an artifact
Problem relevance	The objective is to develop important and relevant solutions to commercial problems
Design evaluation	The utility, quality, and effectiveness of the artifact should be demonstrated by evaluation methods
Research contributions	The research should provide clear and verifiable contributions to the artifact and methodology projects
Research rigor	The research depends on rigorous methods in the construction and evaluation of the artifact
Design as a search process	The search for an efficient artifact requires means available to achieve desired ends while satisfying the laws in the problem environment
Communication of research	The research must be presented to the scientific community

Source: Hevner and Chatterjee (2010)

According to Peffers et al. (2007), the DSR activity stages follow as presented in Figure 15. Hevner et al. (2004) emphasize the project is developed in an iterative and incremental process. With each discovery, knowledge about the subject increases and can assume another form, which requires analysis and changes at earlier stages to re-evaluate the content relevance.

Figure 15: Design science methodology process model



Source: Peffers et al. (2007)

In the first stage, identify the problem and motivate, the research problem is defined and the value of the solution is justified. This definition collaborates with the development of the artifact in the meticulous capture of its complexity. The justification motivates the team in the search for the solution, acceptance of the results and understanding of the reasoning associated with the understanding of the problem. It is necessary to know the state of the problem and the importance of its solution conducting to the inference of the researcher.

The second stage requires the definition of the quantitative objectives for the solution of the problem as possible and feasible. The resources required are knowledge of the state of the problems and current solutions with their effectiveness, when available.

The third stage is the creation of the artifact. In this activity, the desired functionalities and their architecture are determined to create the artifact. The necessary resources are knowledge of the theory that can be brought to the solution.

The fourth stage is the artifact demonstration solving a problem, which may be an experimentation, simulation, case study or other appropriate activity. The necessary resource is the knowledge on how to use the artifact.

The fifth stage is an evaluation, an artifact metric about its compatibility with the problem solution. In this step, the objectives of the solution are compared with the results observed in the demonstration of the artifact. Requires knowledge of analytical techniques and relevant metrics, such as satisfaction surveys, quantitative performance, budgets or produced items. They may be considered empirical evidence or logical evidence. In the end, researchers may decide to repeat stage three to try to improve the effectiveness of the artifact.

The sixth stage seeks to communicate the problem and its importance to the scientific community. Publications can use the structure of this process in the document and also the structure of an empirical research process. Communication requires knowledge of the disciplinary culture.

Thus, this work presents an ontological model as an artifact. Afterward, each activity is detailed with the purpose of presenting the process and activities carried out.

3.3 METHODOLOGICAL PROCEDURE

3.3.1 IDENTIFY PROBLEM AND MOTIVATE

The diagnosis emerged from a bibliometric and systemic literature review joining three axes: PD, costs and ontology (VOLTOLINI et al., 2018). The author showed challenges detected by different authors, solutions proposed and results, which collaborated with this project highlighting opportunities to develop the artifact. The research pointed out the difficulties to deal with uncertainties at the beginning of the project. The initial stages characterize an ambiguity to deal with parameters since there are few data about the customer requirements. When the engineer develops a cost estimation, without data, the result is undefined and full of uncertainties. An ontological approach was suggested to capture and reuse knowledge from specialists in past projects. This solution can create knowledge from past project including parameters and costs stored in the database without additional tools. In spite of different approaches, ontologies are still harsh to be implemented in real cases. It is a research gap with high potential to contribute to intelligent manufacturing.

After the problem diagnosed, the researcher got in contact with HyperLean Company to use the software LeanCOST, indicated by the co-advisor as a strategy to knowledge construction. The software aims for a cost estimation based on the three-dimensional model generated in CAD tool. The learning process was made during simulations in the software used with different materials, geometries and manufacturing processes. The company itself provided tutorials and geometries of parts and assemblies for understanding the features of the tool. Autodesk Inventor software was used to generate CAD geometries where the researcher himself could simulate different situations and specific resources. However, in all tentative of simulating a cost-generating process in the software, CAD models with features representing the desired features were required.

The process of cost estimation starts after the company has customer requirements and created the model. The investigation in this dissertation relies on the initial stages, before the customer requirements when the company still cannot create a CAD model. After training and getting experience, the question raised was how the cost could be estimated without the existence of a formal communication currently used – CAD model. Despite the efficiency of the LeanCOST software, was concluded there is no structured and formalized form of cost estimation in the initial stages of NPD when features describing the functionalities of the proposed component have not yet been defined.

3.3.2 DEFINE THE OBJECTIVES OF A SOLUTION

In agreement with the general and specific objectives, the expected results of this research were defined. The artifact developed in this project is a model, which can be used in the initial stages of NPD in the cost estimation of a product before the CAD model. This model can be applied in different areas, but to demonstrate the functionality clearly, a case study was chosen. The case is a cost estimation of an overhead crane in the initial stages of development.

In the early phases of the project, precise assertions are difficult based on product requirements, especially if the subject is costs. Pahl et al. (2007) describe the combination of solutions with the use of mathematical methods in cases where properties can be quantified. In the early stages, estimations are raw and more important than detailed estimations, which require more detail and can only be done in advanced stages of NPD.

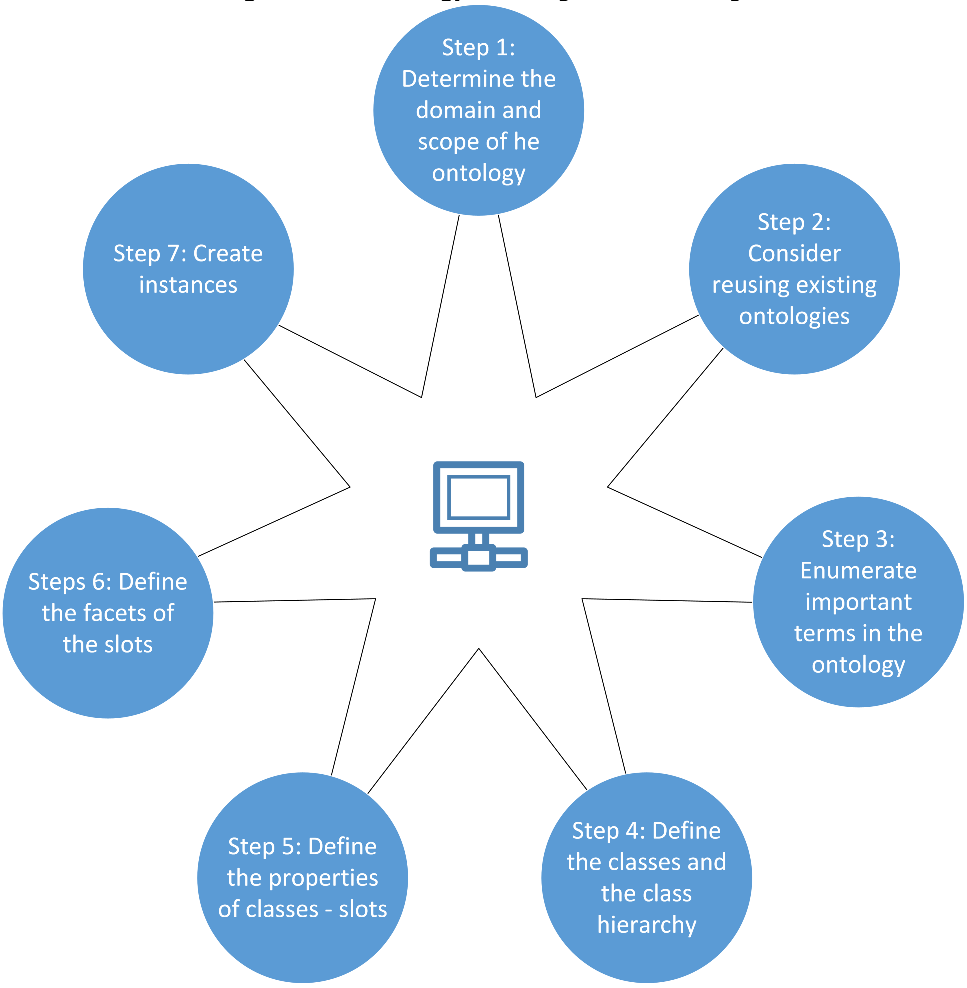
Professionals directly or indirectly involved in the cost area need to generate reports constantly updating stakeholders on NPD. From a list of requirements generated in the early stages, NPD engineers draw up a cost estimation based on company databases, tacit knowledge, or previous projects. In the case of new products, the reference quantity is reduced or non-existent, forcing those responsible to estimate based on past and outdated experiences. Thus, it reduces the accuracy of costs and requires too much time and exclusive attention in the preparation of the document.

In order to create an environment where NPD professionals can access complex information in an agile way in the initial stages, an artifact was developed in an ontological approach. This proposed model collaborate with the estimation of costs in the initial phases of the conceptual project with the use of techniques such as tacit knowledge capture, reuse and knowledge generation from a database. Gruninger and Fox (1995) clarify the importance of creating competency questions to evaluate the ontological model functionality beyond the domain definition to check if the objectives are satisfied.

3.3.3 DESIGN AND DEVELOPMENT

The artifact was developed following the method Ontology Development 101, proposed by Noy and McGuinness (2001). Figure 16 presents the steps to construct the ontological model, in an iterative way. Eventually is necessary to migrate from one step to another for revisions according to the learning acquired in the construction of the model, making each step connected to a knowledge network. Although different alternatives for developing ontologies such as Ontoanimal (HE et al., 2018), TOVE (GRUNINGER; FOX, 1995), OntoTracED (VEGETTI et al., 2016) and Methontology (FERNÁNDEZ; GÓMEZ-PÉREZ; JURISTO, 1997), method 101 is currently used by the LAMIS lab and the colleagues can offer support. Moreover, it is recommended by Protégé team from Stanford as a guide to create the first ontology.

Figure 16: Ontology Development 101 steps



Source: The author

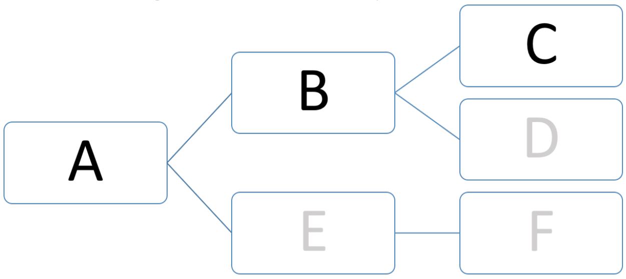
Step 1 determines the domain definition and ontology scope. The following questions can help in the definition: i) What domain ontology will cover? ii) What will the ontology be used for? iii) For what types of questions should the information within the ontology generate a response? Gruninger and Fox (1995) complement with the competency questions, a list of questions to help in the elaboration of the knowledge with content related to the topic addressed. In the case of users with no experience in ontology, competence issues collaborate in the construction of knowledge in parallel to the computational language domain. From the answers, data such as type, characteristic, time, classification can arise and form the content of the ontological model.

Step 2 suggests the reuse of existing ontologies available on the web. If the ontology is similar to or covers the same domain, it is possible to include existing parts to avoid rework. Another way to reuse is to access the list of properties on certain knowledge to import and take advantage of existing classification.

Step 3 requires the numbering of important terms in the ontology. First, a list of terms wished to visualize in the body of the ontology without a logical order is made, just the expression of the knowledge about the theme the developer has. Imagine what properties these terms should have, what could be said about these terms.

Step 4 indicates the definition of classes and the hierarchy between them. From the classes listed in step 3, select the terms that best describe objects independently. The approach can be top-down (from the more generalized definition of the concept to the more specific), bottom-up, or the combination of them. The organization is flexible considering the establishment of a structured hierarchy to avoid the repetition of concepts. It is important to remember that an object will necessarily be an instance of the classes superior to the one directly linked to it. Figure 17 demonstrates it if B is a subclass of A and C is a subclass of B, then C is a subclass of A.

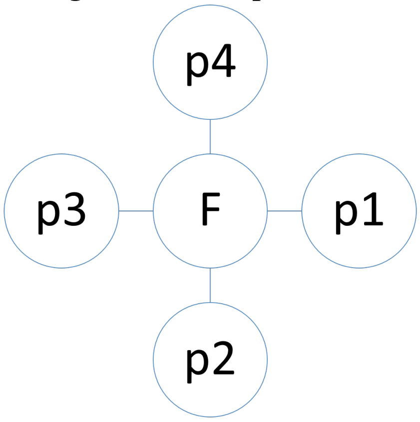
Figure 17: Hierarchy of classes



Source: The author

Step 5 defines the properties of the slots, as they do not themselves provide enough information. These properties are characterized as the internal structure of concepts. Figure 18 represents the class F with its properties (p1, p2, p3, and p4) that describe - in an intrinsic or extrinsic way - the characteristics of F.

Figure 18: Example of class

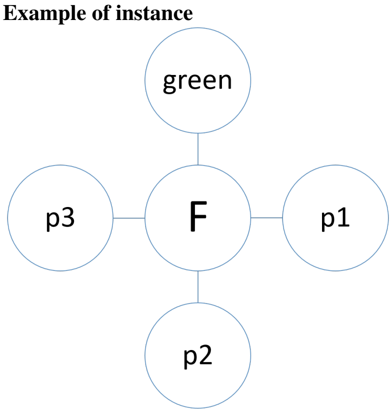


Source: The author

Step 6 defines the facets of the slots, which can receive different types of values, such as textual, numeric, Boolean, enumerated, etc. or what is not allowed.

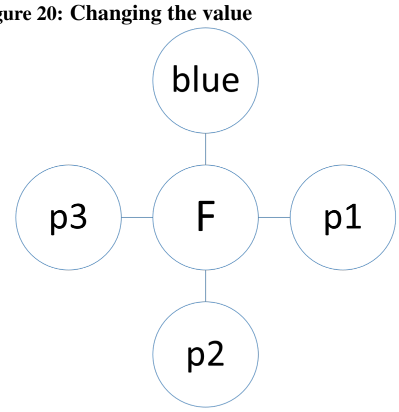
Step 7, creating instances, as the name itself describes is choosing a class, creating an individual instance for that class, and filling it with a certain value. Figure 19 presents slot p4 with the "green" instance that represents a characteristic of this property. From a slot, there is a value characterizing that slot. It is important to note that even though the value is changed, the slot remains the same. In this way, Figure 20 shows that the slot name can change, but the slot continues to represent the same concept.

Figure 19: Example of instance



Source: The Author

Figure 20: Changing the value



Source: The Author

3.3.4 DEMONSTRATION

In this stage, the artifact demonstration was carried out. The ontological model is presented as a cost estimation from product data inserted.

The case study defined is a cost estimation of an overhead crane. As the research was developed in Brazil, a company located in the north of Santa Catarina was considered to collect some specialist knowledge. The equipment data came from industrial technical reports characterized as the ontology instances.

The case was defined as a quote simulation in the initial stages of PD. A client asking for a cost estimation and the sales department using the requirements instantly to generate a cost. The ontology editor Protégé was used to develop the ontology, running the reasoner Pellet. To test the ontology functionality, some queries were created and tested using the query language SPARQL, a resource to find answers based on the ontology. The queries are defined as competency questions, what the ontology has to answer. Each query is a proof of what knowledge the ontology can generate, starting from obvious data saved as instances until information based on inferences of the ontology. The final queries were based on the information given by the cost specialist.

3.3.5 EVALUATION

The fifth step of DSR is the evaluation. As exposed in Figure 15, each topic has to be presented in the communication results to the scientific community at the end of the research. The purpose is to make it explicit: the environment, objectives, artifact testing and metrics used (LACERDA et al., 2013). As this project is academic, the efficiency in a real study case is not expected, but the capacity to be replicated following the structure presented to be applied in industry. Peffers et al. (2007) affirm the evaluation importance is the ability to solve the problem, considering the objectives proposed at the outset. Depending on the problem nature, different evaluations can be applied empirically or logically depending on the artifact nature, as presented in Table 4. In this project, a study case was created to simulate the use in a quotation. The evaluation type experimental is also approached because the artificial data is used, inclusive the monetary values are created to help in the understanding. The competency question can be related to a functional testing since it is a scenario built exclusively to the comprehension. During the evaluation, the researcher must decide between continue the development of the ontology or return iteratively to initial phases to edit some content.

To establish a comparison between the evaluations tools used, Table 5 compare them according to the design science terms. FOCA is characterized as a methodology presenting criteria and a guide to the developer to work as itself and helped by other specialists. OOPS is a tool to diagnosis the ontology. And Debugger is a tool used to check the syntax inside the ontology editor Protégé. The benefits of each one are recognized, but considering more than one the biggest beneficiary is the researcher. Based on the design science, FOCA is more

Table 4: Evaluation methods

Evaluation type	Proposed methods
Observational	Case study: study the existing artifact in depth in the business environment
Analytical	Dynamic analysis: study the artifact during use to assess its dynamic qualities
Experimental	Simulation: Run the artifact with artificial data
Test	Functional testing: run artifact interfaces to discover possible faults and identify defects
Descriptive	Scenarios: Build detailed scenarios around the artifact to demonstrate its usefulness

Source: Hevner et al. (2004)

appropriate to evaluate because it addresses all criteria.

Table 5: Evaluation approaches

Design Science Evaluation	Evaluation approaches		
	FOCA	OOPS!	Debugger
Robustness	X	X	X
Fidelity	X		
Level of detail	X		
Completeness	X	X	
Internal consistency	X	X	X

Source: The Author

The definition of each design science criteria follow:

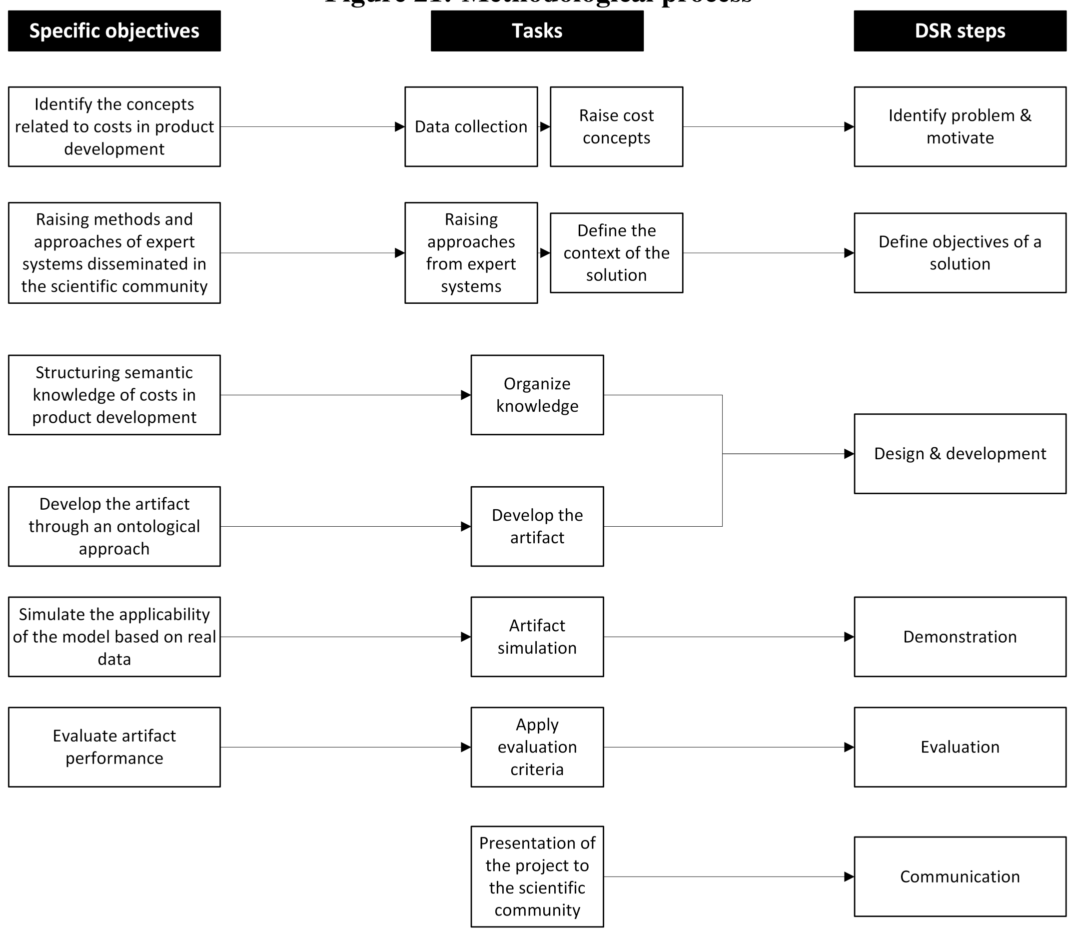
- Robustness: is defined as the ability of a system to cope with errors during execution. The system has to keep an acceptable behavior in execution conditions (FERNÁNDEZ-REYES; HERMOSILLO-VALADEZ; GÓMEZ, 2018)
- Fidelity: is defined as the determination of how well an intervention is implemented in comparison with the original design (O'DONNELL, 2008)
- Level of detail: is the level of abstraction, the precision in using the right words to form sentences (WILSON; GLAZIER, 2014)
- Completeness: in knowledge management it can be asserted as complete assertions, covering all elements (LEVY, 1996)
- Internal consistency: is defined as the internal relations. As higher the correlations, the better. Something consistent cannot be written violating the own database rules established before (BOLLEN, 1984)

3.3.6 COMMUNICATION

The last step, according to DSR, analyzes communication and results obtained. After the dissertation project, the content originates a scientific article to be published in a journal related to the research theme with relevant impact factor. The ontology will be available in an ontology repository to future access.

Hevner et al. (2004) emphasize the importance of communicating results to the scientific community. First, technical areas can continue the research or use the developed artifact. Also, the management area has influence in the power of decision on which methods to implement in industry. Just as this research was developed from other studies, the importance of the communication of results lies in the continuity of the generation of science, making this study a step for others researched in their findings. Figure 21 illustrates the steps of the DSR methodology and the tasks proposed in each step, correlated to the objectives.

Figure 21: Methodological process



Source: The author

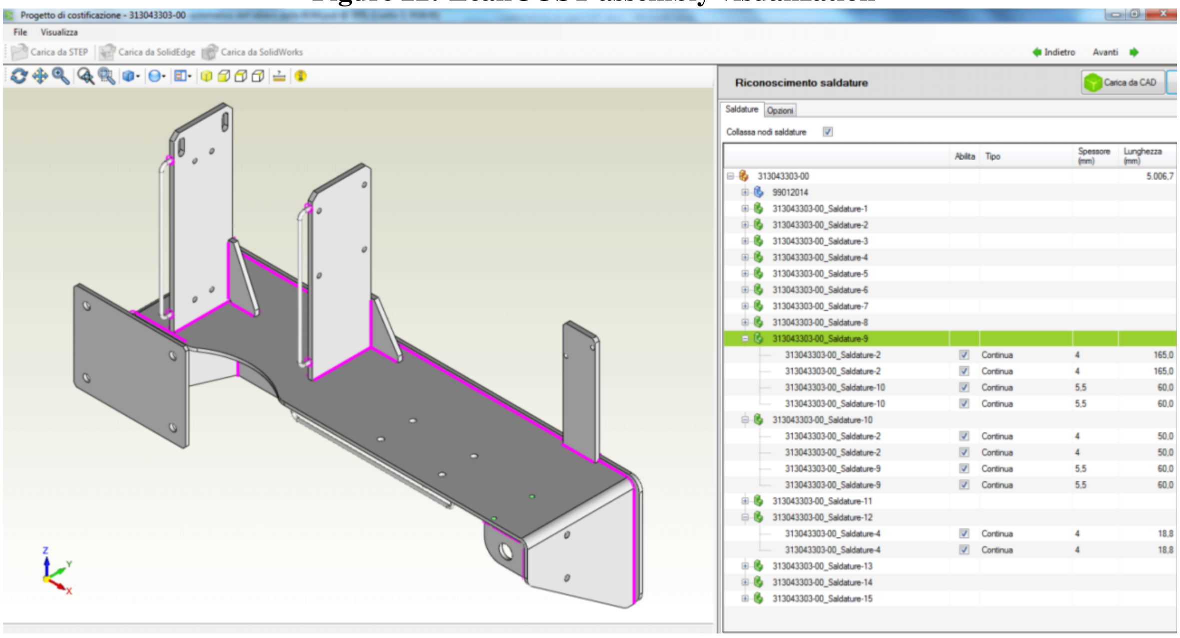
4 RESULTS AND DISCUSSION

4.1 PROBLEM IDENTIFICATION

The researcher started to use the software LeanCOST, from Hyperlean. It acts on the costing estimation of projects under development from a three-dimensional model generated in CAD tool. The computational tool generates a diagnosis on the cost estimation process in the NPD of a mechanical component.

Figure 22 represents an assembly in LeanCost, where each part has a cost. The software aims for a cost estimation based on the material, production process, surface finish, and other resources that the user judge necessary (the company machinery and resources are registered in the database). The final cost is the sum of each part cost and the assembly process.

Figure 22: LeanCOST assembly visualization



Source: The Author

The diagnosis occurred during simulations of the software using different materials, geometries, and manufacturing processes. The company provided tutorials, part geometries and assemblies to comprehension the features. The researcher used Autodesk Inventor to draw geometries and simulate different situations and specific resources. In all simulations of a cost-generating process, a CAD model with features representing the desired features was required. At this stage, it was already necessary to know the customer requirements to sketch the CAD model. In the end, LeanCOST creates a report based on the data inserted.

Figure 23 presents an operations list containing the equipment to produce a specific component. The final cost result comes with the currency predefined and time in minutes. It separates the preparation time, machining time, setup time and others.

Figure 23: Cost estimation result

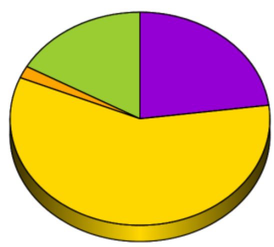
OPERATION	MANUFACTURING COST [EUR]	MANUFACTURING TIME [min]	QTY	TOT. MANUFACTURING COST [EUR]	TOT. MANUFACTURING TIME [min]	TOT. BATCH MANUFACTURING TIME [min]	ACCESSORY TIME [min]	BATCH ACCESSORY TIME [min]	SETUP TIME [min]	BATCH SETUP TIME [min]
Structural steelwork				4.38	10.51	10.51	0.00	0.00	10.00	10.00
Beam				4.38	10.51	10.51	0.00	0.00	10.00	10.00
Saw cutting				4.38	10.51	10.51				
Machining				17.17	19.44	19.44	2.67	2.67	79.76	79.76
Turning				15.12	17.12	17.12	2.67	2.67	79.76	79.76
Facing (Roughing)				0.76	0.86	0.86				
External cylindrical turning (Roughing)				12.30	13.93	13.93				
Socket head screw				2.06	2.33	2.33				
Milling				2.01	2.28	2.28	2.67	2.67	79.76	79.76
Edges machining				2.01	2.28	2.28				
Operations				0.04	0.05	0.05	2.67	2.67	79.76	79.76
Rapid traverse time				0.04	0.05	0.05				
TOTAL AMOUNT				**21.55 EUR**	**29.95 min**	**29.95 min**	**2.67 min**	**2.67 min**	**89.76 min**	**89.76 min**

Source: The Author

Figure 24 presents a cost compilation using a graphic. It organizes the data, estimates the cost and produces a report as the user requires.

Figure 24: Cost estimation graphical report

Raw material cost	29.38 EUR	23.00 %	
Investment cost:	0.00 EUR	0.00 %	
Set-up cost:	74.62 EUR	58.30 %	
Accessory cost:	2.36 EUR	1.80 %	23.91 EUR
Manufacturing cost:	21.55 EUR	16.80 %	
Item cost:	**127.91 EUR**		
Batch cost:	**127.91 EUR**		



Source: The Author

The author had an experience time who was able to define the problem adequately. How the cost could be estimated without the existence of a CAD model? Despite the tool efficiency, the initial stages are not presented in the process. It opens an opportunity to develop an artifact to satisfy this gap. Following the approach presented by LeanCOST, the final result is a single value. It is ignored possible costs variation that can appear in the cost estimation in initial stages. Moreover, the production volume is not considered, focusing on single parts or single assemblies.

4.2 DESIGN AND DEVELOPMENT

Following the DSR, the problem identification was described and now the design and development are presented. The design means creating the artifact, represented in this case as an ontological model. Each subsection present the Ontology Development 101 steps to support the developer in a systematized process.

4.2.1 DETERMINE THE DOMAIN AND SCOPE OF THE ONTOLOGY

According to the problem identification and objectives established, the ontology covers the following domains:

- Cost estimation
- Initial stages of NPD
- Overhead crane product
- Those involved are:
  - The ontology user as the cost sector
  - The ontology developer as the ontologist
  - The customer as the beneficiary

To determine the ontology scope it is indicated to list some questions based on the domain knowledge (GRUNINGER; FOX, 1995). These questions, called competency questions, will act as a base to check if the ontology is capable to answer all of them and to guide the developer in the abstraction of the domain. Also, it is not recommended to abstract too much beyond the context intended. Based on this context, the following competency questions were created simulating a phone call between the sales department and a customer:

- How much does it cost to hoist the load X1, with two lifting speeds X2 and X3, moving the load with speeds X4 and X5, in lateral and longitudinal directions, respectively?

Also, it is required a robust body, remote-controlled device to handle tubes and collision sensors. The shed has the following measures: W x L x H meters

- What if we have to include the lifting in the area of a large well where we have restricted access? Could be useful a virtual control to operate considering high temperatures that can corrode the coating. Impurities may arise with the load
- What if a control cabin with noise control is required to avoid operator risk? It is also necessary to detect the variable depth of the well and the load to be hoisted without collision
- In other application we have two wells where it is necessary a double overhead crane synchronized, is it possible to design for the first time?

During the development process, other simple questions were used to the knowledge construction as "Which rope has the adequate load capacity for 40 tons?" or "How much is the cheapest rope?". All this content is formally presented posteriorly.

4.2.2 CONSIDER REUSING EXISTING ONTOLOGIES

It is recommended to reuse ontologies available in repositories. The objective is to avoid wasting time creating something that already has been done before. Moreover, based on previous studies, develop new ontologies with knowledge reuse. The following repositories were consulted:

- DAML Ontology Library
- Dmoz Tools
- Sharable Ontology Library
- DBpedia

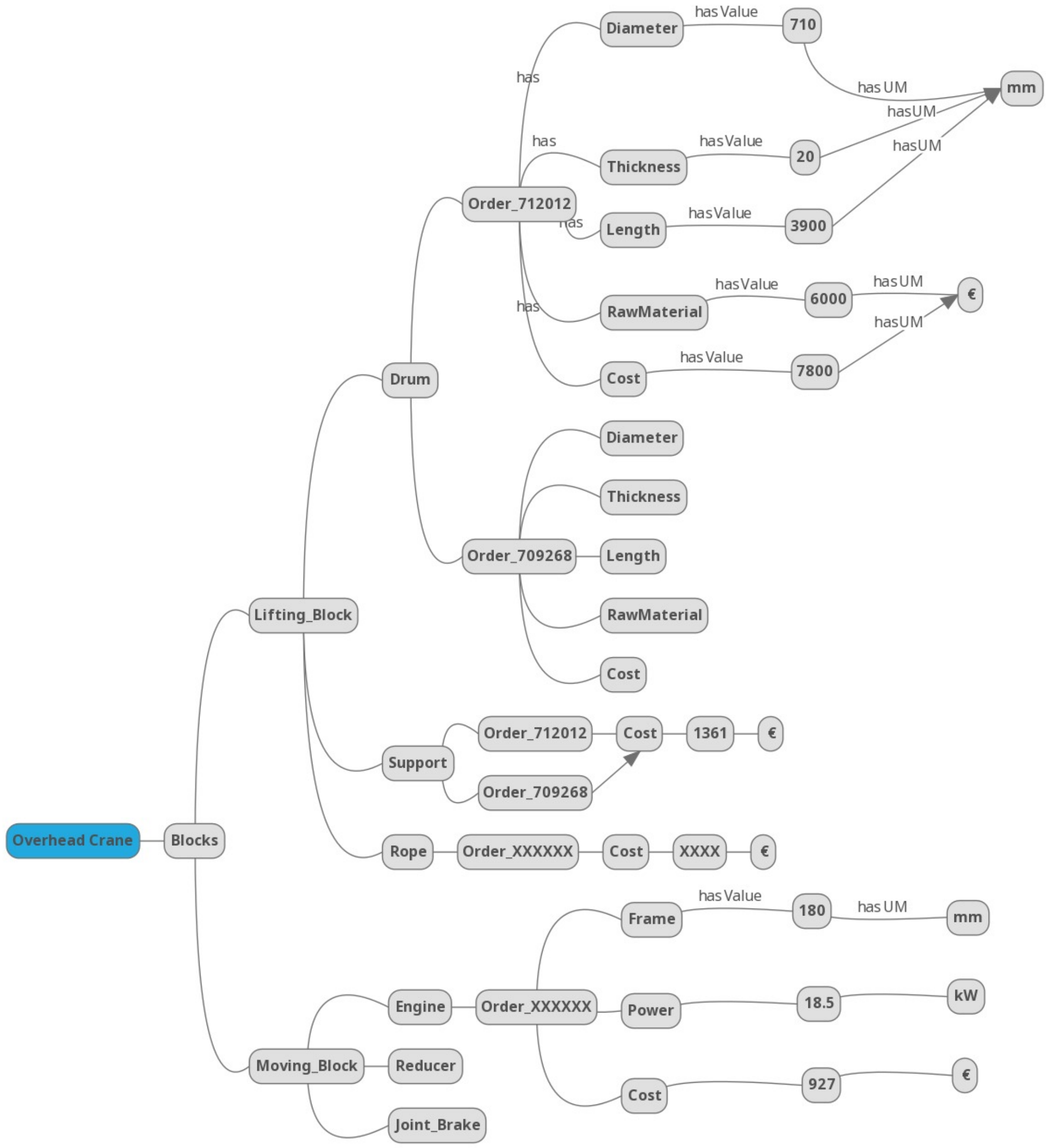
The search resulted without any ontology in the exact context that could represent a significant reducing time resource. The solution was to create an ontology from the begging. An alternative to reduce development time is to reuse knowledge and vocabulary from different basis. Raffaeli, Savoretti and Germani (2017) described a cost estimation from past projects. Company reports provided vocabulary and technical content about the product ((CSM, 2018), (CIMAF, 2012), (GOSAN, 2018), (EMH, 2018)). Fiorentini et al. (2007) and Borsato (2017) provided semantic knowledge to organize the ontology following a pattern. Megliorini (2012) and Munhoz (1989) provided cost knowledge.

4.2.3 ENUMERATE IMPORTANT TERMS IN THE ONTOLOGY

The objective is to list, understandably, terms representing the concepts about the subject. What it is intended to represent with the ontology. It is recommended to write as much as possible to help the developer in the abstraction task. The important is to define terms that express what the ontology have to cover under the domain. Is no need to worry about being overlapping concepts at this stage.

Figure 25 illustrates the idea of thought at the beginning of the project. In the context of an overhead crane, the equipment was divided into blocks. There are representations of some parts and components installed individually depending the configuration required. The idea was to separate the commercial orders to organize each cost center. It was used components specification and orders, as the “power capacity”, to identify the capacity of the individual equipment. The slots were filled with instances and measure unit. At this stage the ideas were still shuffle about the ontology domain and how to represent it.

Figure 25: Mental map containing terms relevant to the context

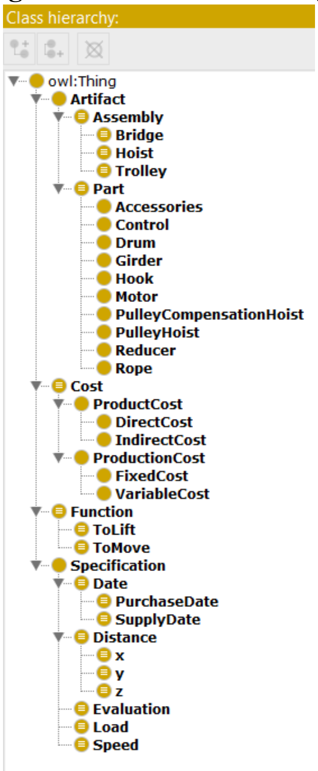


Source: The Author

4.2.4 DEFINE THE CLASSES AND THE CLASS HIERARCHY

There are different approaches to develop this step as bottom-up, bottom-down or a combination of them. Respectively, the definition can start with the most specific class, or the most general or the combination of them. They both were used in this project according to the abstraction of the concepts have been created. Sometimes occurs the perception of a misunderstood in determined class. Comparing the Figures 26 and 25, with classes represented by a yellow circle, the terms “order” and “block” disappeared. They were rearranged in distinct situations following the ontology construction. During the ontology development, it is possible to perceive different allocations and concordances. In an iterative approach, the possibilities to return and modify previous stages are very common and useful.

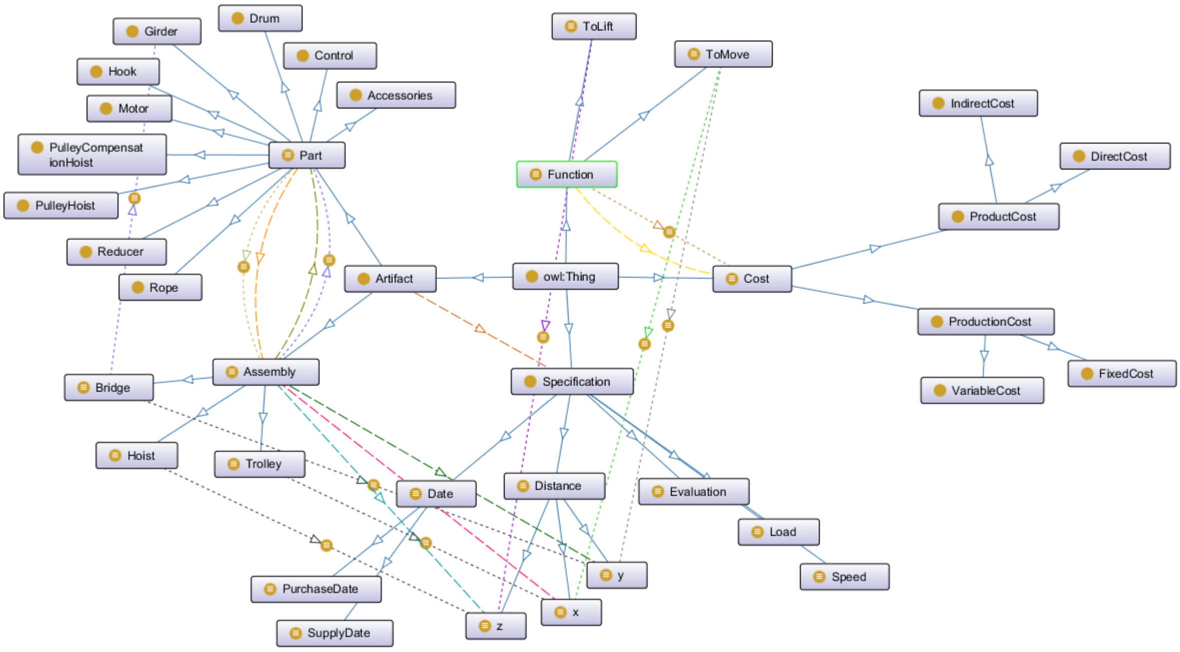
Figure 26: Classes in Protégé



Source: The Author

The top level is represented by the classes ARTIFACT, COST, FUNCTION, and SPECIFICATION. ARTIFACT means the product described by the case study. During the development process, this class changed as the developer abstractions changed as well. The idea was to separate the final product in a few groups to represent all equipment. BRIDGE means the structure formed by the beams that sustain the overhead crane. TROLLEY means the cart that moves by the bridge and keeps all equipment responsible for pulling the loads. Then, HOIST is the component responsible to lift the load. All classes belonging to ARTIFACT are physical components of an overhead crane, produced or bought. Figure 27 brings the radial visualization with the central class THING and going distant according to the bottom level increase using OntoGraf plugin. THING is the begin of all projects in Protégé ontology editor.

Figure 27: Classes in Protégé in radial view



Source: The Author

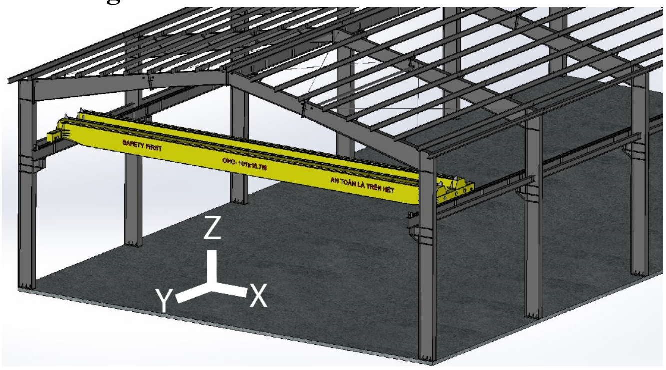
The class PART means all the unique components compounding the equipment. For example, DRUM and MOTOR are sub-classes of PART and represent a concept belonging to PART. When it is desirable to describe parts of an overhead crane, the class PART will assume. This is an academic project and aims to represent the knowledge in place of developing the final ontology ready for the market. For this reason, just a few parts were described to create the ontology and represent the concepts. In the real world, PARTS have to contain all possible components that a company has available to the market and turn the ontology more consistent possible.

ACCESSORIES is a class made to receive few instances used in the equipment. If the company changes the project or create a regular one using certain part, this instance can migrate to the class PART. For example the instance `LoadCell`, that means a transducer used to measure the force magnitude being measured, it will just be used if a customer requires the component because it is not standard.

COST is responsible to describe the cost estimation of a product. PRODUCTCOST is the class representing the costs with product metric, identified by the quantity of what is consumed by each marketed item. The sub-classes are DIRECTCOST and INDIRECTCOST representing the costs with a specific register of the quantity used and some allocation criteria, respectively. The class PRODUCTIONCOST brings the concepts of costs related to the production volume, represented by FIXEDCOST and VARIABLECOST. The classes were named by the real terms used in the cost business to facilitate the comprehension and knowledge reuse.

There are two classes that specifically represent the basis of an overhead crane and are useful to compound the functions of the equipment showed in the classFunctions. The sub-classes are ToLift and ToMove. Figure 28 represents the equipment moving directions, the class Bridge represents the movement in the y-axis, the Trolley the x-axis, and Hoist the movement in the axis z. The function ToLift, as the own class name means, is responsible for the movement in the z-axis, to lift a load.

Figure 28: The axis directions in the shed



Source: The Author

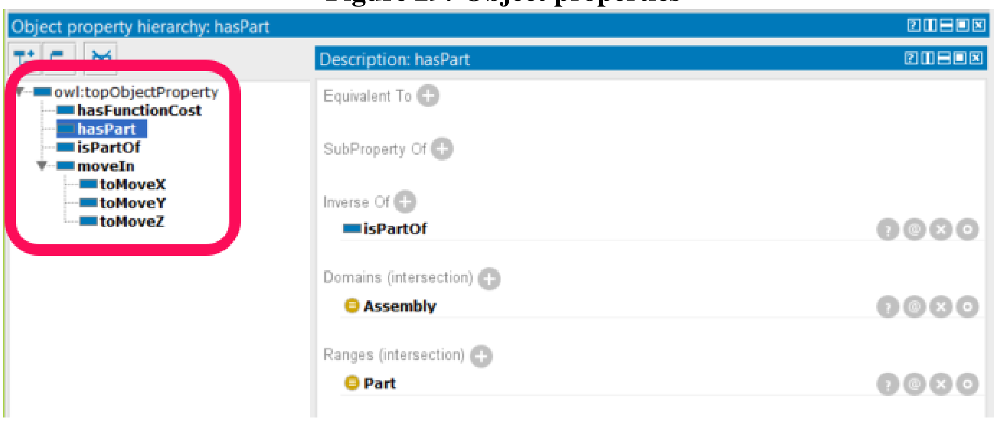
Specification means other characteristics which compose the artifact, they are Date, Distance, Evaluation, Load, and Speed. All sub-classes of Specification have the responsibility to label a unit measure, as speed and meters. After filling the unit measure in an upper class, all sub-classes receive the same parameter. The class Date organizes the exact date which the item was bought or sold. The sub-classes of Date are PurchaseDate and SupplyDate. In case of some part be bought long ago and be sold recently it can affect the costs and can be a factor to the cost department refresh some values according to the market.

The class Distance acts as a support to specify the axis according to the moving directions following the international system, meters. The classes X, Y, and Z support to differentiate the axis between them. Each assembly moves in its own axis and they are characterized by the measure unit meters represented in the description of the class. Evaluation is a metric which the company gives a grade to a certain part or assembly from 01 to 05, as higher is better. It helps to classify internally the supplier or the well successfully project and sale in a specific order. When is considered to reuse knowledge, it is important to advance only with good results and avoid failed projects. The class Load represents all instances that have to lift a load in tons. At last, Speed is a class to label the instances with a velocity unit measure in meters by minutes. An overhead crane does not require different velocities to operate, but a good project includes this variation and offers different speed options to the client decide.

4.2.5 DEFINE THE PROPERTIES OF CLASSES AND SLOTS

Connecting the classes there are properties – object and data properties – describing the concept structure. Each class is described by a property. The object properties create a relation between classes. Figure 29 presents the object properties. The first one, `hasFunctionCost`, creates a link between the classes FUNCTION and COST, because functions have a cost relation in the ontology. Then, `hasPart` means the class ASSEMBLY has a part contained in the class PART. The opposite is also represented as `isPartOf` to represent that a PART can be part of an ASSEMBLY. Sometimes its useful to invert the property to achieve a result.

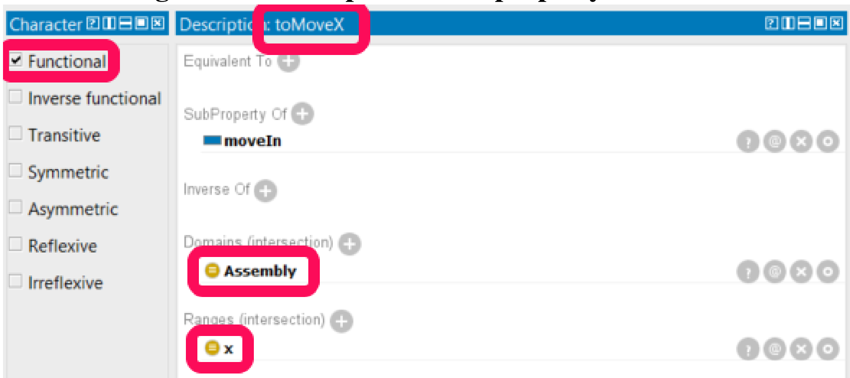
Figure 29: Object properties



Source: The Author

The `moveIn` property has sub-levels: `toMoveX`, `toMoveY` and `toMoveZ`. The objective is to represent all assemblies moving in a specific direction. Figure 30 shows the Object Property `toMoveX` representing something inside class ASSEMBLY that has a relation of movement with the class X. The box Functional is selected, which means a single-valued property. ASSEMBLY moves only in the direction of class X and not the opposite.

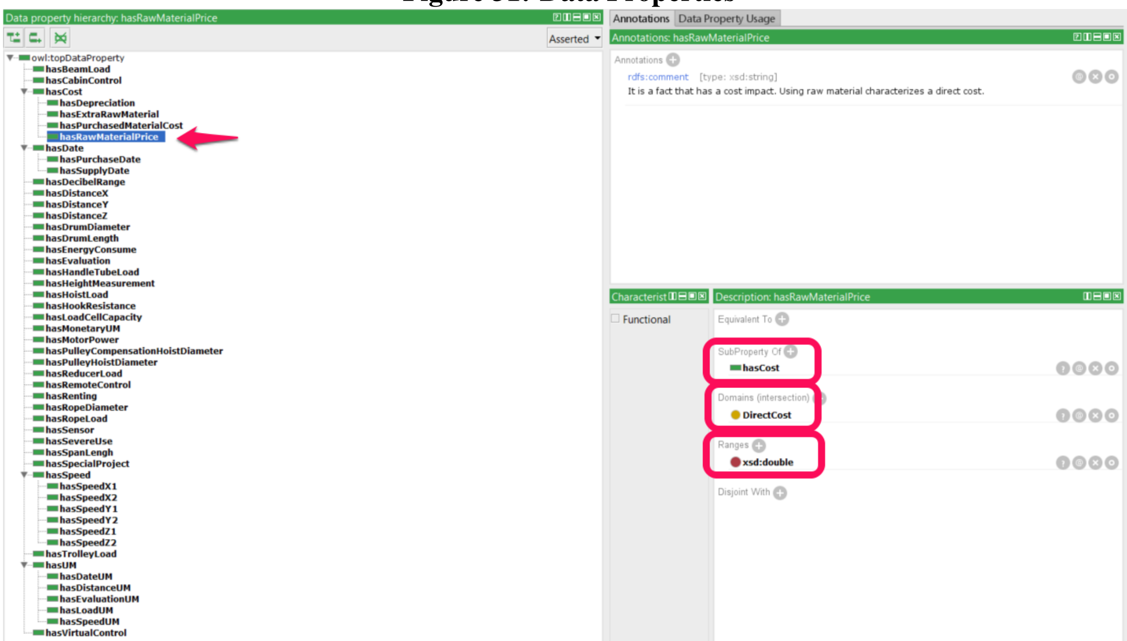
Figure 30: Description of the property `toMoveX`



Source: The Author

Figure 31 brings the Data Properties describing relationships between an individual and data values. Each property is used to state a specific value about the context. To facilitate the organization, some properties are located as sub-levels of a property, as `hasCost`. Under this property are presented some different variations of costs. For example, `RawMaterialPrice` means cost classified as a direct cost belonging to the class DIRECTCOST. The slot receives a numeric value as the cost. The value-type set is double because a decimal numeric value is required.

Figure 31: Data Properties



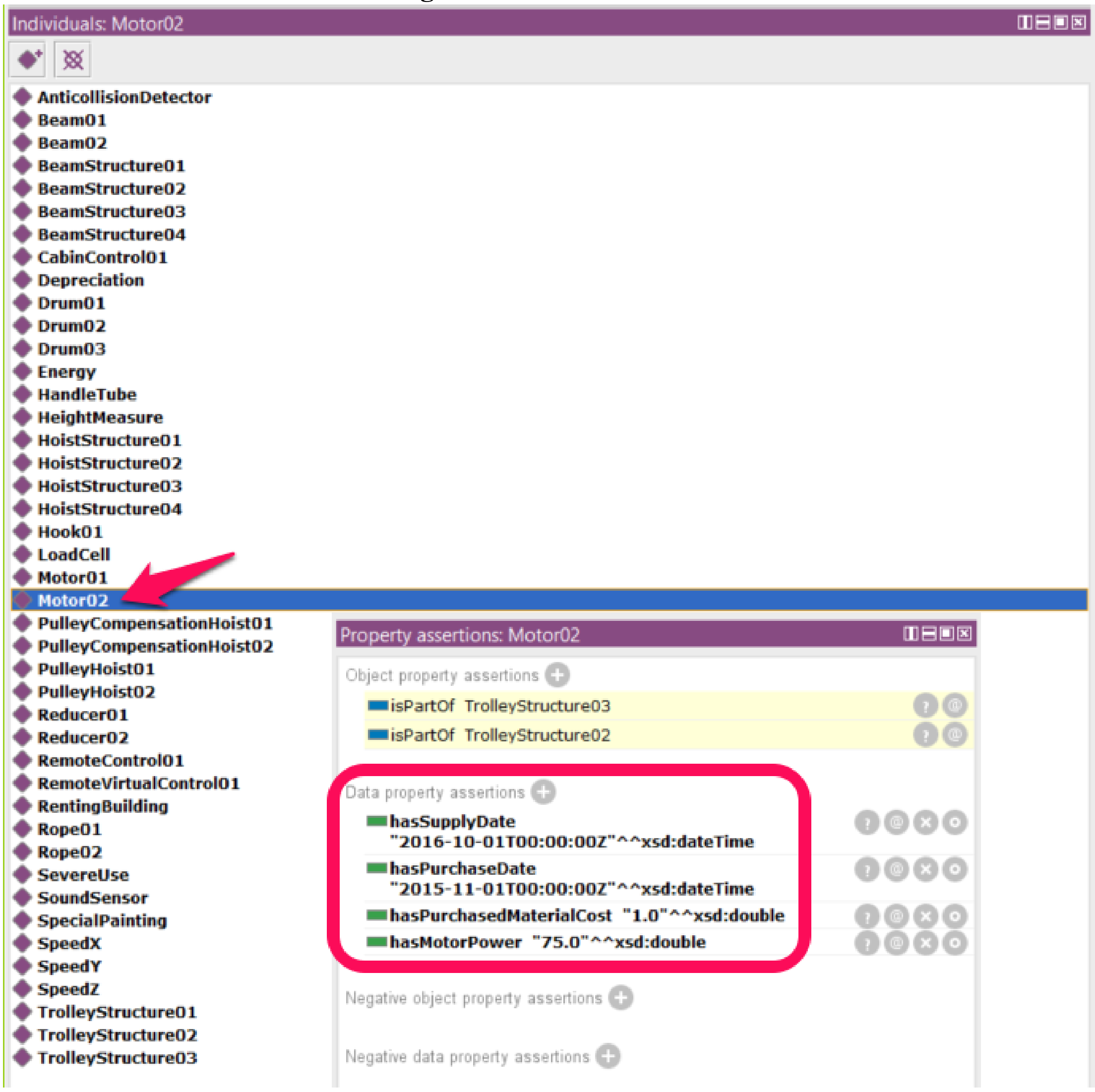
Source: The Author

The facets of the slots were created simultaneously with the slots. This directive is useful to fortify the comprehension, it flows with the development.

4.2.6 CREATE INSTANCES

The last tab in the software Protégé brings the individuals as shown in Figure 32. Each instance is related to a class to create individual characteristics in the hierarchy. The selected instance is `Motor02`. The slots available give the purchase and supply date, the speed, power and the item cost.

Figure 32: Individuals list

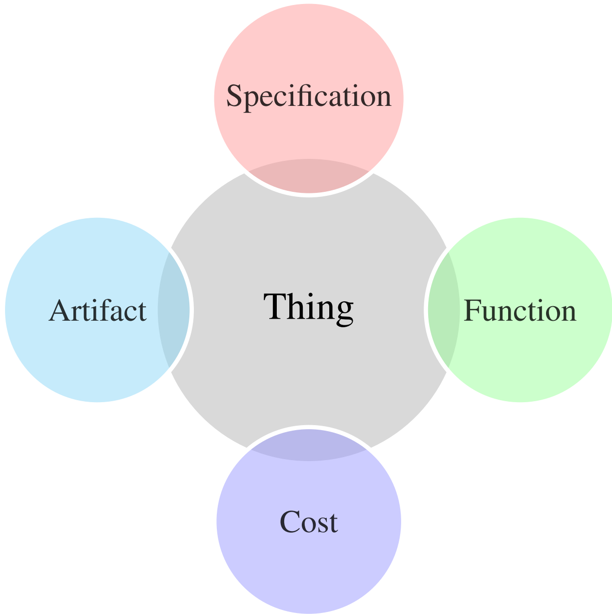


Source: The Author

4.2.7 FUNCTIONALITY

This subsection is not indicated in the 101 steps, but is useful to express the developer ideas. The ontology functionality is divided into four categories as showed in Figure 33. The artifact brings the data from the equipment, passing by costs to collect the values referred to the

Figure 33: Ontology functionality

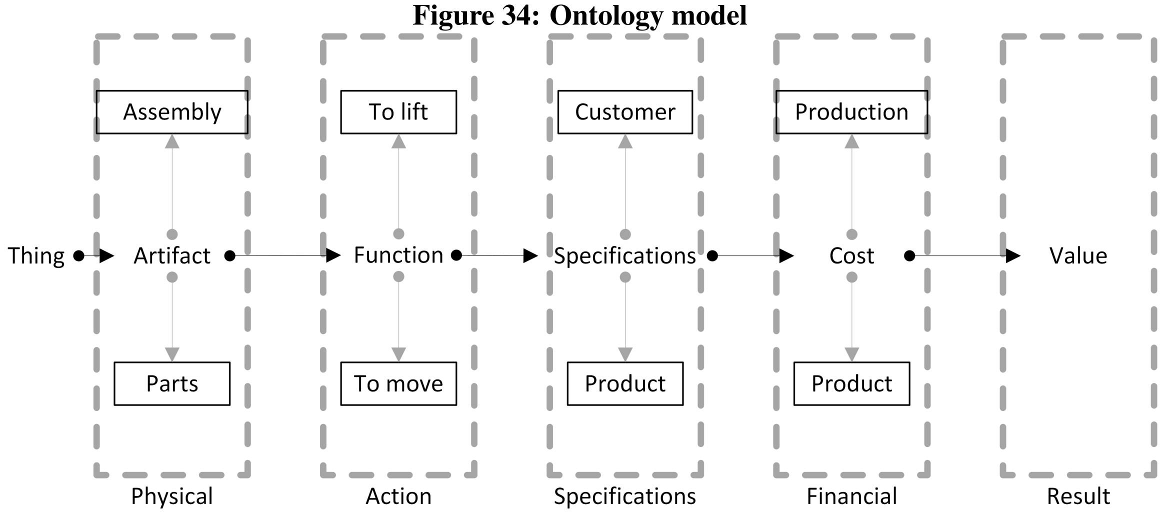


Source: The Author

domain. The function based logic are the orientation to construct any knowledge and create a query. At last, specification differs the equipment accordingly to the configurations required.

Figure 34 supply an overview of the ontology structure and the relation with each element. THING is a start point to any ontology due Protégé ontology editor. The first stage, PARTS, represent the physical stage. Integrate this group material objects, specific parts and assemblies compounding the equipment. To state any argument or construct a logic to generate knowledge the ontology uses FUNCTION. The basis product functionality relies on the functions to lift and to move. Both produces movement characterizing the equipment actions.

Figure 34: Ontology model



Source: The Author

What differ one product variation to another one are the SPECIFICATION. An assembly can share any components, but one different single part characterize it as a new product with it own specifications. It can have a strong capacity or it has a special controller, it is already a new customer requirement transformed in a product. Then, to estimate the costs of the new product developed the stage COST consider product and production costs. As this ontology aims to reuse knowledge, each part has a singular cost stored in the database from previous projects. When a new cost estimation is done, compounding parts, assemblies, satisfying the functions the customer required grouping the right specifications, the ES sum all costs and retrieve a product final cost. It can be complete product or a specific assembly, depends on what the query asks for.

Functions can be used in different ways. To lift and to move appear in the ontology connected to the core. The product cannot work without consider to use the functions. Or it will lift a load or it will move it in some direction. As presented in the general objectives, the ES aims to act in initial stages. The customer requirements are unclear and it represent a risk to the project. The strategy, in this case, is to transform regular requirements used in past projects in functions. This approach contributes to the reuse of requirements whenever necessary. As all products have a function, this solution collaborates with the interoperability of the ontology. Table 6 list the functions considered to query the ontology and find information.

Table 6: Customer requirements translated in functions

Project requirement	Function
Load capacity	To lift minimum load To lift maximum load
Movement speed	To move slow To move fast
Lifting speed	To lift slow To lift fast
Severe use classification	To resist severe use To resist regular use
Lifting height	To suspend large heights To suspend regular heights
Runway length	To move large distances To move regular distances
Command	To use remote control To control virtually To control by cabin station
Standardization	To standardize suppliers
Specific needs	To buy special items To design special items To develop new products
High temperature	To resist high temperatures
Special paintings	To coat with special paint
Special handling devices	To handle by electromagnet To handle pallet To handle steel bars To handle tubes
Load Cell	To measure load
Special sensors	To detect collision To detect distance To detect noise

Source: The Author

In the costs context, the use of functions allows estimating the value of the action. The crane product itself does not have a definite final cost. But the sum of the functions added to it has. In order to construct the equipment within the ontological model, the customer requirements are inserted along with a verb and predicate. The question ”How much cost to lift 25 kg?” contains the following information. The cost question refers to the price. The function is tied to the verb to lift, as in to lift a load. The magnitude and unit of measurement in the value of 25 kg are representations of the customer's requirements. The question in natural language is translated by the ontology expert for the artificial language and inserted in the Sparql plugin. The result is composed of agents that meet the assumptions described in the question.

Before thinking about the description of the equipment, its primary functions are listed. A product to hoist loads with a magnitude and to move them by a certain distance. These functions may comprise products such as hoist, overhead crane, moving devices and even the human being himself. In addition to the functions ”to lift a load” and ”to move a load”, the ontology takes advantage of formal relations that interconnect one instance to another also by functions. For example: to move faster, to control virtually, to measure magnitude, among others. This generality allows the model reuse for other products. At the beginning of the project it is complex to imagine classes and instances and connect them to functions. But in the development of the solution the process becomes fluid and the mechanisms create links giving meaning to the structure.

During the demonstration, the function column in Table 6 is highlighted by the dialog between the sales department and the customer. In addition, queries developed to construct the knowledge are presented.

4.3 DEMONSTRATION

The demonstration is performed by using queries with Sparql in Protégé. The first query is presented in Algorithm 1. It can be presented in artificial or natural language. In natural language, the query asks for the cost of an item, the motor. The query is not specifying any model variation, then the answer has to return all costs of all items. The artificial language follows a different approach. The first stage is to declare the prefix, the scheme used in the query (W3C, 2018). It appoints the variable `?t` and says it has a part which belongs to the variable `?motor`. `?motor` is still an empty slot. Then, the query states `?motor` has a power motor with the data property `FC:hasMotorPower`. The variable `?power` is just auxiliary. Also, the query says `?motor` has a certain cost with the data property `FC:hasCost`. The cost is called by the variable `?cost`. The result, presented in Figure 35, are the individuals called `Motor`. Both registered result are presented. The second column is the costs. The results are all the number one due to the strategy to use symbolic value to simulate the application.

The cost estimation could contain actual industry data. But this process takes time and availability from both the industry and the researcher. The decision to use illustrative data cooperated with the restricted timeline. Each instance that represents a cost to the assembly received the value of a single monetary unit. A product with 5 components costs 5 monetary units as well as a product with 1000 items costs 1000 monetary units. To simulate the cost estimation this approach collaborated with the Protégé fast compilation and satisfactory results for the artifact understanding. In real industrial cases it is necessary to change the values of the instances slots, which does not reduce the applicability of the model.

Algorithm 1 Query #01 - How much is the motor?

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX FC:</function_cost_18#>

SELECT ?motor ?cost
WHERE
{
?t FC:hasPart ?motor.
?motor FC:hasMotorPower ?power.
?motor FC:hasCost ?cost.
}
```

Source: The Author

Figure 35: Query #01 result

?motor	?cost
FC:Motor02	1.0
FC:Motor02	1.0
FC:Motor01	1.0

Source: The Author

The second query asks for the registration date of purchase and supply. As shown in Algorithm 2, `?t` has a part characterized by the variable `?motor`. It is important to mention a variable named motor does not characterize the individual as a motor. The data property `hasMotorPower` is used to filter the parts named motors. Using this property, only instances that are motors will satisfy the condition. The items inserted in the slot `?motor` has a cost and the data property is requesting this data to store in the variable `?cost`. At last, the data properties `hasPurchaseDate` and `hasSupplyDate` request the registration date to store in the variables `?datep` and `?dates`, respectively.

Algorithm 2 Query #02 - Are there any purchase and supply date register of the motor item?

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX FC:</function_cost_18#>

SELECT ?motor ?cost ?datep ?dates
WHERE
{
?t FC:hasPart ?motor.
?motor FC:hasMotorPower ?power.
?motor FC:hasCost ?cost.
?motor FC:hasPurchaseDate ?datep.
?motor FC:hasSupplyDate ?dates
}
```

Source: The Author

Figure 36: Query #02 result

?motor	?cost	?datep	?dates
FC:Motor02	1.0	2015-11-01T00:00:00Z^^xsd:dateTime	2016-10-01T00:00:00Z^^xsd:dateTime
FC:Motor02	1.0	2015-11-01T00:00:00Z^^xsd:dateTime	2016-10-01T00:00:00Z^^xsd:dateTime
FC:Motor01	1.0	2017-10-01T00:00:00Z^^xsd:dateTime	2018-01-10T00:00:00Z^^xsd:dateTime

Source: The Author

The next query has the intent to request an assembly which the motor is part of. Algorithm 3 exposes `?t` has a part - a component - containing a property of motor power. Still, it is part of an assembly. The result is sorted in ascending alphabetical order. Figure 37 present the ontology has two motor variations belonging to three different assemblies. It indicates a motor can be part of different assemblies. `TrolleyStructure` is an instance representing an assembly, if it has a different component inside it is characterized as a different assembly.

Source: The Author

Algorithm 3 Query #03 - Which assembly has a motor item?

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX FC:</function_cost_18#>

SELECT ?motor ?Assembly
WHERE
{
?t FC:hasPart ?motor.
?motor FC:hasMotorPower ?power.
?motor FC:isPartOf ?Assembly.
}
ORDER BY ASC (?Assembly)
```

Figure 37: Result of Query 03

?motor	?Assembly
FC:Motor01	FC:TrolleyStructure01
FC:Motor02	FC:TrolleyStructure02
FC:Motor02	FC:TrolleyStructure02
FC:Motor02	FC:TrolleyStructure03
FC:Motor02	FC:TrolleyStructure03

Source: The Author

All assembly is compound by parts. It means the assembly cost is the sum of each part. Algorithm 4 uses the function SUM to return the sum of all parts of the assembly. The query asks for the parts belonging to the assembly `TrolleyStructure01` and then the cost of each one. Figure 38 presents the value 4.0 because this assembly has four parts with the cost 1.0.

Algorithm 4 Query #04 - How much is the assembly TrolleyStructure01?

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX FC:</function_cost_18#>

SELECT (SUM (?cost) as ?total)
WHERE
{
FC:TrolleyStructure01 FC:hasPart ?parts.
?parts FC:hasCost ?cost
}
```

Source: The Author

Figure 38: Result of Query 04

?total
4.0

Source: The Author

Algorithm 5 asks for the sum of part costs of the assembly TrolleyStructure03. The function SUM deliver the final result in the variable ?total. Figure 39 present the result seven because this is the number of parts belonging to the assembly (Drum03, SpecialPainting, Motor02, Reducer02, SevereUse, AnticollisionDetector, PulleyCompensationHoist02).

Algorithm 5 Query #05 - What is the cost of the assembly TrolleyStructure03?

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX FC:</function_cost_18#>

SELECT (SUM (?cost) as ?total)
WHERE
{
FC:TrolleyStructure03 FC:hasPart ?parts.
?parts FC:hasCost ?cost
}
```

Source: The Author

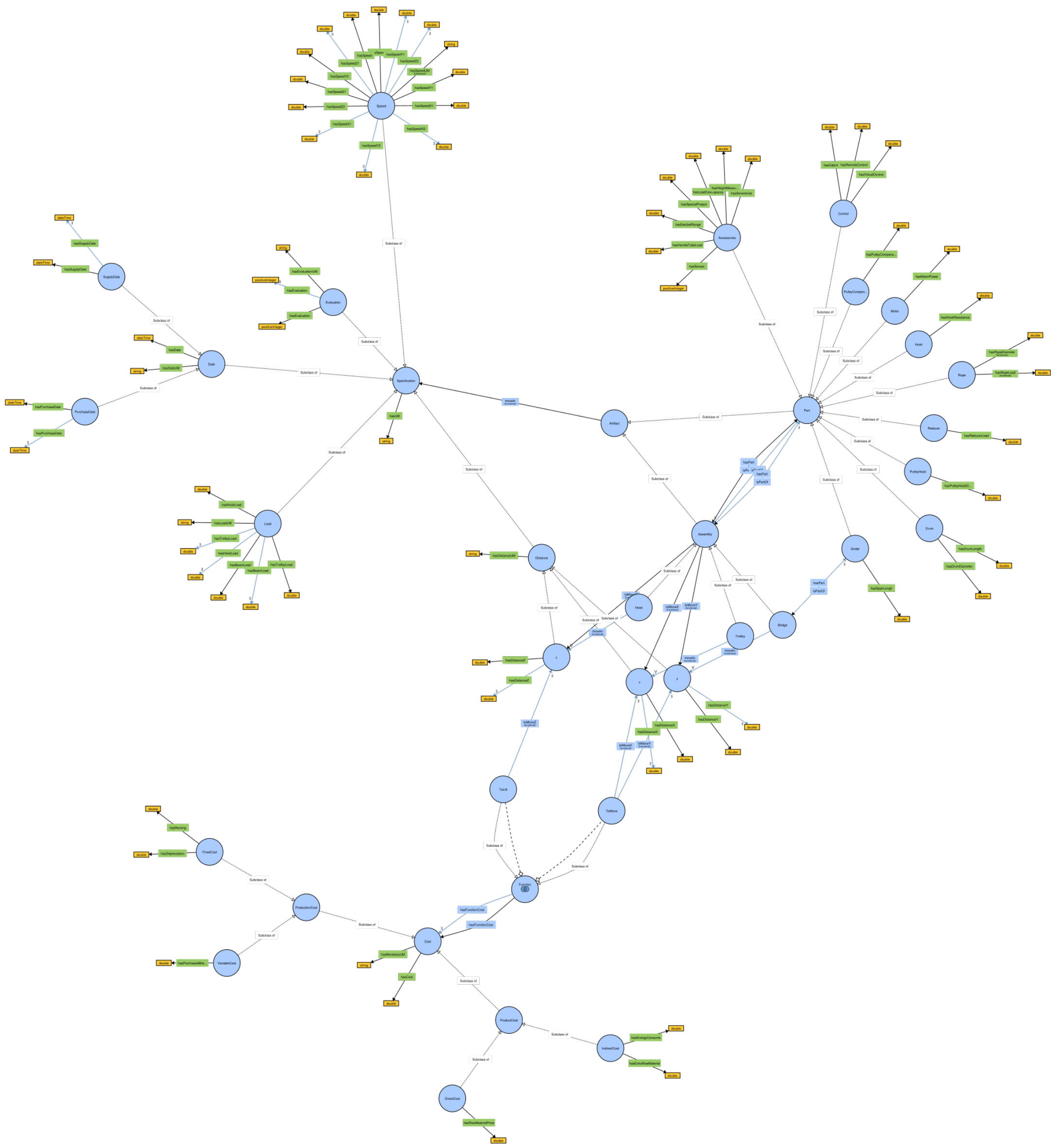
Figure 39: Result of Query 05

?total
7.0

Source: The Author

An ontology has different alternatives to be represented, it depends on the plugin or software used. WebVOWL is a web application to support the ontology visualization. Figure 40 is an overview of all ontology. In blue there are classes, in green data properties and in yellow the datatype (is the type of the data the slot accept).

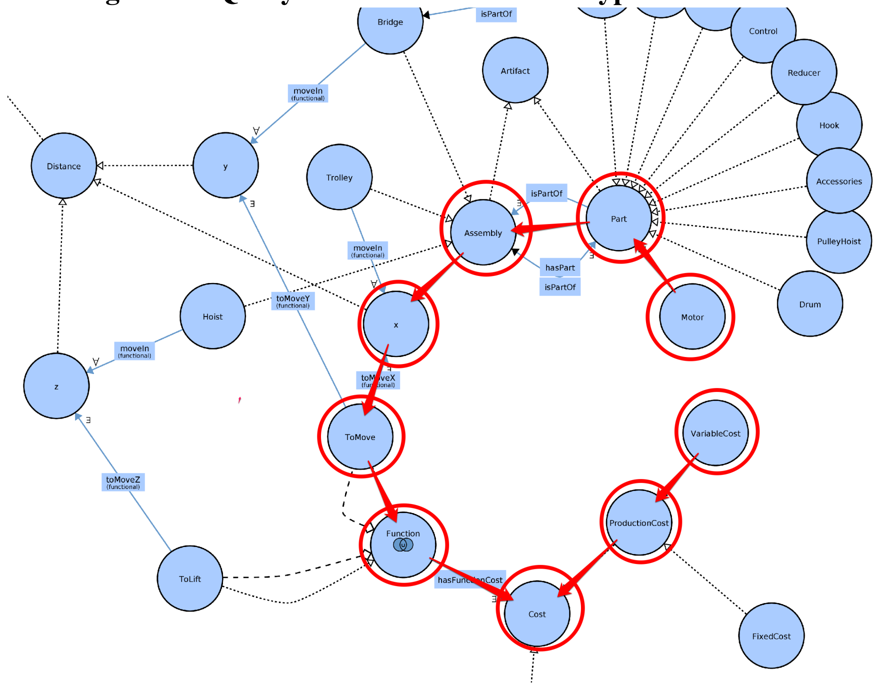
Figure 40: WebVOWL ontology visualization



Source: The Author

Assuming a different approach to understand the ontology content, Figure 41 asks for the motor cost type. Still using WebVOWL with a different visualization, it is possible to see the connections to achieve the result. The objective of this approach is to show the logic behind the ontology. The class MOTOR is a sub-class of PART, which is a sub-class of ASSEMBLY. The assembly TROLLEY always moves in a direction. Thus, the MOTOR passes by the function TOMOVE in the X axis which belongs to the class FUNCTION. The ontology logic state the functions are always connected to a COST. As MOTOR is classified as a VARIABLECOST, it is a sub-class of PRODUCTIONCOST been part of COST. The ontology make connections between classes considering triples in the form of subject–predicate–object expressions. For example, MOTOR - `isPartOf` - ASSEMBLY, the subject MOTOR uses the predicate `isPartOf` to indicate the relation with the object ASSEMBLY.

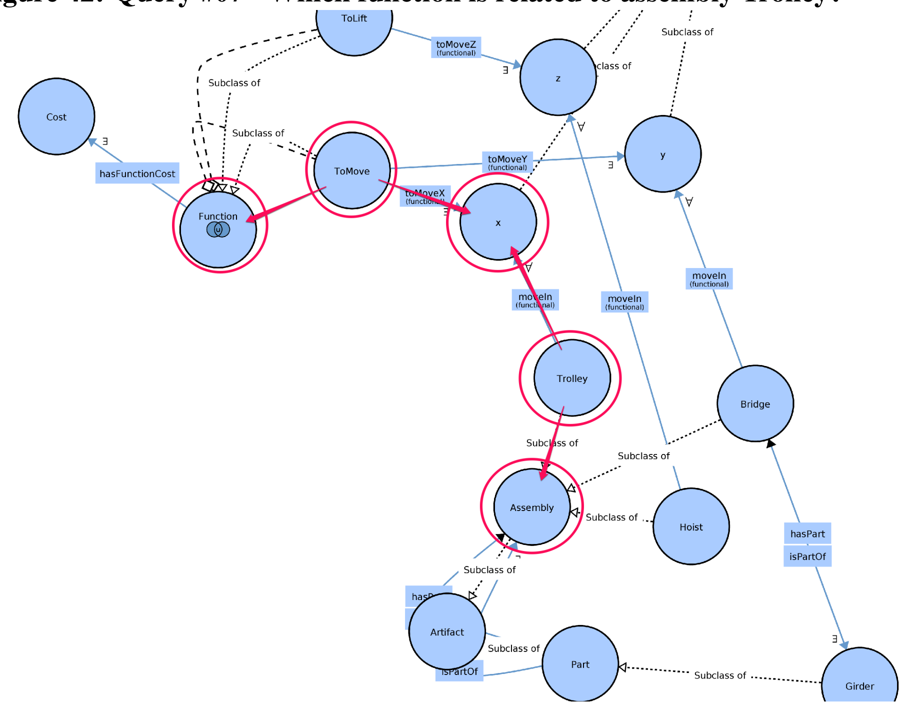
Figure 41: Query #06 - Which is the cost type of motor item?



Source: The Author

Figure 42 seeks to represent a connection between an assembly to a function. All assembly instances inferred in TROLLEY has in common the movement in x-axis. The function TOMOVE is responsible for the axis X and Y. In this case the X is used due to the connection with TROLLEY while BRIDGE is ignored.

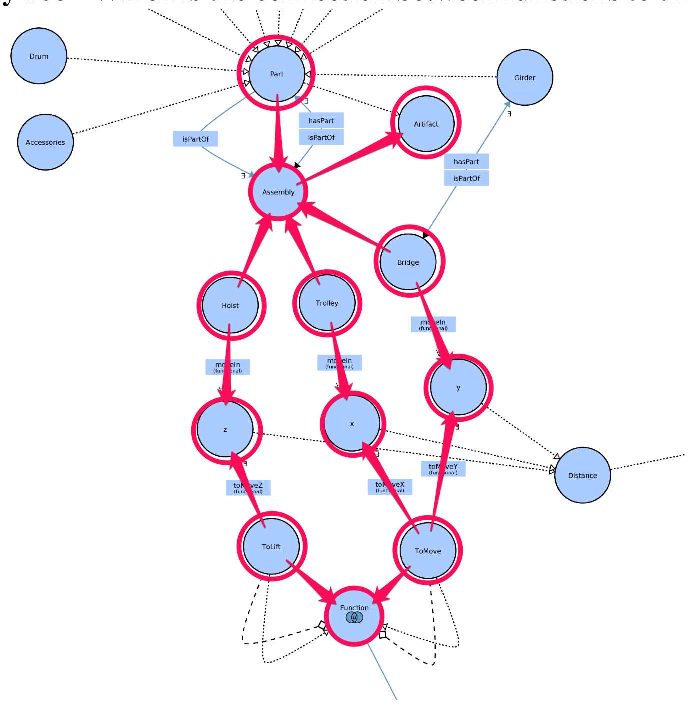
Figure 42: Query #07 - Which function is related to assembly Trolley?



Source: The Author

The equipment overhead crane has mostly two main functions. To lift a load from the inertia and to move the load through a distance by the field plane. Figure 43 focus on the relation between the equipment and the functions. Analyzing from the bottom, FUNCTION has two sub-classes, TOLIFT and TOMOVE. The only alternative to perform a given function is through the axis X, Y or Z. Following the structure logic, all assemblies are connected to a specific axis. In the end, they belong to the ASSEMBLY which has PART and are sub-class of ARTIFACT. Thus, the equipment has a close connection to the functions.

Figure 43: Query #08 - Which is the connection between functions to the equipment?



Source: The Author

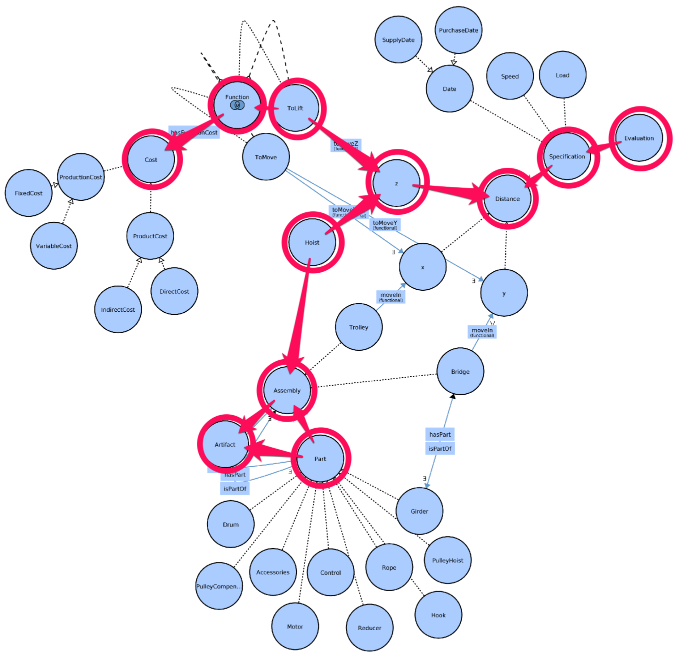
Now bringing together the two approaches the result is enlightening. The Algorithm 6 brings the question referring a specification. It uses the data property `hasHoistLoad` because the instance `HoistStructure` have an evaluation integrated. The `hasEvaluation` is used to draw the evaluation. This query is accompanied by the both alternatives answers. Using WebVOWL, Figure 44 presents the connections. The EVALUATION is a sub-class of SPECIFICATION connected to the axis Z by the class DISTANCE. As requested by the query, the Z-axis is connected to the class HOIST, which is an assembly compound by parts defining an artifact. The function linked to the Z-axis is TOLIFT, always related to costs. Figure 45 present the results with grades varying between 4 and 5. The benefits of using grades when the knowledge is reused relies on avoiding mistakes from past projects. Results without any register does not appear.

Source: The Author

Algorithm 6 Query #09 - Is there a performance feedback from an assembly in past sales?

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX FC:</function_cost_18#>

SELECT  ?item ?grade
WHERE
{
?item FC:hasHoistLoad ?load.
?item FC:hasEvaluation ?grade
}
```

Figure 44: Query #09 - Is there a performance feedback from an assembly in past sales?



Source: The Author

Figure 45: Result of Query 09

?item	?grade
FC:HoistStructure03	5
FC:HoistStructure01	5
FC:HoistStructure02	4

Source: The Author

The following demonstration example brings the competency questions described previously in the methodology aspects. It is represented the customer getting in contact with the sales department in natural language. Then, the artificial language is presented. The example is illustrative and in a shortened version of real speech case. Surely the customer would not have so much initial conviction of what he or she seeks. Figure 46 presents the customer query and the sales department retrieving a direct answer faster as it was using the ontology to support the service. The company produces overhead crane and the customer have in mind an equipment with a specific capacity and distance limit. The sales specialist certainly could ask for a pause to retrieve the answer, however using the ES the process is instantaneous. The inference lasts a few seconds on average depending the computer processing.

Figure 46: Query #10 expressed in natural language - Competency question #01

How much does it cost to hoist the load X1, with two lifting speeds X2 and X3, moving the load with speeds X4 and X5, in lateral and longitudinal directions, respectively? Also, is required a robust body, remote-controlled device to handle tubes and collision sensors. The shed has the following measures: 20x100x20 meters (W x L x H). (Consider X1=50 t, X2=4 m/min, X3=8 m/min, X4=20 m/min, X5= 30m/min)

Customer

Sure, the cost estimation is 16 monetary units.

Sales department

Source: The Author

The resulting value is illustrative. It means that 16 things are monetized. If the ontology has real values from a company, the final result can be approximated to the real cost estimation. Algorithm 7 presents the Query #10 in an artificial language using the plugin Sparql in Protégé, the reasoner Pellet is used to compile. The query is divided in three modules using `UNION` to join them. The first takes the x-axis results, the second the y-axis and then, the third the z-axis. Looking the first module, the query asks for the distance the variable `?crane` will move. Then, the load capacity and the speed. The `hasTrolleyLoad` variable is specific to the x-axis, which filter most part of results avoiding other axis. `hasSpeedX1` means one speed alternative. If the result is not sufficient, the query must use both speed limits to filter the right result. The distance is kept in `?x`, the load in `?xl` and the speed in the `?sx`. Then, the query focus on all parts compounding `?crane` and asks for the cost of each item using `hasCost`. The filter exclude any out-of-context result. The function `sum( )` takes all costs and unify in the same slot called `?result` to present a single result.

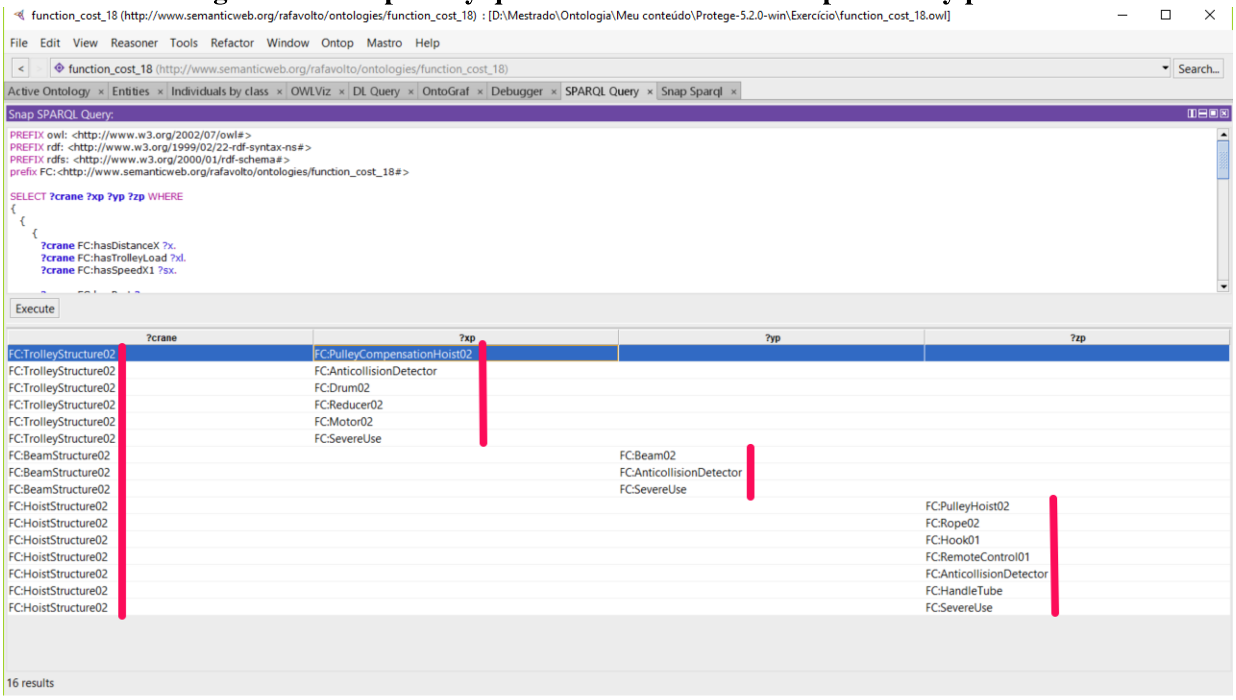
Algorithm 7 Query #10 - Competency question #01

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix FC:</function_cost_18#>

SELECT  (SUM(?cost) as ?result) WHERE
{
    {
            ?crane FC:hasDistanceX ?x.
            ?crane FC:hasTrolleyLoad ?xl.
            ?crane FC:hasSpeedX1 ?sx.

            ?crane FC:hasPart ?xp.
            ?xp FC:hasCost ?cost.

            FILTER(?x = 20 && ?xl =50 && ?sx=20)
    }
UNION
    {
            ?crane FC:hasDistanceY ?y.
            ?crane FC:hasBeamLoad ?yl.
            ?crane FC:hasSpeedY1 ?sy.

            ?crane FC:hasPart ?yp.
            ?yp FC:hasCost ?cost.

            FILTER(?y=100 && ?yl=50 && ?sy=20)
    }
UNION
    {
            ?crane FC:hasDistanceZ ?z.
            ?crane FC:hasHoistLoad ?zl.
            ?crane FC:hasSpeedZ1 ?sz.

            ?crane FC:hasPart ?zp.
            ?zp FC:hasCost ?cost.

            FILTER(?z=20 && ?zl=50 && ?sz=4)
    }
}
```

Source: The Author

Figure 47 presents the 16 results obtained in Protégé. Column `?crane` is the variable where all possible results were deposited, the assemblies are shown there. The three remaining columns are the `Parts` with the single value.

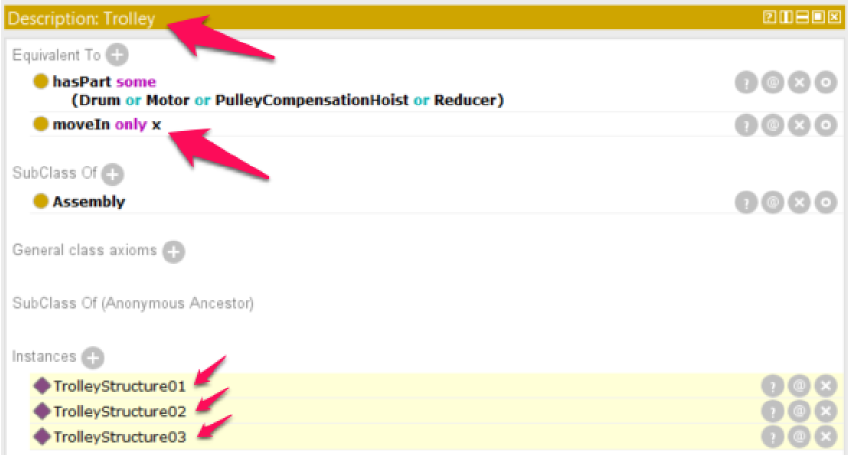
Figure 47: Competency question #01 - Result list separated by parts



Source: The Author

Figure 48 brings the process as Protégé infers the answer in the first module. TROLLEY is the only class moves in x-axis. The three instances belonging to the class are `TrolleyStrucute01`, `TrolleyStrucute02` and `TrolleyStrucute03`. Sparql finds the load considering these three options.

Figure 48: Competency question #01 - Class TROLLEY inferences



Source: The Author

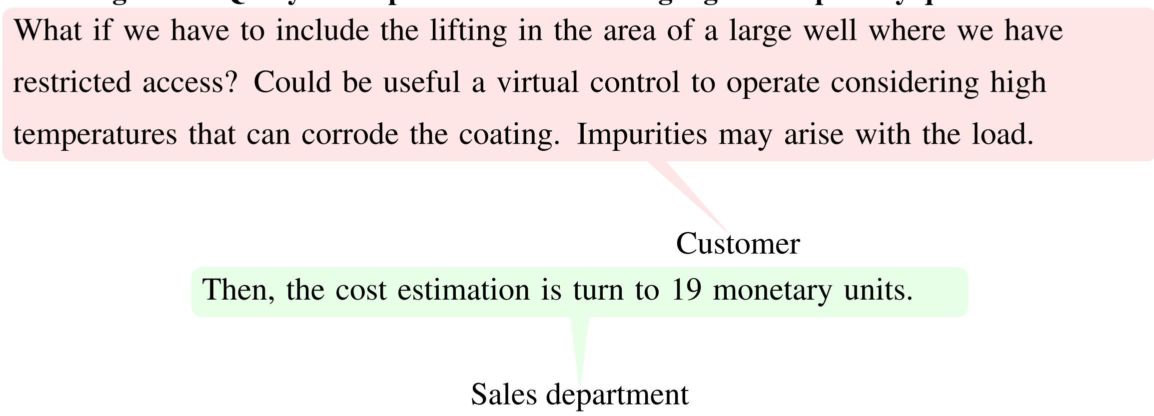
The function `Filter` focuses on `TrolleyStructure02` according to the requirements. Several parts are connected to the assembly, but only the results that fit the filter are suitable. Figure 49 presents the Data Property assertions with the green rectangle the filter uses to select the appropriate result.

Figure 49: Competency question #01 - Assembly TROLLEYSTRUCTURE02

Source: The Author

On the second competency question the customer changes the approach and reconstructs the structure of their requirements. When the natural language changes, the artificial language query has to change accordingly. Figure 50 presents the customer inserting specific conditions as the restricted access. Also, he/she adds components with special characteristics and uncertainties. In the real world it represents a changing of the customer requirements, starting the cost estimation from the begin. But, as the ontology reuse knowledge, it does not change nothing and the cost estimation continue normally. If the ontology has not the database complete, the benefits vanish.

Figure 50: Query #11 expressed in natural language - Competency question #02



Source: The Author

The Algorithm 8 presents the second competency questions in the artificial language. The customer looks undecided and he/she is changing requirements that has to be changed in the code. A few lines included are enough to find the result.

Algorithm 8 Query #11 - Competency question #02

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix FC:</function_cost_18#>

SELECT  (SUM(?cost) as ?result) WHERE
{
   {
          ?crane FC:hasDistanceX ?x.
          ?crane FC:hasTrolleyLoad ?xl.
          ?crane FC:hasSpeedX1 ?sx.
          ?crane FC:hasPart ?xp.
          ?xp FC:hasCost ?cost.
          FILTER(?x = 20 && ?xl =50 && ?sx=20)
   }
UNION
   {
          ?crane FC:hasDistanceY ?y.
          ?crane FC:hasBeamLoad ?yl.
          ?crane FC:hasSpeedY1 ?sy.
          ?crane FC:hasPart ?yp.
          ?yp FC:hasCost ?cost.
          FILTER(?y=100 && ?yl=50 && ?sy=20)
   }
UNION
   {
          ?crane FC:hasDistanceZ ?z.
          ?crane FC:hasHoistLoad ?zl.
          ?crane FC:hasSpeedZ1 ?sz.
          ?crane FC:hasPart ?zp.
          ?zp FC:hasCost ?cost.
          FILTER(?z=20 && ?zl=50 && ?sz=4)
   }
}
```

Source: The Author

The third competency question, presented in Figure 51, includes even more requirements. The customer includes a control to avoid risks to operator and distance detectors. Even with query changes, the ontology specialist finds the results instantly changing the query.

Figure 51: Query #12 expressed in natural language - Competency question #03

What if a control cabin with noise control is required to avoid operator risk? It is also necessary to detect the variable depth of the well and the load to be hoisted without collision.

Customer

With these requirements, the final cost is 23 monetary units.

Sales department

Source: The Author

Algorithm 9 is similar to the others competency questions, with more components to consider.

Algorithm 9 Query #12 - Competency question #03

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix FC:</function_cost_18#>

SELECT (SUM(?cost) as ?resposta) WHERE
{
   {
          ?crane FC:hasDistanceX ?x.
          ?crane FC:hasTrolleyLoad ?xl.
          ?crane FC:hasSpeedX1 ?sx.
          ?crane FC:hasPart ?xp.
          ?xp FC:hasCost ?cost.
          FILTER(?x=20 && ?xl=60 && ?sx=20)
   }
   UNION
   {
          ?crane FC:hasDistanceY ?y.
          ?crane FC:hasBeamLoad ?yl.
          ?crane FC:hasSpeedY1 ?sy.
          ?crane FC:hasPart ?yp.
          ?yp FC:hasCost ?cost.
          FILTER(?y=130 && ?yl=50 && ?sy=20)
   }
UNION
   {
          ?crane FC:hasDistanceZ ?z.
          ?crane FC:hasHoistLoad ?zl.
          ?crane FC:hasSpeedZ1 ?sz.
          ?crane FC:hasPart ?zp.
          ?zp FC:hasCost ?cost.
          FILTER(?z=120 && ?zl=50 && ?sz=4)
   }
}
```

Source: The Author

After presenting the queries, Table 6 can be improved with the demonstration of where it was applied. Table 7 bring the questions allied to the functions. To clarify the understanding of the project requirements, the function column works as the connection between each query and the doubt solved. The column Class/Instance brings the classes or instances related to subject. The other three columns present the competency question where the requirement was presented.

The first competency question asked a regular content, a specific load with different speed to lift and move. The severe use means a body with resistance to deal with shocks and also harsh environments. The remote control is an optional as the special part to handle tubes. The collision detector is a security components important in this situation. The column class present the classes in caps lock and the instances in the soft typing to better represent the right relation with the project requirement. The standardization have blank spaces due to the company choice to check this variable. The specific needs are also a company choice, because it represent a value summed when a project begin to satisfy a customer request.

The second competency question include a bigger area, not specified yet. Could be bigger then what is informed. The accessory virtual control is required and is informed high temperatures, which the severe use may deal with the special painting. Finally, the third competency question refers to a noise place. The customer request a cabin control with noise resistance to protect the operator. An equipment to measure the sound around the cabin is a good practice. A detector is included to measure the depth during the service, as well a load cell to measure the load.

The standardization line means a resource the company can complies as an internal data. If the supplier is or the product are part of the standard line, it means a different value to accomplish the final cost. They are not included in the table, but available in the logic. Specific needs could represent the forth competency question presented in the begin of the section. If exist the opportunity to design for the first time, an additional cost could be included and marked in the specific need line. Maybe a new accessory or device, or a totally new product letting the responsibility to the design and development team. The customer have to know this implies an additional cost.

Table 7: Customer requirements translated in functions

Project requirement	Function	CLASS/Instance	Q1	Q2	Q3
Load capacity	To lift minimum load To lift maximum load	LOAD	X		
Movement speed	To move slow To move fast	SPEED	X		
Lifting speed	To lift slow To lift fast	SPEED	X		
Severe use classification	To resist severe use To resist regular use	`SevereUse`	X		
Lifting height	To suspend large heights To suspend regular heights	DISTANCE		X	
Runway length	To move large distances To move regular distances	DISTANCE		X	

Command	To use remote control
	To control virtually
	To control by cabin station
		`RemoteControl`
		`RemoteVirtualControl`
		`CabinControl`
			X	
				X
					
					X

Standardization	To standardize suppliers	-	-	-	-
Specific needs	To buy special items To design special items To develop new products	ACCESSORIES	-	-	-
High temperature	To resist high temperatures	`SevereUse`		X	
Special paintings	To coat with special paint	`SpecialPainting`		X	
Special handling devices	To handle by electromagnet To handle pallet To handle steel bars To handle tubes	ACCESSORIES ACCESSORIES ACCESSORIES `HandleTube`	 X		
Load Cell	To measure load	`LoadCell`			X

Special sensors	To detect collision
	To detect distance
	To detect noise
		`AnticollisionDetector`
		`HeightMeasure`
		`SoundSensor`
			X		
					X
					X

Source: The Author

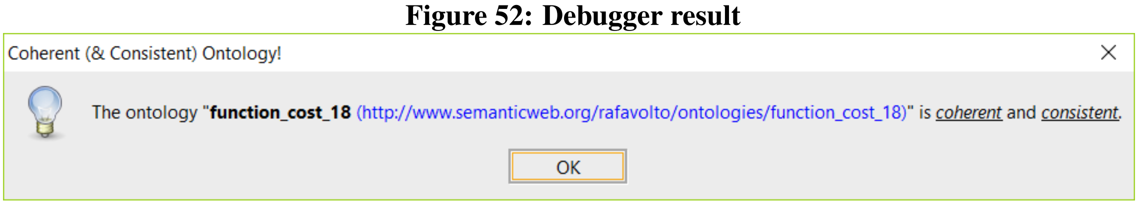
The ontology knowledge-based reuse data from past projects. However, if the query refers to a new case not described in the database, the ontologist could have difficulties to find the answer. A new case represent different applications or the costumer requiring two overhead crane synchronized. Is it possible to develop for the first time? The answer is yes, despite leak of explicit knowledge in the ontology database. The company can consider a instance with a cost to develop new projects. Searching for data is also an ontology advantage. It is not the faster solution, but acts as a support.

4.4 EVALUATION

The evaluation means to test the artifact on solving a problem. While in the demonstration the artifact needs to show that it meets the objectives, in the evaluation phase it is necessary to prove that it serves well. The ontology must answer the competency questions satisfactory. Peffers et al. (2007) suggest relevant metrics and analysis techniques. The researcher has to decide if the artifact satisfies the objectives or if it is necessary to return to the initial stages to solve problems. Improve the development according to the metrics chosen is an iterative process. The artifact evaluation was conducted with the following methods: Debugger, OOPS! and FOCA. Debugger is a plugin of Protégé to verify if the ontology is coherent and consistent. OOPS! is a tool for detecting pitfalls and possible errors. Finally, FOCA is a methodology to evaluate ontologies based on quality criteria.

Figure 52 presents the Debugger result. First, the plugin verify the existence of a reasoner. The ontology already uses the reasoner Pellet, so the plugin moves on. It checks the consistency and coherence. There are none obvious errors, but Debugger indicates possible faulty axioms. The user has to check the consistency off all axioms to verify if it is rightly defined. If the plugin finds a doubt, it asks for a positive or negative answer. If yes, the statement is true; if no, not true. As no axioms had this doubt, the ontology is approved on this evaluation stage.

Figure 52: Debugger result



Source: The Author

The second alternative was OOPS!. The tool is a scanner looking for possible modeling errors called pitfalls. Figure 53 present the result containing pitfall and frequency from the previous version. None of all errors discovered are exactly an error. It is necessary to analyze one by one, read the pitfall description and decide on your own if the result impacts negatively on the ontology. As fewer pitfalls, better. After improvements, Figure 54 presents the results of the last ontology version. Pitfalls not considered relevant were ignored. For example, the annotations, even annotations been inserted in all classes, instances and properties the error is accused. If the developer has more time, more efforts can be applied to reduce the pitfalls.

Figure 53: OOPS! result of a previous ontology file

Results for P08: Missing annotations.	108 cases | Minor
Results for P10: Missing disjointness.	ontology* | Important
Results for P11: Missing domain or range in properties.	7 cases | Important
Results for P13: Inverse relationships not explicitly declared.	4 cases | Minor
Results for P19: Defining multiple domains or ranges in properties.	1 case | Critical
Results for P22: Using different naming conventions in the ontology.	ontology* | Minor
Results for P30: Equivalent classes not explicitly declared.	1 case | Important
Results for P41: No license declared.	ontology* | Important

Source: The Author

Figure 54: OOPS! result of the current ontology file

Results for P08: Missing annotations.	103 cases | Minor
Results for P10: Missing disjointness.	ontology* | Important
Results for P13: Inverse relationships not explicitly declared.	4 cases | Minor
Results for P22: Using different naming conventions in the ontology.	ontology* | Minor
Results for P30: Equivalent classes not explicitly declared.	1 case | Important
Results for P41: No license declared.	ontology* | Important

Source: The Author

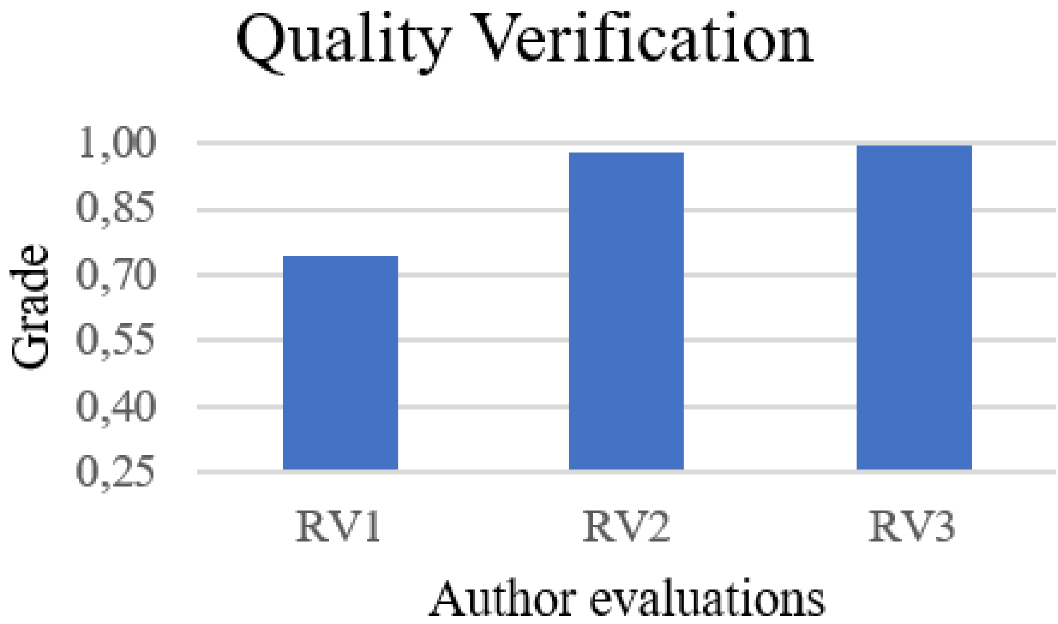
The current ontology version 18 had some troubles indicated and could be improved. The important ones will be discussed. The OOPS advised about missing disjointedness between classes or properties that should be defined as disjoint. This kind of error has to be analyzed calmly, even though the functionality of the ontology was not affected, it is important to eliminate all errors as possible. Other important error is the equivalence between classes FUNCTION and PART. It indicated missing definition of classes as they were duplicated. As the ontology functionality is running well, the error was kept in quarantine. It is necessary to pay attention and avoid this situation in future versions.

Until this stage, both tools depend on the developer ontological knowledge. While DSR collaborates in the all work development, the FOCA seeks to assist in the development of the ontological artifact. From the objectives to be achieved, the ontology receives grades according to certain metrics, such as completeness, adaptability, consistency, among others. Although different ontology evaluation alternatives have criteria, they depend on the evaluator's experience and may therefore be imprecise. Considering this, the methodology FOCA was used as a systematic guide to the developer without experience.

The first evaluation corresponds to a personal analysis. The researcher applied the questionnaire himself during the ontology development to verify the own performance. The evaluations occurred in April, July, and October. It is important to clarify FOCA analyses the participant according to the capacity to answer questions, if it is misunderstood or incapable to answer, the result is zero. The questions applied are established by the authors as presented in Figure 10.

Figure 55 indicates the quality growing over time. RV1 means the tentative on April when the author had low knowledge about the OWL language and could not respond all questions. RV2 characterized a stage with some knowledge, but the ontology was incapable to answer the queries. On October, RV3 indicated performance improvements. The vocabulary, comprehension about the theme and domain increased. FOCA will not allege the ontology is good or not, but will guide the user with metrics to evaluate itself. The questions are always the same, but each time the questionnaire is applied the ontology is different, with more expectations.

Figure 55: FOCA - Personal quality verification



Source: The Author

Then, the next step is to look for external opinions to evaluate the ontology. The methodology suggests specialists on ontology and/or on the domain, in this case, costs. It was published on YouTube - https://www.youtube.com/watch?v=oC5Jpmu6WDw - a video to introduce the participants on the ontology domain. The questionnaire sent using Google Forms - https://goo.gl/forms/VBwfOSF66IMQRMey1m - reproducing the questions defined by the ontology evaluation authors. Attached, four competency questions in natural and artificial language were sent to exemplify the ontology functionality. The questionnaire was sent to 08 ontology specialists, with 06 replies. None of the interviewed had specific knowledge about cost domain, just superficial. It was not sent to cost specialists due to the difficulty to comprehend the computational language. Figure 56 presents the result of the quality verification based on the FOCA general result. The specialist #05 indicated a low grade compared to the others specialists.

Figure 56: FOCA results - Quality Verification general view

Source: The Author

Following the FOCA statistical equation, the results requires an approximation to expose differences between interviewers as presented in Figure 57. The grades can vary from 0.25 to 0.99.

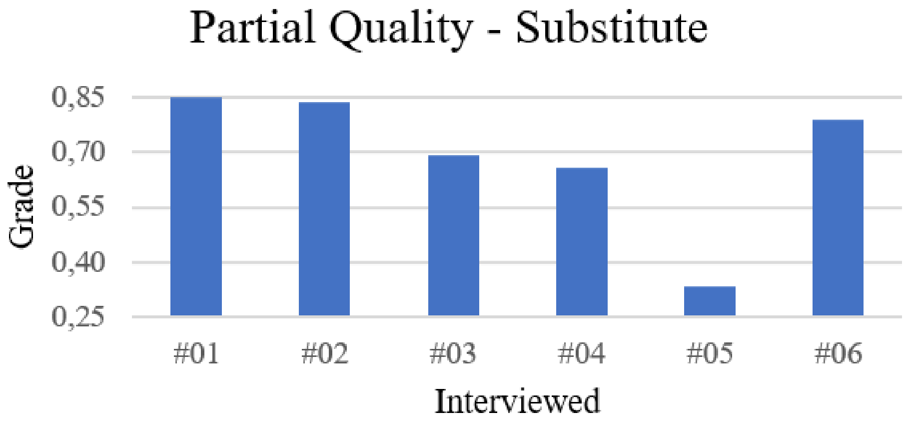
Figure 57: FOCA results - Quality Verification with zoom

Source: The Author

It was suggested new queries to construct the knowledge to the interviewed understand and visualize better. Starting from simple queries and elevating the complexity, as presented in this dissertation followed by three competency questions. All of them argued about missing annotations on ontology version 17, in version 18 it was resolved. The first introduction about the content was not adequate and had improvement, presenting the domain and case. In general, the domain was clear to most part of participants and the ontology was objective to what was specified. As this graphic presents a compilation of all contents, it is important to analyze partially the correspondent roles find the deficiency.

The first partial quality evaluation is the substitute, presented in Figure 58. Substitute role means how the ontology describes the real world by concepts, as closer the concept to the real world better. The result can vary from 0.25 to 0.87 according to the FOCA equation. The interviewed #05 indicated the worst grade because was unclear the ontology based on the competency questions. It was suggested to create queries to be applied before and construct the knowledge until the final competency question as presented in this dissertation. The reuse of others ontologies was unclear to some interviewed. The suggestion was to use the Active Ontology tab to inform the user about the content as clear as possible. In this case the ontology version 18 has an introduction in the first tab satisfying the suggestion.

Figure 58: FOCA results - Substitute



Source: The Author

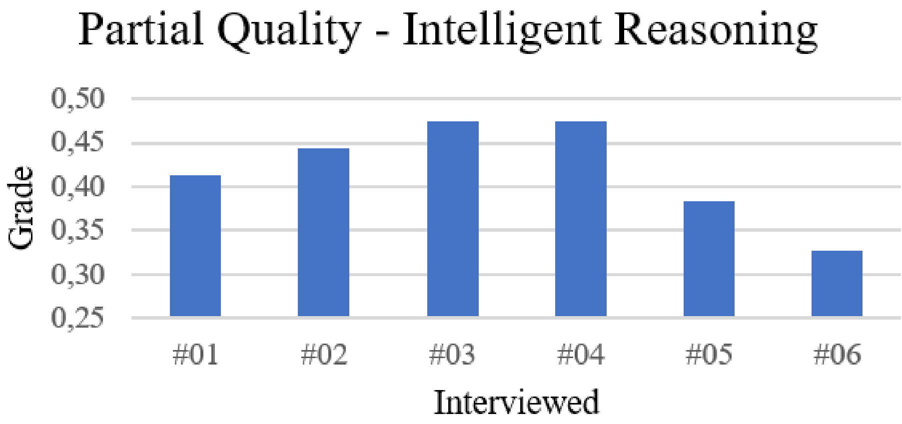
The role ontological commitments, Figure 59, creates a relation to the real world, how similar the ontology is. The result can vary from 0.25 to 0.71. A good grade means consistency in the representation, a high level of abstraction. It was suggested to interview more domain specialists to fortify the cost domain. More insertions about the product could also increase the commitments.

Figure 59: FOCA results - Ontological Commitments

Source: The Author

The intelligent reasoning, Figure 60, means how the ontology infers the world, how the relations and attributes are defined. The grades can vary from 0.25 to 0.48. The specialist #01 commented about the use of terms shared with different domains. For example `Drum`, it can be used as a part of an overhead crane and a musical instrument. The annotations were revised to clarify the user about the content. More consistency could be achieved by increasing the content about the product and cost domain.

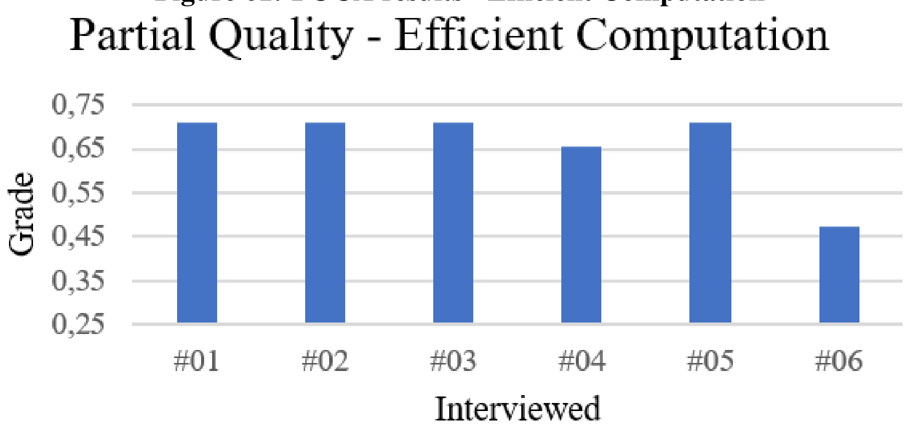
Figure 60: FOCA results - Intelligent Reasoning



Source: The Author

The efficient computation, Figure 61 represents how the ontology can think about a domain in computer applications. The grades can vary from 0.25 to 0.71. The researcher tested different reasoners (Pellet, HermiT, Ontop). Pellet was the faster been used during all the development process. To answer the questionnaire, it was suggested this reasoner to achieve satisfactory grades. As only one interviewed evaluated with a low grade, this case was disregard because could represent a local case or incapable machine.

Figure 61: FOCA results - Efficient Computation



Source: The Author

The human expression, the fifth goal, means how easy it was to understand the modeling. All grades were 75% or 100% positive, characterizing a good understanding between ontology specialists without knowledge about the domain.

Sharing the knowledge of ontology experts was a beneficial decision. Several tips helped to build the artifact and learning. Exposing the code to other experts is a risky, as an apprentice still commit mistakes that are characteristic of a lack of understanding about the subject. Some interviewees are part of the LAMIS laboratory and collaborated with the abstraction of the researcher. Using the FOCA methodology could be a prerequisite for the development of ontologies in the lab. Research colleagues improving the artifact continuously. Despite of Baliyan and Verma (2019) describe the method as cumbersome, it is useful to guide the ontology evaluation in the lab, even more with non-experience developers.

Some suggestions were simple and should have been corrected at first. The absence of annotations is a basic error in the construction of the ontology and must be inserted in all classes, instances and properties. One of the evaluators suggested the use of the WebVOWL virtual resource for visualization of the ontology. When the user changes the perspective of how the artifact is viewed, it changes the mental understanding of the object of study. There were comments describing the difficulty of understanding the application domain and consistency about cost domain. OOPS and Debugger collaborated on syntax and architecture, but shared benefits that the editor Protégé itself offers.

Finishing the evaluation phase the author was satisfied with the artifact working well. Many improvements were made from the previous version 17 to the last one, version 18. The OWL code is available in https://github.com/rafavolto/FC_ontology.

5 FINAL REMARKS

To estimate costs in initial phases of PD is a complex activity which can be supported by intelligent systems. Many variables and uncertainties of the conceptual project make the specialist unsafe to develop an assertive product in a short time. In order to construct an artifact that assists involved professionals, it is necessary to follow a systematic structure. Methods ensure a process of artifact construction focused on the result. The artifact, in an ontological model form, reuses data of previous projects in order to generate knowledge to new cost estimates. Although the research follows an academic pattern, the developed structure can be adapted to industrial scenarios.

It is presented a case study about an overhead crane for a cost estimate supported by an ontological model in PD. The costs are generated in a structured way through semantic knowledges. The artifact was developed using Protégé ontology editor in order to construct and to simulate the model applicability. Different from tools that use CAD model to generate costs, like LeanCOST, the proposal is to estimate the initial phase costs before the existing tools.

The product's final costs being defined at the beginning of the project contribute to decision makings. Components and assemblies had their costs quickly revealed by the artifact with the information reuse. The ontology benefits the scenario when one uses the cost estimate based on cost specialist's implicit knowledges. Assemblies with different component possibilities now instantaneously have a defined cost. Costs dependent of unavailable information are not a problem anymore.

Database can be responsible for the cost gap. The ontology does not make monetary adjustment. It seeks components and/or assemblies which can integrate the product and it deliveries the requested cost. Hence, if database is constantly updated, cost estimate will be assertive; with outdated data, the ontology reduces the level of proximity with the final cost. The more consistent the database is, the closer is it the real value.

To construct an ontology is a hard process. The developer needs to create logical links with the content where mind maps contribute with the organization of ideas. The use of methods as 101 is indispensable. Researchers with no experience have guidelines to achieve structured results at their disposal. Once each ontology is unique, systemic process is a key to promising results.

It is necessary to understand the OWL and semantic intelligence to construct the artifact. It is also necessary a database about a product and to organize ideas that allow to structure the ontology. Each activity requires a part of the available time. Among the steps described by DSR, the assessment is where the artifact is open to constructive criticism and where it can be improved. FOCA exposed vulnerabilities of the ontology that were imperceptible in the solution development. It makes evident the worth of a concise rather than a superficial assessment. The larger the openness to find flaws, the more consistent the artifact becomes. The use of the FOCA methodology could be a strategy to develop ontologies in the laboratory, the work team continuously seek improvements.

To migrate the artifact to the industry, the actual amount of data must be larger. This means a database that can be accessed by the ontology. A consistent database collaborates with consistent results. The inclusion of classes, and consequently properties, is another possible improvement by the proximity to the industry. In this project, the management of the ontology was restricted to the developer, but in the industrial context it is necessary to analyze who can really work with this tool. To find the answers and generate knowledge, an ontology expert is suitable. Since the search is performed in artificial language, it is necessary to understand about the domain of the ontology to extract from the properties and instances of the questions. The cost specialist can help build the ontology, but he is unable to extract data without specific knowledge.

As many authors highlight, the importance of the ontological approach in the industrial context is relevant. There are opportunities to reduce the time in customer service. Reducing the cost sector dependency on the engineering sector contributes to the flow of the process. If the company produces data continuously, not using them is a waste. The reuse of information gives the industry the capacity for interoperability and exponential growth of knowledge about its own product. Competitiveness is directly benefited by the ontological model.

On the other hand, despite the merits of the artifact, the use of the intelligent system is still complex and restricted to specialists of information technology. Not all companies have a sufficient database to feed AI. The search for information using the Sparql plugin in the Protégé ontology editor requires practice and knowledge in other technologies. The editor on his own does not meet industrial demand. Unless there are efforts to create a favorable environment to the construction of the ontology, it is important to question if it compensates for the development of an ontology without proper support.

More research could be developed to address the use of machine learning. With each inference, the machine increases the amount of data. With each question, a new information feeds the database in the construction of knowledge. It can be an alternative to avoid repetitive tasks. Another future research is the use of local databases that allow the ontology to access the data and infer remotely. Or, even, the use of Stardog tool (STARDOG, 2018) instead of the Protégé Sparql plugin. This tool is fed by a virtual database, for example DBPedia, and makes inferences in the Stardog itself. Approaches that improve the human-machine interaction usually have multiple benefits.

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