

Sharing Knowledge when it Cannot be Made Explicit: The Case of Product Lifecycle Management Systems

Pierre-Emmanuel Arduin, Université Paris-Dauphine, PSL Research University, CNRS DRM
Julien Le Duigou, Roberval UMR CNRS 7337, Université de Technologie de Compiègne
Marie-Hélène Abel, Heudiasyc UMR CNRS 7253, Université de Technologie de Compiègne
Benoît Eynard, Roberval UMR CNRS 7337, Université de Technologie de Compiègne

ABSTRACT

Information systems often strengthen a preference for working alone: interoperability as much as interpretation variance restrain the ability of people and systems to interact and to work together within an extended enterprise. In this paper, we propose to extend Product Lifecycle Management (PLM) systems in order to share not only (1) knowledge that has been made explicit and which is strongly contextualized so that there is no interpretation variance, but also (2) knowledge that cannot be made explicit and which remains tacit knowledge, needing social interaction and shared understanding to be actually shared. The use of a collaborative platform is proposed in this paper in order to allow stakeholders to produce a shared understanding of what a concept means through the use of ontologies. The conditions as well as the limits of our proposition are discussed at the end of this paper.

KEYWORDS

Knowledge Management, Tacit Knowledge, Ontology, Shared Understanding, Product Lifecycle Management.

INTRODUCTION

Working together within an extended enterprise is not as natural for people as working alone to pursue their own objectives. Within an extended enterprise, i.e. a network of firms collaborating in a project to achieve a common goal (Ross et al., 2006), systems interact in order to share information throughout a product lifecycle. Product Lifecycle Management (PLM) aims at an integrated management of all product-related information and processes throughout the entire lifecycle for Saaksvuori & Immonen (2006) and Terzi et al. (2010). The limit of PLM systems is reached within extended enterprises when there is no awareness that the same information on the same product shared within the same extended enterprise through the same PLM system may lead to different interpretations. Authors as Walsham (2001) highlighted that kind of limit which may result from meaning variance, in the sense of Arduin (2014).

The aim of this paper is (1) to outline how a collaborative platform can be used within a PLM system in order to produce a shared understanding through the use of ontologies, and (2) to highlight the conditions under which a piece of information shared through a PLM system may lead to one and only one interpretation. Step (1) allows individuals to produce a shared understanding, supporting tacit knowledge sharing, i.e. knowledge that cannot be made explicit

according to Polanyi (1958), whereas step (2) leads to ensure made explicit knowledge sharing, i.e. knowledge that has been made explicit by someone within a certain context.

After remembering the vision of knowledge in the organization adopted in this work, a few PLM models are presented. Then the research proposition is introduced and the way we propose tacit and made explicit knowledge sharing within PLM systems will be explained. The limitations of this work as well as its added value will finally be discussed at the end of this paper.

BACKGROUND LITERATURE

Relying on the assumption that within extended enterprises individuals may interpret differently the same information, this work focuses on knowledge as being the result of the interpretation of information by someone, according to Tsuchiya (1993).

The vision of knowledge in the organization adopted in this paper is introduced in the first part of this section. A few models of PLM are then presented in the second part of this section.

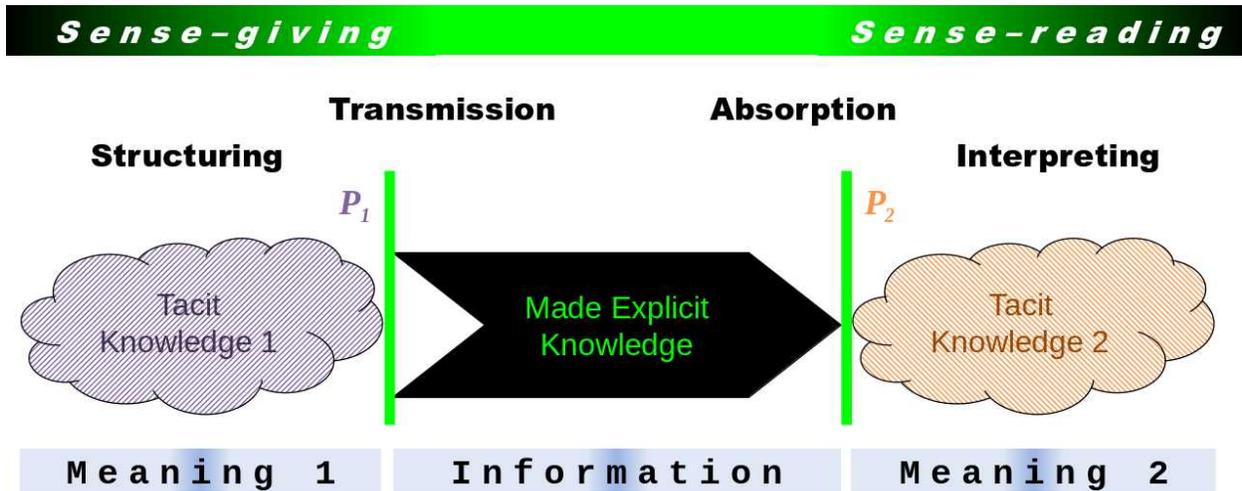
A vision of knowledge in the organization

As the authors of this paper, we have got tacit knowledge, i.e. an individual cognitive construction that we have structured into information during a process of sense-giving. As the readers of this paper, you have interpreted this information perceiving forms and colors, absorbed words, data, during a process of sense-reading, possibly creating new tacit knowledge for you (see Fig. 1). Sense-giving and sense-reading processes are defined by Polanyi (1967) as follows: “Both the way we endow our own utterance with meaning and our attribution of meaning to the utterances of others are acts of tacit knowing. They represent sense-giving and sense-reading within the structure of tacit knowing” (Polanyi, 1967, p. 301 ; Arduin et al., 2015). Information is continuously interpreted during sense-reading processes. Within extended enterprises, information can be transmitted by speaking, writing or acting, and also through PLM systems. Knowledge can then be:

- made explicit, i.e. it has been made explicit by someone within a certain context, it is socially constructed and can be supported by information technologies in the same way that information. Individuals, as well as computers are “information processing systems” as said by Hornung (2009, p. 9),
- tacit, it is not always articulated and cannot always be articulated, relying on Polanyi (1958) notably: “we can know more than we can tell”.

So that made explicit knowledge is tacit knowledge that has been made explicit by someone within a certain context. It is information source of tacit knowledge for someone else. It is “what we know and can tell” answering to Polanyi (1958) quoted above. The term “explicit knowledge” is often used (by Nonaka & Konno, 1998, or Nonaka & Takeuchi, 1995, notably), whereas it does not reflect the dynamic of the sense-giving process as well as the term of “made explicit knowledge”. Indeed such process is attached to a certain person acting within a certain context. That is the reason why we prefer to use the expression “made explicit knowledge”, which clearly shows how every piece of information can be seen as a piece of knowledge that has been made explicit by someone within a certain context.

Figure 1. Knowledge sharing: P1 makes explicit his/her tacit knowledge within a certain context by creating made explicit knowledge. P2 may interpret such made explicit knowledge within another context by creating his/her own tacit knowledge



Authors as Nelson & Winter (1982) consider that whereas made explicit knowledge can be regarded as a resource necessary to carry out processes, tacit knowledge ensures their efficiency: routines, non-written procedures, skills, crafts, job secrets, etc. That is notably the reason why PLM systems should particularly share tacit knowledge throughout a product lifecycle. As remarked by Davenport & Prusak (1998, p. 101), knowledge sharing, called “transfer” by them, is not reduced to the transmission of information. They wrote: “Transfer = Transmission + Absorption (and Use)”. Indeed whereas knowledge transmission concerns made explicit knowledge, knowledge transfer concerns not only made explicit knowledge, but also tacit knowledge, which needs effective individual interpretation to be shared. One interprets information and creates a piece of tacit knowledge, which has a meaning for him/her. Within an extended enterprise, there may be someone who has received the same information and, interpreting it, has created a piece of tacit knowledge, which has a meaning for him/her. We have to be aware that this meaning can differ from one person to another, particularly within extended enterprises, where stakeholders may be spread throughout the world (Platonov et Bergman, 2011 ; Ngoma et Lind, 2015).

PLM systems often try to extract and to organize information necessary for automating business tasks of the company, regarding each piece of information as a piece of knowledge. We defend that knowledge cannot be reduced to information created when someone made explicit his/her tacit knowledge within a certain context. Individuals and their own tacit knowledge have to be involved in knowledge sharing processes in order to ensure that tacit knowledge has not been neglected.

The use of a collaborative platform leads to the production of a shared understanding through the collaborative development of ontologies. We present in this paper how the use of such platforms within a PLM system leads to go towards knowledge sharing, even for knowledge that cannot be made explicit. Now a few models of PLM are going to be presented.

Product Model: a data kernel for PLM systems

The product data model is used to filter, to structure, to integrate and to control the voluminous information flow during the whole product lifecycle (Eynard et al. 2004 ; Sudarsan et al., 2005 ; Tang & Yun, 2008 ; Penciu et al., 2016). Product data model were firstly introduced by Krause et al. (1993) and Mony et al. (1992) in the early 90's. They aim to structure product related information and to facilitate its reuse or exchange. Nowadays, different types of product data models have been proposed depending on the industrial context or the lifecycle stage. The main objective of product data model is to support Product Data Model (PDM) functions of Product Lifecycle Management (PLM) throughout the product lifecycle (Demoly et al., 2013). Nowadays, several product data models and their extensions have been proposed. In this section three of the main product data model used in PLM systems will be presented: STEP (STandard for the Exchange of Product model data), CPM (Core Product Model), and IPPOP (Integration of Product, Process and Organization for engineering Performance Improvement).

STEP is actually a series of standards, known as ISO 10303 developed by experts worldwide (SCRA, 2006). STEP is intended to handle a wide range of product-related data covering the entire lifecycle of a product (Pratt, 2001). As the area of application of the STEP standard is extremely broad, it is issued in numerous sections, identified as Parts. The Parts known as APs (Application Protocol) define the scope, context and information requirements of applications (Smith, 2002). STEP has developed more than forty standard APs for product data representation, and they reflect the consolidated expertise of major industries for more than twenty years, covering the principal product data management areas for the main industries (Jardim-Goncalves et al., 2006). In other words, the APs are specific data models based on STEP standard covering the entire lifecycle of a product or / and a certain industrial domain. Nowadays, the STEP APs are widely used in mechanical design domain as AP 239, which provides integration and exchange capability for product lifecycle support data, and AP 214 specific to automotive industry.

CPM, an abstract model with generic semantics, initially developed at NIST (National Institute of Standards and Technology), can support the full range of PLM information (Fenves et al., 2008). CPM is based on two principles. First, the key object in the CPM is the artifact. Artifact represents a distinct entity in a product, whether that entity is a component, a part, a subassembly or an assembly. Second, the artifact is an aggregation of three objects representing the artifacts three principal aspects: Function, Form and Behavior. CPM consists of two sets of classes, called object and relationship classes (Fenves, 2001). In order to meet the requirements of multidisciplinary design, some extensions of CPM have been proposed.

IPPOP is a French project labeled by the French Ministry of Economy, Finances and Industry (Roucoules et al., 2006 ; Noël & Roucoules, 2008). The IPPOP project is based on the PPO (Product, Process and Organization) model which describes information of product, process and organization. The product model developed during the IPPOP project consists of four main concepts: Component, Interface, Function and Behavior.

Le Duigou et al. (2012) proposed a PLM structure adapted to SMEs. Supported by the French Technical Institute of Mechanical Industries (CETIM), the aim of this proposal was to provide a PLM solution for SMEs. With this PLM system, they can get into an extended enterprise structure with measured investments and time (Le Duigou et al., 2012). Based on a Product – Activity – Resource – Organization meta-data structure (Fig. 2), this proposal has to be aligned

with the previous value-based proposal, in order to be used to assess the product lifecycle model. Atrash et al. (2013) already focused on tacit knowledge sharing in SMEs through the use of ontologies.

Such PLM models may interoperate with others collaborative systems in order to produce a shared understanding. Indeed knowledge cannot always be made explicit and shared directly through PLM systems such as information.

The considered background literature points out a restriction of PLM systems, which despite of sharing information throughout a product lifecycle, lead to neglect tacit knowledge held by individuals. Tacit knowledge cannot always be made explicit (Polanyi, 1958). When it is possible, individuals create made explicit knowledge, which can be shared notably through PLM systems if it leads to one and only one interpretation. PLM models focus on sharing information related to a product throughout its lifecycle. To do so, interoperability and standardization are aimed by PLM models such as STEP or CPM for example (Song et al., 2006 ; Assouroko et al., 2010 ; Etienne et al., 2011 ; Barbau et al., 2012).

In this paper, the use of a collaborative platform in order to develop ontologies within PLM systems is proposed. The considered platform relies on the MEMORAe approach. This approach supports the production of a shared understanding through social interaction (Reinhardt et al., 2012). It can be considered as good a way to ensure tacit knowledge sharing within PLM systems, even if it cannot be made explicit (McMahon et al., 2004 ; Kiritsis 2013).

RESEARCH PROPOSITION

PLM systems allow information sharing throughout a product entire lifecycle. We present in this section how the use of a collaborative platform within such systems may lead to share knowledge, whether tacit or made explicit by someone within a certain context.

The first part of this section presents the MEMORAe approach, which allows the production of a shared understanding through the development of ontologies. We consider that such shared understanding ensures tacit knowledge sharing, which is notably discussed in the second part of this section.

The MEMORAe approach

In Abel (2008) the MEMORAe approach is presented as aiming to offer an alternative to the loss of competencies and knowledge in an organization. A competency is then considered as a way to put into practice some knowledge within a specific context (Abel, 2008). The MEMORAe approach offers an ontology-based learning organizational memory.

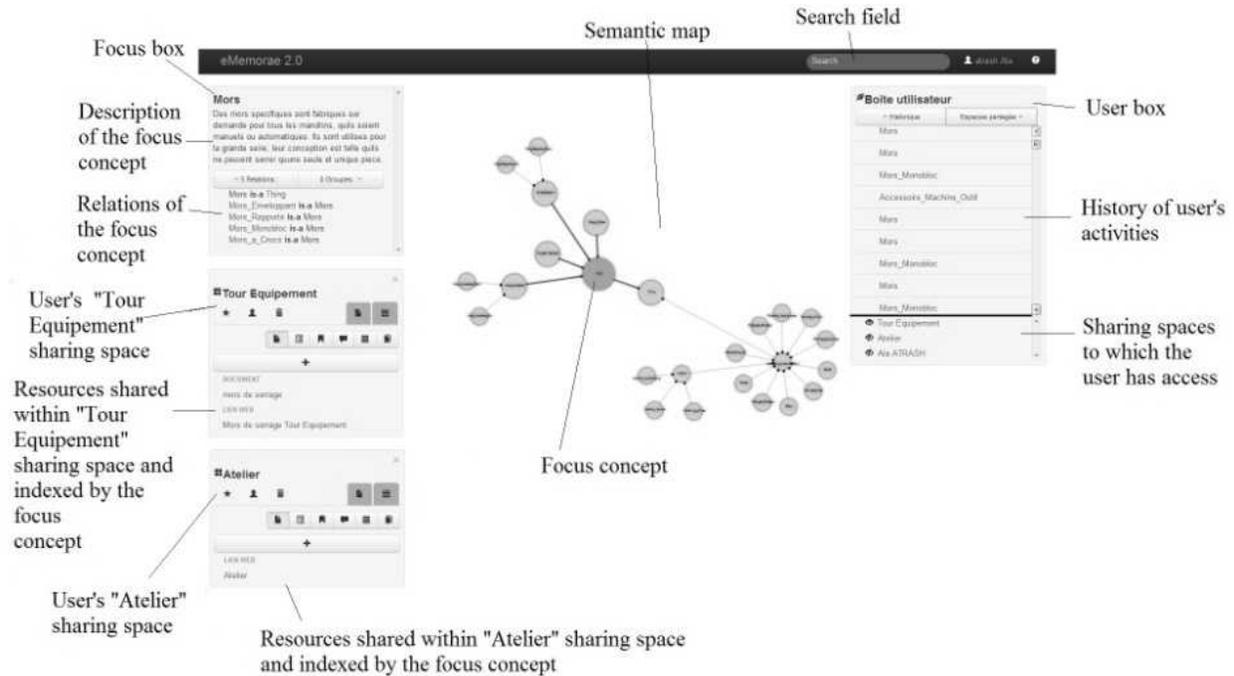
As explained by Davenport & Prusak (1998), transmitting information is not sufficient to share knowledge, due to the existence of individual interpretation in sense-giving and sense-reading processes (Polanyi, 1967). So that sharing information is not sufficient to share knowledge. Moreover even if authors as Ball et al. (1999) say that “more information is better”, others as Berners-Lee et al. (2001) consider that a web of information with well-defined meaning facilitates collaborative work between computers and individuals. Ontologies could then clarify the structure of information source of knowledge. They are a way for sharing and for re-using knowledge, whether tacit or made explicit by someone within a certain context.

Ontologies reflect a shared world view and for Domingue et al. (2001). They can support communication and knowledge sharing through a community of practice. Wenger (1998) presented what kinds of practices are involved within a community of practice: “Such a concept of practice includes both the explicit and the tacit. It includes what is said and what is left unsaid; what is represented and what is assumed. It includes language, tools, documents, images, symbols, well-defined roles, specified criteria, codified procedures, regulations, and contracts that various practices make explicit for a variety of purposes” (Wenger, 1998, p. 47). With Web technologies, communities become present online. For Grundstein (2000) an online community consists of people, a shared purpose, protocols and rules that guide interaction and computer systems. The use of a collaborative platform such as the platform of the MEMORAe approach ensures the production of a shared understanding within a community.

The MEMORAe project (see <http://www.hds.utc.fr/memorae/> and Fig. 3) is a prototype showing the ways to help users to capture knowledge. Entry points at the left of the screen provide direct access to a concept, whereas a history of the navigation is shown on the right of the screen. The part of the ontology describing current resources appears in the center of the screen and is framed by a short description of the current concept and by a list of shared resources related to the current concept (text or multimedia content) at the left of the screen. Within different spaces (“Tour Equipement” and “Atelier” in Fig. 3), individuals may have access to different resources and may be authorized to interact with different stakeholders (by chatting or through a wiki as in

Hsu et al., 2017, for example). By discovering new concepts, users ensure that they interpret them correctly by browsing the entire screen of the MEMORAE project or by interacting.

Figure 3 The platform of the MEMORAE approach



The ontology is an essential element of this approach as it serves at the same time the purpose of semantic indexing, common-reference enhancing collaboration through a common vocabulary and interoperability-enabler. Such ontology gives a context to capitalized made explicit knowledge and provides advanced search mechanisms, when the ontology is expressed in a logic-based formalism. To support organizational learning, a common reference has to encompass the representation of information source of knowledge related to a specific domain, as well as information related to the day-to-day life of the application in which the MEMORAE project is used. The MEMORAE core ontology is structured according to this separation between the application-specific versus domain knowledge, as follows:

- the domain ontology gives a description of organizations and characterizes the resources exchanged: people, groups, type of resources used, etc.,
- the application-specific ontology has to be defined for each application; e.g. in a product-development setting the application ontology may describe knowledge related to the product to be developed.

As part of a research work applied to the analysis of requests for proposal during the design of railway systems (Penciu et al., 2013), several supplementary elements were considered as part of the common-reference ontology. A high-level view of the resulting ontology is shown in Fig. 4.

In a design context, communities are formed and have to closely work together leading to trust issues (Lohikoski et al., 2016). This fact generates particular collaboration needs, which have to be reflected in the ontology content and use: teams are created ad-hoc, collaborators need to be aware of the human and the geographical organization as well as the actual product development process and the reference solution. The context in which knowledge has been made explicit, through a process of sense-giving in the sense of Polanyi (1967), can be identified based on the ontology and on the resources affected.

The MEMORAe domain ontology is generic and may be re-used from one application to another. Fig. 5 highlights a part of the domain ontology describing the organization: persons, groups, hierarchy and relationship between employees (managers or peers), the roles they play depending on the activity and on assigned responsibilities, division of the organization into departments and sites. Another example is the resource ontology which is part of the domain ontology. It describes the resources which can be capitalized into the organizational memory (Chundi, 2017): a resource may be a document, a requirement, an annotation, or a set of resources (collaborative resources: chat, forum, wiki, etc., or a set of documents). Annotations are part of a resource and represent a resource on their own. They may be classical annotations, as defined in DAML (see <http://www.daml.org/ontologies/>): note, comment, etc., collaborative resources (forum, chat, etc.), or technical-related (risk, solution, etc.) The resource properties are defined based on the DublinCore vocabulary (see <http://dublincore.org/>): a resource has a version and contains another resource, notably.

Figure 4 Ontological levels in the MEMORAe approach

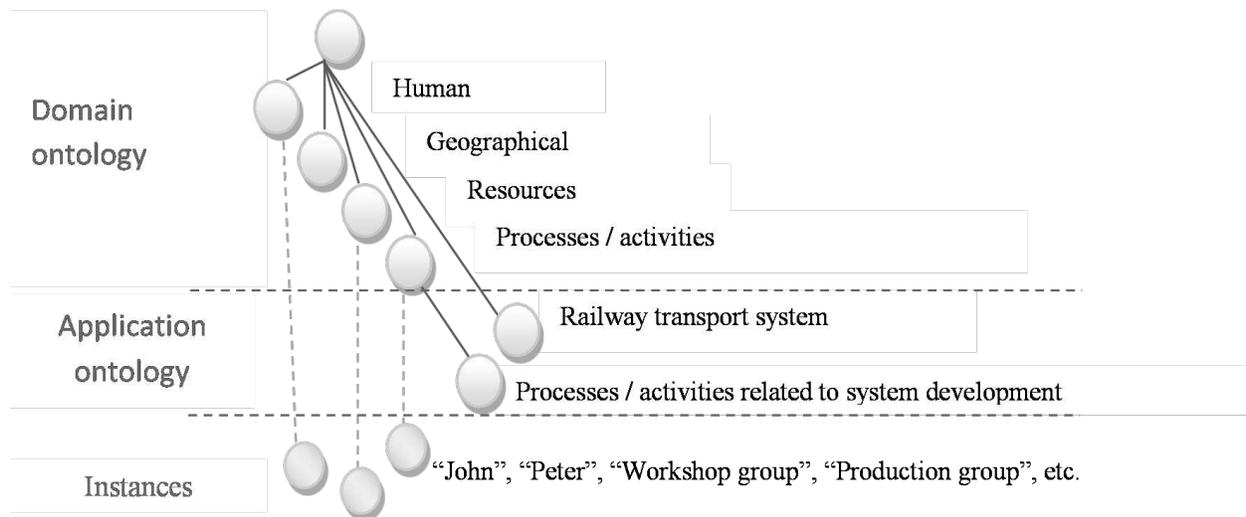


Figure 5 Part of the domain ontology defining the organization

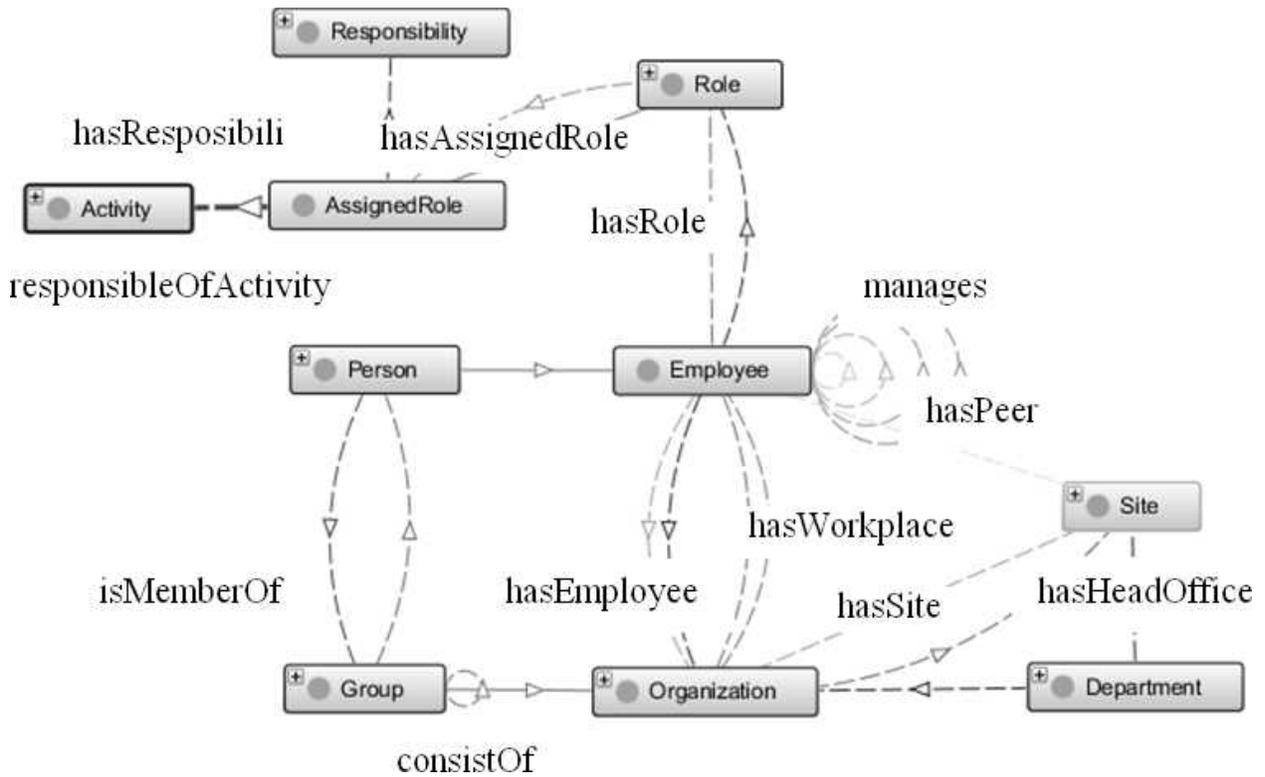
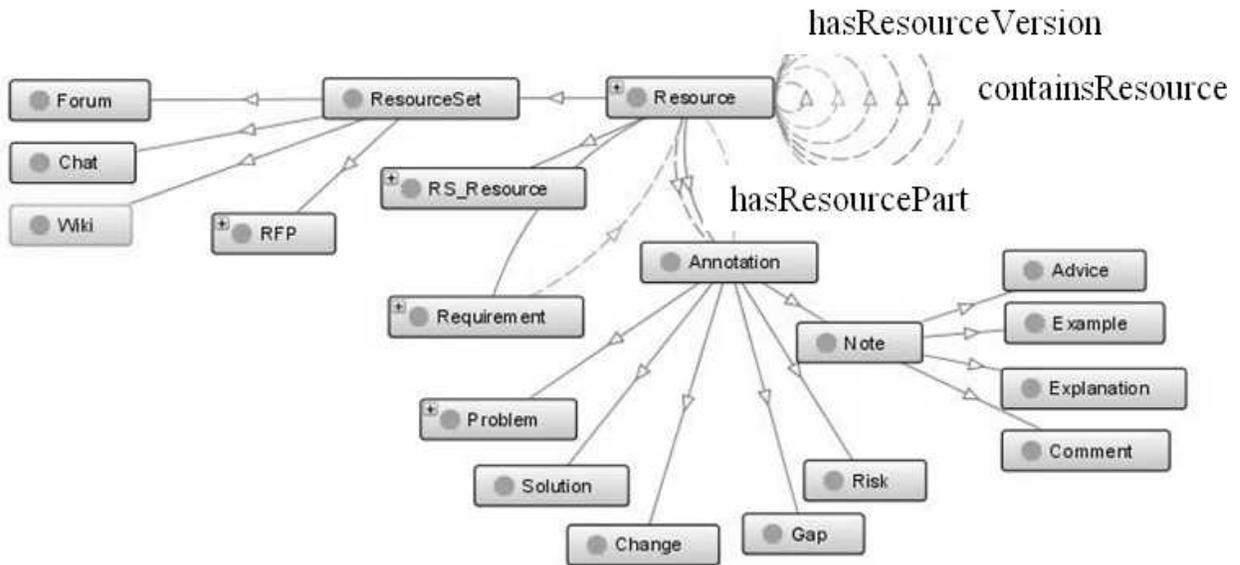


Figure 6 Part of the domain ontology defining the resources



Collaborative working systems such as Computer-Supported Cooperative Work (CSCW) result of information technology whose implementation has been polarized around the individual user for Schmidt & Bannon (1992). Individuals are users and they are individually using a system. Stockdale & Standing (2006) notice that neglecting social activity leads to “meaningless conclusions”, and Jordan (1996) insists when she reminds that knowledge is not only based on the group but is also tacit, embodied in individual interpretation: “We believe that there is yet another dimension that needs to be explored and that is the knowledge that is not only group-based but also tacit, implicit, embodied, and not articulated.” (Jordan, 1996, p. 18).

Tacit and made explicit knowledge sharing within PLM systems

The use of a platform such as the platform of the MEMORAe approach leads to collaboratively produce a shared understanding, so that tacit knowledge sharing is supported. Indeed tacit knowledge cannot always be made explicit according to Polanyi (1958). Collaboratively produce a shared understanding is a way to share tacit knowledge even if it cannot be made explicit. Additionally, within extended enterprises, PLM systems may disseminate information in every corner of the globe. Under certain conditions, a piece of information disseminated within a PLM system leads to one and only one interpretation. So that under certain conditions, disseminating information within PLM systems is sufficient to share made explicit knowledge. We are now going to explain these two major strengths of our proposal: (1) ensuring tacit knowledge sharing within a PLM system through the use of the platform of the MEMORAe approach, and (2) identifying the conditions allowing made explicit knowledge to be shared through a PLM system.

We assume that the use of collaborative ontologies may increase in future organizations such as the structuring of information has done in recent decades. Throughout a product lifecycle, knowledge is created and used by several actors, within several information systems and in every corner of the globe in an extended enterprise. The platform of the MEMORAe approach (Fig. 3) relies on Web Semantic standards. It allows the creation of institutional or dynamic groups (Deparis et al., 2013), which refer to:

- institutional groups, which are created and led by a manager and include two or more collaborators,
- dynamic groups, which are created by any member of the organization without requiring a validation from the hierarchy. It can be a community of interest around a specific topic, person or both. The opening of such a group to other members of the organization may be restricted within private groups.

So, a shared environment is proposed and allows stakeholders, regardless where they are and regardless who they are, to produce a shared understanding through the use of ontologies. They can additionally actively participate in communities by creating them, by managing them, or by inviting relevant persons in them. This shared environment ensures tacit knowledge sharing and its integration by stakeholders: within such communities they all give the same meaning to the same information disseminated through a PLM system. This constitutes one of the major strengths of our proposition.

Made explicit knowledge is tacit knowledge that has been made explicit by someone who created information within a certain context. It can be supported by information technology such as a

PLM system. Nevertheless, contrarily to tacit knowledge, made explicit knowledge is detached from its meaning, which depends of the person who is receiving it and of the context of its use. A piece of made explicit knowledge EK is a piece of information created by a person P_1 from his/her tacit knowledge TK_1 within a certain context C_1 . That piece of made explicit knowledge EK may be disseminated through a PLM system and it becomes then information source of tacit knowledge TK_2 for another person P_2 within a certain context C_2 . Note that even if EK is a raw object (it is information), TK_1 , C_1 , TK_2 , and C_2 may differ from one person to another, except under the following conditions, which may of course be refined in future works:

- *highly contextualized made explicit knowledge* refers to made explicit knowledge attached to a context avoiding meaning variance (in the sense of Arduin, 2014). For example the sentence “the cutting speed on such material is x” may lead to different interpretations depending on the tool, the engine, the geometry of the piece, the lubrication, etc. Such piece of information is not highly contextualized and cannot lead to efficiently share made explicit knowledge through PLM systems, because it may lead to different interpretations.
- *technical and unambiguous made explicit knowledge* refers to made explicit knowledge detached from natural language ambiguity. It may not lead to different interpretations. For example “15°” is detached from natural language but it may lead to different interpretations: disseminated within a PLM system, “15°” may mean “a temperature of fifteen centigrade degrees” or “an angle of fifteen radius degrees”. Such piece of information is not technical and unambiguous, and cannot lead to efficiently share made explicit knowledge through PLM systems, because it may lead to different interpretations.

These two conditions under which made explicit knowledge can actually and efficiently be shared through PLM systems have been identified: there is no ambiguity, no discussion, and no need of explanations.

Discussing the results, the added value, and the limitations of this work

Whereas information can efficiently be disseminated through PLM systems, knowledge, whether tacit or made explicit by someone within a certain context, is extremely difficult to share. Information may be useful throughout a product lifecycle, nevertheless knowledge is a crucial resource whose absence can disrupt ongoing processes (Grundstein, 2009).

We proposed in this paper a way to share tacit knowledge within PLM systems: the use of a collaborative platform in order to allow stakeholders to produce a shared understanding. So that even if it cannot be made explicit (Polanyi, 1958), tacit knowledge and its meaning are shared through PLM systems, when they use such collaborative platform.

By highlighting the conditions under which a piece of information may lead to one and only one interpretation within PLM systems, we also proposed in this paper a way to share made explicit knowledge within PLM systems. So that when it is disseminated, made explicit knowledge and its meaning are shared through PLM systems, when these conditions are satisfied.

Some differences between the MEMORAe approach and PLM models must now be highlighted. Indeed, they form a limitation of this work that we need to be aware of. For example, whereas PLM models consider that a “product” is related to activities and resources, the MEMORAe approach considers that a “product” is a resource able to produce information potentially source

of knowledge to capitalize. On the same way, the “user” is a human resource for PLM models, whereas a “user” is not the same as a “person” for the MEMORAe approach. Such differences form a limitation of this work if and only if we are not aware of. So that they are studied in order to be understood and managed.

During early experiments realized with students, it has been observed that the use of a collaborative platform, such as the platform of the MEMORAe approach, facilitates and encourages interaction between stakeholders (Abel, 2008). Observed students learned rapidly studied concepts and they all understood the same thing, whereas some of the studied concepts usually lead to different interpretations. These early experiments strengthen our proposition that developing ontologies together is a good way to produce a shared understanding between stakeholders, i.e. a good way to share tacit knowledge even if it cannot be made explicit.

Nevertheless, this work must now rely on industrial fieldworks in order to identify whether the proposal will actually be useful throughout a product lifecycle. At the time of writing this paper, it is not possible to present an industrial case study validating or invalidating the proposed approach, as it has been done by Arduin et al. (2013) for example. This constitutes a weakness of this work, which is currently tested within several enterprises. The preliminary design phase in a product lifecycle may for example be facilitated when stakeholders share efficiently knowledge on the product to be designed. Such phase is facilitated when stakeholders, regardless where they are and regardless who they are, share not only information on their wills about the envisaged product, but also knowledge, and particularly tacit knowledge even if it cannot be made explicit, through the use of a collaborative platform. They have the means to collaboratively produce a shared understanding of information disseminated through the PLM system. So that knowledge and its meaning are shared through such PLM system, which goes towards knowledge sharing even if it cannot be made explicit.

CONCLUSIONS AND PERSPECTIVES

As pointed out along this paper, knowledge, whether tacit or made explicit by someone within a certain context, is a crucial resource which should be shared through PLM systems.

This paper proposes (1) to outline how a collaborative platform can be used within a PLM system in order to produce a shared understanding, and (2) to highlight the conditions under which a piece of information shared through a PLM system may lead to one and only one interpretation.

The proposal aims at sharing knowledge through PLM systems, even if it cannot be made explicit, i.e. it remains tacit knowledge in the sense of Polanyi (1958). To do so, it is firstly proposed to use the platform of the MEMORAe approach within a PLM system. Indeed, the MEMORAe approach allows individuals to produce a shared understanding, which supports tacit knowledge sharing. Then even if it cannot be made explicit, tacit knowledge and its meaning can be shared through a PLM system. Secondly, the conditions under which a piece of information disseminated within a PLM system may lead to one and only one interpretation have been highlighted. Then not only information has been disseminated, but also made explicit knowledge and its meaning have been shared through a PLM system.

After remembering the vision of knowledge in the organization we adopted in this work, a few PLM models were presented. Then the research proposition has been introduced and tacit and

made explicit knowledge sharing within PLM systems has been explained. The limitations of this work as well as its added value have finally been discussed at the end of this paper.

PLM systems have a real strength which is that they are strongly integrated and used throughout a product lifecycle. They give individuals the ways to collect, to process and to share huge amounts of information throughout a product lifecycle. This work considers that when it has no meaning, information is useless for an organization. So that within extended enterprises, where individuals may be spread throughout the world, it is crucial to ensure that the same information on the same product disseminated through the same PLM system will have the same meaning for the stakeholders, regardless where they are and regardless who they are.

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Pierre-Emmanuel Arduin is associate professor in Computer Science at Université Paris-Dauphine. After having studied psychology, computer science and management, he now focuses on knowledge management, which remains his main research topic. Considering that individuals interpret information and create their own knowledge, he tries to highlight how information systems may be used in order to share more than just information between individuals. He is also IT and KM consultant within several large companies.

Julien Le Duigou is associate professor at Université de Technologie de Compiègne and researcher in Roberval Mechanical Laboratory (UMR CNRS 7337). He obtained his MSc in Mechatronics and a Mechanical Engineering Degree from Supmeca in 2006 and a PhD in Mechanical Engineering from Ecole Centrale in 2010. Currently, his research interests include Product Lifecycle Management, Enterprise Modelling, Interoperability and Product/Process integration.

Marie-Helene Abel is Professor in the Computer Engineering Department (University of Technology Compiègne, France). She is in charge of the pedagogical specialization “Knowledge Engineering and Information Media” since 2003, and leader of the Research Team ICI (Information, Knowledge, and Interaction) – UMR CNRS HEUDIASYC Laboratory since 2008. She has been involved in several research projects at different levels, regional, national and European with e-learning and audiovisual for main application domains.

Benoît Eynard is currently the Director of the Institute for Mechatronics at the Université de Technologie de Compiègne - UTC. He is also member of the UMR CNRS/UTC 7337 Roberval and a recognised researcher in product lifecycle management, systems engineering, digital factory, smart manufacturing, eco-design and sustainable manufacturing. Since 2013, he is general chairman of the academic group of French Association of Mechanical Engineering dealing with Factories of the Future: integrated design and advanced manufacturing.

Dr. Pierre-Emmanuel Arduin
Université Paris-Dauphine
Laboratoire DRM (UMR CNRS 7088)
Place du Maréchal de Lattre de Tassigny
75775 Paris Cedex 16, France
Tel: +33.(0)1.44.05.48.19
Fax: +33.(0)1.44.05.40.23
pierre-emmanuel.arduin@dauphine.fr

Dr. Julien Le Duigou
Université de Technologie de Compiègne
Department of Mechanical Engineering – UMR UTC/CNRS 7337 Roberval
CS60319 – rue du Dr Schweitzer
60203 Compiègne Cedex, France
Tel: +33.(0)3.44.23.45.78
Fax: +33.(0)3.44.23.52.29
julien.le-duigou@utc.fr

Prof. Marie-Hélène Abel
Sorbonne universités
Université de technologie de Compiègne
CNRS, HEUDIASYC, UMR 7253
CS 60 319, 60 203 Compiègne cedex - France
Tel.: +33.(0)3.44.23.49.50
Fax: +33.(0)3.44.23.44.77
marie-helene.abel@utc.fr

Prof. Benoît Eynard
Université de Technologie de Compiègne
Department of Mechanical Engineering – UMR UTC/CNRS 7337 Roberval
CS60319 – rue du Dr Schweitzer
60203 Compiègne Cedex, France
Tel: +33.(0)3.44.23.45.78
Fax: +33.(0)3.44.23.52.29
benoit.eynard@utc.fr