Integration of Design Intent during the Product Lifecycle Management

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Abstract. There has been significant achievement in integrating product data during the whole lifecycle phases with shared common ontologies while taking advantage of intelligent retrieval mechanisms. In order to support integrated decision making on product redesign or maintenance operations, we should solve a challenging issue: 'how the product lifecycle management (PLM) stores and retrieves the know-how and the knowledge of an organization concerning manufactured products'. This paper describes the extension of a previously developed PLM Semantic Ontology Model toward integration with design intent. The proposed approach uses OWL2 to represent product lifecycle data and design knowledge. The approach was applied to the redesign of a car door part for laser welding. Our work demonstrates how to retrieve design intent as a specific type of knowledge data in the context of design decisions. Such an approach can ultimately contribute to reducing design time, making knowledge transfer clear and thus improving the quality of designed products.

Keywords: product lifecycle, semantic ontology, design intent, knowledge, know-how, OWL, Protégé, QLM

1 Introduction and motivation

The closed-loop product lifecycle management (PLM) system focuses on tracking and managing the information of the whole product lifecycle, with possible feedback on information to product lifecycle phases. It provides opportunities to reduce the inefficiency of lifecycle operations and improve competitiveness (Kiritsis 2013). Thanks to the advent of hardware and software related to product identification technologies, e.g., radio frequency identification (RFID) technology, closed-loop PLM has been recently highlighted as a tool for companies to enhance the performance of their business models. However, the information on PLM has primarily dealt with some predefined physical product data, i.e., material characteristics of designed products and their usage information. Knowledge data concerning the design of products has not been dealt with sufficiently in depth in currently available PLM approaches. Within the range of our knowledge, there are very few research results which handle the design knowledge coming from the product design phases or redesign phases. The impact of design changes on the other manufacturing information has not been sufficiently studied, so there is a lack of experience in this area.

The management of companies' intangible assets and intellectual capital has long been a key issue in the domain of business and management science. Some parts of product data should be shared with the other intangible assets of a company. Product design requires intensive communication between designers and production engineers. In a general case, only the geometry and numerical data remain in the company's database once a product shape has been determined. This entails the loss of information about why this design was determined and what designers intended during redesign. The design is defined as this-is-the-way-we-do-things in the company. Lost knowledge, however, is critical information when introducing new manufacturing technology or new composite materials.

For the reasons mentioned above, domain professionals have already acknowledged the importance of representing and sharing product data during the different phases of the product lifecycle. There has been significant achievement in integrating product data from beginning of life (BOL), to the middle of life (MOL), until its end of life (EOL), especially using shared common ontologies and intelligent retrieval mechanisms (Matsokis and Kiritsis 2011). PLM has specific objectives in each phase of the lifecycle: During the BOL, the improvement of product design and production quality is the main concerns; During the MOL, improving reliability, availability, and maintainability of products is the most interesting issue; In the EOL, optimizing EOL products' recovery operations is one of the most challenging issues.

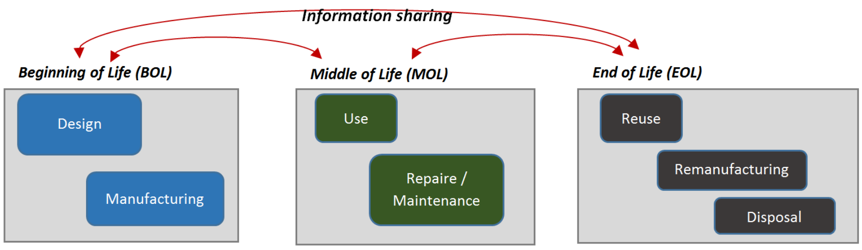

Fig. 1. Product lifecycle phase and data sharing

Turning to the research on representing know-how and knowledge, we can find some literature about approaches using meta-data and history-based models in design activities of BOL. At the end of the 1970s and early 1980s Kjellberg proposed having a 'description of origin' associated with geometric elements (Kjellberg 1983). After the publication of standard for product data exchange, Pratt mentioned the necessity to capture the intention of the designer which can get lost during product changes (Pratt and Anderson 2001). Mun defined 'design intent' and proposed macro files for saving the modelling commands with the parametric approach, which was standardized by ISO 10303 (Mun et al. 2003). Han also realized a macro-parametric method in commercial CAD systems (Han 2010). Through the efforts of these researchers, the fundamental of capturing design intents is possible. In the context of aircraft manufacture, Price tried to maintain intent by redesigning the parameters of frames related to joining processes in (Price et al. 2013).

This paper discusses new concepts for capturing general knowledge and shows how to share it during the real redesign process of an automotive door assembly line. Such integration will play an important role during decision making across different divisions including decisions about product redesign or maintenance operations.

From now on the paper is organized as follows. Section 2 presents a global concept of extended PLM Semantic Ontology Model (SOM) based on our previous work (Matsokis A. and Kiritsis D. 2011). Section 3 is devoted to the introduction of our case study: a car part manufacturing example focusing on its design data and parameters in use. Then in Section 4, we will show how the model presented in Section 2 is adapted to the case study, in terms of data popularization and query proposition for knowledge retrieval. Finally, Section 5 gives a short summary of our work and its impact.

2 Product-lifecycle data management with knowledge management

2.1 Semantic model

Ontology-based approaches to semantic modelling of product lifecycle management were one of the main outcomes from the European project PROMISE (Promise 2009). The PROMISE approach manages information and knowledge generated during the product lifecycle which are then linked with decision support systems and data transformation software. Their implementation demonstrated that the use of ontology makes it possible to reuse the PLM model increasing interoperability between different PLM phases. Currently the results are being submitted to Open Group Open Platform 3 (OpenPlatform3) in order to get the status of approved standard, which is one of the main activities of the QLM workgroup (Quantum Lifecycle Management – *see* QLM)

Fig. 1 illustrates the different phases of product lifecycle in general. The products' beginning of life (BOL) phase can be further divided into two categories of activity: i) The design of products, ii) the manufacturing of products. In PROMISE, the management of BOL data was mainly considered based upon the fact that a product has already been designed (Fig.2). As a result, the model describes well some details on the physical product, their composition and manufacturing information, however, still missing the capability of describing knowledge related with design activity of BOL.

Subsequently, our work focused on the extension and integration of Beginning of life (BOL) product data, putting special emphasis on the Design Phase BOL (corresponding to the upper-left part of Fig.1). Given that "Personal_Resource (the role of Human Actor)", "Material Resource" and "Physical Product" are already defined in PLM SOM, the new concepts in the extend semantic model include (Fig. 3):

1. Integration of the concept (i.e., ontology class) of "Knowledge Data" and "Knowledge Resource"

2. Definition of the "Competence" concept
3. Integration of the concept of "Service" which is on the hub of four other concepts, i.e., "Competence", "Knowledge", "Material Resource", and "Actor"

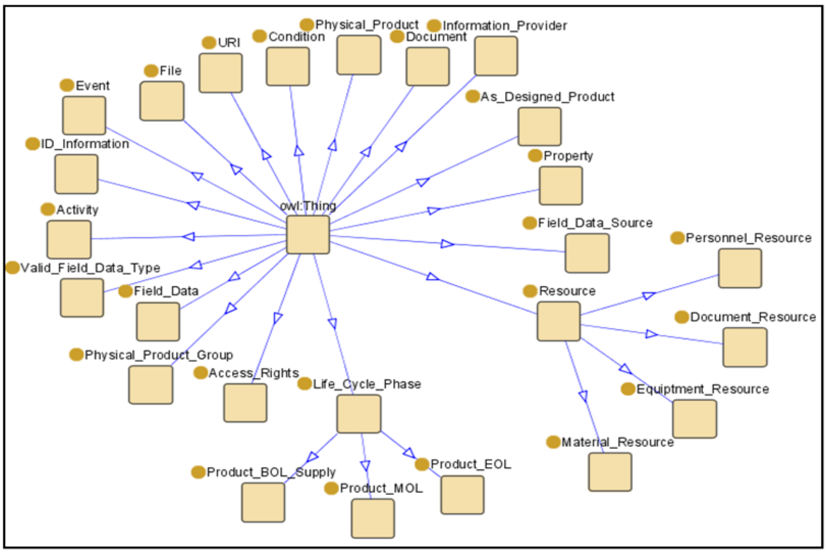

Fig. 2. PROMISE Product Data and Knowledge Management (PDKM) Semantic Object Model (SOM)

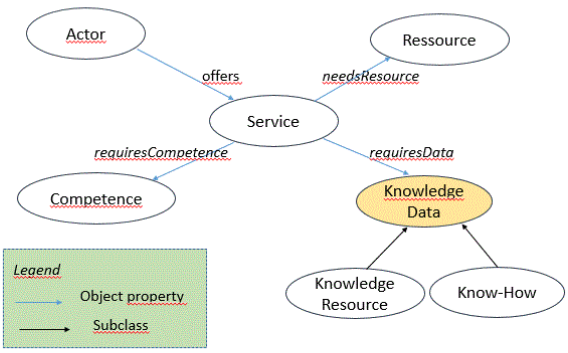

Fig. 3. Extended model of PLM SOM – High-level concept

The service concept represents general business activities offered by a human actor, a team or an organization. In that context, "Competence" is an important intangible asset for achieving the required service by a distinctive actor. Competence can be reinterpreted as being capable of doing some activities; capable of managing some situations; capable of using a tool or an application. Knowledge Data has two sub-concept definitions: i) Knowledge Resource, and ii) Know-How.

The Know-how class represents the company's information on cumulative, lifelong experience and activities which are related with the tangible and intangible product creation and improvement. Different to the technical knowledge on physical products, Know-How data may contain even some negative experience and resulting outcomes. From the point of a company's competence development, such kind of know-now management is important for the purpose of studying past cases and use it for "learning from experience". Therefore the following two points have driven this research direction: i) how to integrate an industry's intangible assets which are related to the product PLM data; and, ii) how to reuse them.

For that purpose, the model extension has been achieved being based on the high-level semantic model presented in Fig. 3. The resulting model was then further specialized in order to be suitable for an industrial design case: the welding assembly line of the car door frame (Fig. 4). Here we use the words 'class' and 'concept' as mutually interchangeable (similar) terms, which are the object class definition in Protégé (Protégé).

1. The class of Design_Parameter is created for the purpose of modelling some important parameters which are considered through design decision making.
2. Design_Process_Activiy class is defined as a subclass of existing Activity concept.
3. Computer_Aided_Tool is further specialized containing several subclasses: CAD_tool, CAM_tool, Specific_Software.
4. In this extended model, another product information in design phase is added, i.e., Design_InProgress, for the purpose of associating data which can either be produced or referenced during the product design phase. Consequently, the classes which indicate product lifecycle phases are also distinguished while representing more specialized product lifecycle phases, i.e., Product_BOL_Design and Product_BOL_Supply.
5. The Design_Intent class is newly created as a subclass of Know_How. Another subclass of Know_How, Consumer_Intent plays a similar role from the customer sides and internal service designe teams, which will not be detailed in this paper.
6. The existing class Physical_Resource is specialized providing three subclasses: i) Environmental_Asset which represents information such as buildings, workshops; ii) Equipement; iii) Materials.

2.2 Model description

The above-presented semantic model was built and tested using the Protégé-OWL ontology tool. Since its creation, OWL-DL(Description Logic) was used for the purpose of describing classes and individuals included in PLM PDKM SOM. OWL-DL was initially developed to provide the maximum expressiveness in tandem with guaranteeing both computational completeness (all conclusions are guaranteed to be computable) and decidability (all computations will finish in finite time). OWL-DL includes all OWL language constructs (such as transitive properties, which allow more of the semantics of sequences to be represented explicitly than in RDF or OWL lite) and it allows modelling at multiple levels of abstraction (and thus, sequences of classes can be characterized by their general or more specific properties).

In PROMISE SOM, there are already more than 70 object property definitions which relate different concepts and individuals. Some of them are given below as an example:

- isDesigned: in order to relate a physical product to its design details;
- hasDefined: as an inverse relation of isDesigned, that is to say, from a designed product to a physical product;
- Life_Cycle_Phase2Activity: which links the life cycle phase of a product to its activity details;
- Life_Cycle_Phase2Physical_Product: similarly to Life_Cycle_Phase2Activity, this property allows to retrieve the physical product of a given life cycle phase;
- Equipment_Resource2Property: for the purpose of searching the property of a given equipment resource, and so on.

For the purpose of complementing the existing object properties, we have newly created some supplementary relationships. Some key elements are given below.

- Contains_DesignedPart: this object property helps, based on a given types of physical product, retrieve the information of a designed product part.
- Defines: this object property is added in order to get the evaluation criteria of a given resource characteristic. The material characteristics are retrievable by giving a certain design intent category with the help of 'DesignResource_Concerns' (see below).
- DesignResource_Concerns: thie property links a particular design intent type to all related resources. Such an information is important for the purpose of retrieving a part of physical product information which were designed according to a certain design intent type.
- Design_Concerns: this property links a particular design intent type to a physical product for the purpose of retrieving information on past experience. With the help of this object property, we can answer to the questions as 'which products are designed as a result of design intent type xxx?'
- Refers2_Parameters: in order to search the KPI parameters which are related with a give design intent and to find further information such as equipment and material resources.

3 Case study

An example of the importance of explicit design intent can be illustrated using the example of a car door and its use in the Remote Laser Welding project RLW Navigator. The RLW Navigator project studies laser welding, in particular in the car industry and uses the welding of a car door as an example.

Laser welding is an alternative to spot welding and offers several benefits over the traditional technology. However, it is not easy to realise all the benefits because current practice is built into the design at an early stage. In addition, the car door is a complex product for which commercial time pressures preclude rationalisation of the design process. However, without such rationalisation it is difficult to change process elements and hence take advantage of new technological advances. The car door example and its handling in the RLW project can be illustrated in Fig. 4.

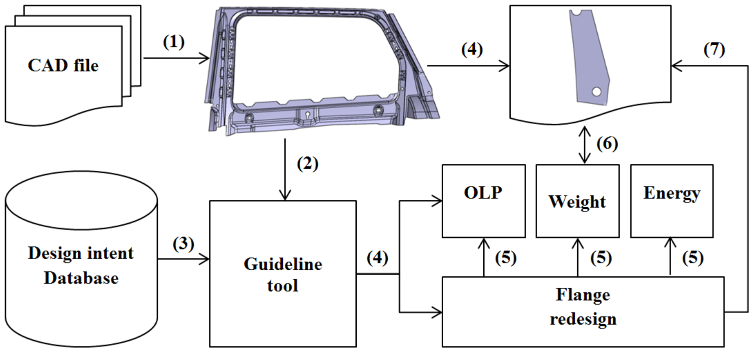

Fig. 4. Operation procedure of guideline

The input for the modification task is a CAD file which lacks design intent information. As for many other applications the design intent has to be supplied through human interaction or semi-automatic feature recognition. The relevant features are those which can be modified for laser welding, in this case the flanges. The flange redesign tool is illustrated in Fig. 5. The flanges are classified, resized and reintroduced into the design to make the final CAD model.

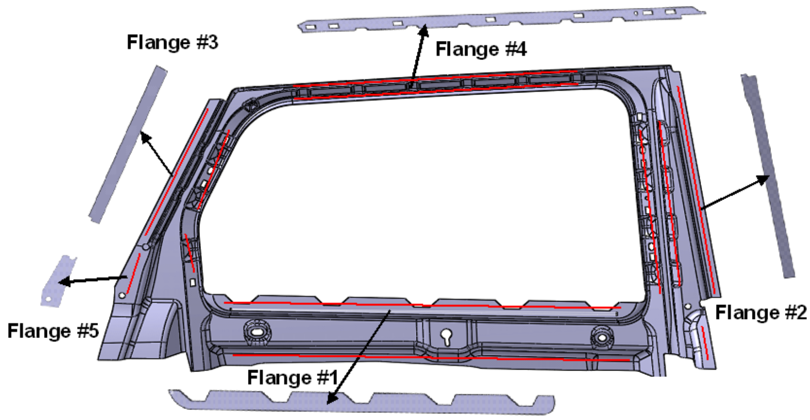

Fig. 5. Flange classification

In terms of design intent, this work is hindered both by the lack of special CAD tools and the integration of manufacturing information into the design at an early phase. Logically there should be a shaping phase to determine the part to be made and then a manufacturing phase to realise the shape, making appropriate modifications to the original shape to accommodate the manufacturing decisions. The realisation decision has various implications for manufacturing. For example, if the door is to be made as a solid frame with overlaid panels then this would be recorded as a decision, the door frame shape extracted from the overall shape and the door panels designed. A different decision about the manufacturing method would start from this point.

Current practice involves making the door out of pressed sheet metal. This involves creating a sheet metal frame which is done by splitting the door shape into parts, pressing them and then welding them together. Another consequence of this decision is that the hinge part needs to be reinforced because the rest of the door has to be made from thin material for weight reasons which is too weak for normal use. Other elements, such as a strengthening bar, are also added for different reasons. All these decisions need to be recorded and structured in order to be able to cope with future developments and avoid becoming locked into an inefficient production cycle. The flanges are added to the design as a consequence of the decision to split the door shape. The flange shapes depend on the join line and it would be logical to have an automatic tool to create the flange shape. This would also mean that the shape can be classified automatically as a flange rather than identified manually later. The use of advanced application tools to provide high-level information about complex shapes is an important step in recording design intent.

4 Instantiation of the semantic model for the purpose of data popularization

The following individuals (i.e., instances of classes) are created in order to associate required field data with the PLM Semantic Ontology Model. Fig. 6 shows a part of individuals created and visualized using Protégé:

1. The five parts of flanges are modeled as five distinctive individuals of the Complex_Physical_Product, e.g., Flange1, Flange2, Flange3, Flange4, and Flange5.
2. Individuals of Design_Parameter class is created and linked : Efficiency, Energy_Use, Welding_Reduction, Processing_Time, Quality, Environmental_factor.
3. The individual elements of Design_Process_Activity have been created according to the general concept described by Nigel Cross, (Engineering design methods, Cross 2008): Clarifying_objective, Establishing_function, Setting_Requirement, Determining_characteristics, Generating_alternative, and Evaluating_alternative, Improving_details.
4. While using the existing class “Parameter” in PLM SOM, Designe_Parameter is associated.

Afterward, we verified the model using “Pellet” reasoner (Protégé). As a proof of concept of the case study, we used the DL Query and SPARQL Query tabs supported by Protégé, while looking for answers to the following queries:

- Which types of design intent were used in the past?
- Which design intent variables (primitives) are primarily considered for each type of design decision?
- Which design intent types are used for the purpose of “Flange design”, for

example?
- Which physical products are related with a given type of design intent? And in what PLM cycle (BOL, MOL, EOL) is the product currently?
- Considering a given material resource, which design intent is associated with it? This question is particularly important for the purpose of knowing the impact on the material resources and equipment in the case of choosing a certain design intent among several options.

5 Concluding remarks

The purpose of the work presented in this paper is to demonstrate how to extend and improve previously developed ontology for product lifecycle management with the design intent know-how data within a semantically understandable concepts and relationships. The benefits from such integration are clear:

1. The relationship between a) Design Decision data (i.e., design intent) and b) Designed Product data (manufacturing details determined through some design intent and design decision.) during the whole cycle of PLM is visible and traceable.
2. We can predict which parameters or manufacturing processes are important whenever new design is proposed, and which tools were used for evaluating previous design. It means how to use the know-how and how to collaborate with related persons.
3. Supposing that individuals of human resources shall be provided according to the defined ontology, we shall be able to find as well who are the persons related to the decision of each part design or manufacturing process, which means who has the know-how.

Our work demonstrates suitable ontology model as well as the way of retrieving a particular type of know-how (i.e., design intent) in the context of current design decisions. Such an approach can ultimately contribute to reducing design time, making knowledge transfer clear and thus improving the quality of designed products.

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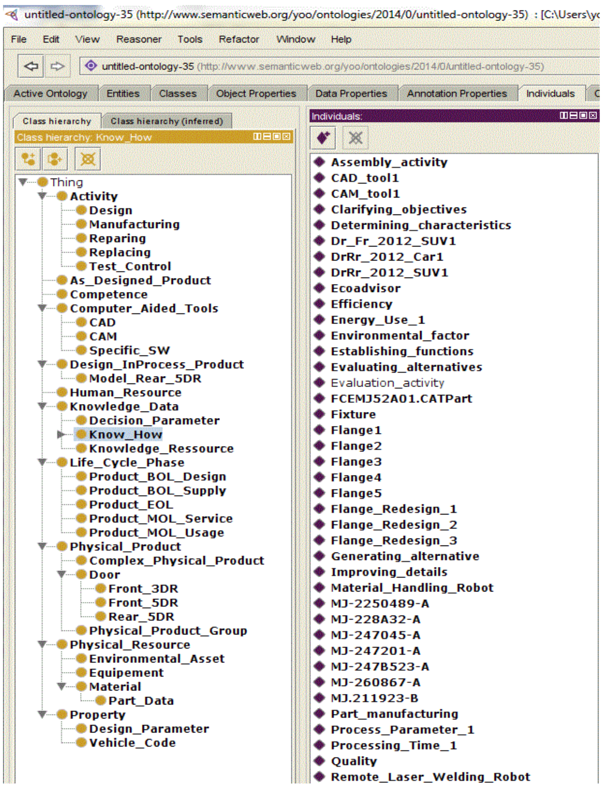

Fig. 6. Extended PLM Semantic Object Model – Classes in Protégé (Protégé)