Ontology for Colaborative Development of Product Service Systems Based on Basic Formal Ontology

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***Abstract*— the paper is one of the few attempts to develop a Product Service System (PSS) ontology aiming to facilitate Knowledge Management in collaborative PSS design, focusing upon machine industry. The PSS ontology includes concepts such as products, services, PSS, PSS lifecycle, process and stakeholders, including direct customers, consumers and their feedback. The context sensitivity approach is proposed to fully support the use of different tools for PSS development by various stakeholders. The context model includes both PSS ontology and a so-called user-centric ontology. The process to develop the ontologies is described. The approach to build the PSS ontology is based on the so-called Basic Formal Ontology (BFO). The foreseen applications of both ontologies in industrial practice of machine vendors and the expected benefits are being elaborated.**

Keywords—Product Service System; Ontology; Product service lifecycle management ; context sensitivity; machine industry

I. Introduction

The paper addresses the development of Product Service Systems (PSS) in manufacturing industry. PSS development, including dynamically building new services around products, requires strong collaboration among various actors/stakeholders across the value chain. Building services today is connected with adding/upgrading of cyber-physical features, e.g., by adding sensors and intelligence to the products which can be used for various services. This in turn, requires dynamic feedback loops between the design, manufacturing and product-service use. PSS development requires collaborative work among a number of stakeholders: product designers and vendors, services providers, material suppliers, customers, etc. In the case of machine and equipment vendors, the design of PSS is even more challenging. Besides the involvement of direct users of machines and equipment, the so-called business customers, PSS design has to take into account feedback from consumers, i.e. the users of products manufactured by the machines. Collaboration in such a complex ecosystem requires effective knowledge management (KM). PSS design processes require effective (re-)use and sharing of both formally captured knowledge, such as design documents, Product Data Management/Product Lifecycle Management (PDM/PLM) systems etc., and experience-based knowledge captured within various social media, such as MediaWiki. Especially the knowledge relevant for PSS development from shop-floor is often not easy to use within the PSS design processes.

The current paper is one of the first attempts to develop a PSS ontology, aiming to facilitate KM in collaborative PSS development for manufacturing industry and specifically for machine industry. The approach selected to build the PSS ontology is based on the so-called Basic Formal Ontology (BFO) [12]. Furthermore, the context sensitivity approach is proposed to fully support the use of knowledge and different tools, by various stakeholders within the complex collaborative PSS development process. To model the context under which these stakeholders are working on the PSS design, an ontological approach was chosen as most appropriate, thus, besides the PSS ontology (static part of the context for the developed tools), a so-called user-centric ontology is developed, describing concepts relevant for the dynamic part of the context (user interaction with the tools), such as location, time, activity etc. A combination of these two ontologies is therefore, the notion of context, or context model used in this research.

II. Relation to Existing Theories and Work

A. PSS Design

All industries, including manufacturing, have shifted their focus to the combined ecosystem of products - services. This innovative business strategy of PSS, provides an integrated solution that promotes sustainability in business, customer and environmental aspects. These integrated PSS offerings are distinctive, long-lived and easier to defend from competition based on lower cost economies, particularly in the manufacturing sectors where there is a high amount of base installed products [1].

An overview of the approaches and tools to support PSS design is provided [2], however, methods and tools analyzed use different terms and definitions. This often generates some overlapping of meaning among terms, as already highlighted in [3]. As the number of PSS-oriented software tools is limited, the adoption of PSS methodologies and tools in different companies is rather poor. Only few companies have adopted

PSS methodologies so far, and these are mainly multinational companies involved in experimental projects jointly with research institutes, while the application of PSS methodologies in the context of smaller companies is very limited. Especially, it can be concluded that there are no tools to support the PSS design and management appropriately, especially for machine vendors, acting at the global market and faced with mass customization requirements, even though some academic software has been making breakthroughs, potentially in relation to collaborative engineering of PSS.

B. PSS Ontology

In order to bond various tools that can be used for PSS engineering, such as the classical engineering tools and PDM/PLM systems, and social software, a common ontology for PSS is needed. An ontology is defined as "a formal explicit specification of a shared conceptualisation" [4, 5]. Research on PSS has been carried out for many years and in various disciplines, however, even a consolidated set of terminologies has not been established as indicated above (in spite of several earlier attempts [6, 7, 8, 9]). A common understanding of PSS is arising, but a common ontology has not been released beyond research schools [10]. One of the most elaborated solutions in PSS ontology is developed by a Cranfield University team [11]. This work, however, also has not reached industrial maturity and wide acceptance. Thus, the goal of the research presented in this paper is to develop a flexible, open engineering environment (with different tools) and an ontology, to realize the environment and interconnect various software approaches and tools. As a basis for integrating various disciplines along the entire PSS lifecycles, the different engineering domains and the modules of PSS development environments, an overall PSS ontology is needed, representing a common technical glossary of terms and describing the interdependencies of all related concepts.

C. Basic Formal Ontology (BFO)

In [12] it is argued that issues such as terminology selection, term definition and classification can be better solved if the ontology is related to a top-level ontology. This also brings advantages in terms of sharing ontologies and governance of ontology development. Therefore, it is suggested to use the Basic Formal Ontology (BFO) as a starting point for categorization of entities and relationships in the specific research domain. BFO is an upper-level ontology developed to support integration of data obtained through scientific research. It is already used to build several ontologies, such as the Cell Ontology, the Foundational Model of Anatomy, the Ontology for General Medical Science, etc. The paper presents one of the first attempts to model PSS ontology using the BFO.

D. Context sensitivity

With the recent advances in context-aware computing, an increasing need arises for developing formal context modelling and reasoning techniques. In particular, additional challenges arise in context modelling for collaboration design teams, as these teams are highly dynamic in their constitution and objectives, reside in distributed environments and are usually knowledge-intensive [13]. The amount of information to be handled by "collaboration tools" is significant, as a result of the number of ICT systems that act as information sources. The success of collaboration depends on a timely-accurate access to the relevant information by the adequate collaborator. One of the key problems on how to extract context from the PSS development processes, and how to manipulate the information to meet the requirements of knowledge enrichment, has to be solved. Since in this research it is planned to model context with ontologies, context extraction remains as the main issue of context reasoning and context provisioning: how to inference high-level context information from low-level raw context data [14].

E. Context Modelling

The basis for context-aware applications is a well-designed context model, which enables tools to understand the user's activities in relation to situational conditions. The definition of the context model is a key approach to assure usability of the tools in different domains. The application of the solution to a specific domain usually requires adjustment of the context model [15]. With the emerging and maturing of semantic web technologies, ontology-based context modelling gains popularity in both academy and industry. Present research on context modelling is mostly focused on ontologies, as for example, the EU-funded project inContext, which used OWL to build the context model to support collaborative working environments [16], as well as the K-NET and SelfLearning projects, which used ontologies to support collaborative work and context sensitive devices in manufacturing industry [17, 18]. Ontology-based methods offer many advantages, such as allowing context-modelling at a semantic level, establishing a common understanding of terms and meaning, and enabling context sharing, reasoning and reuse [19]. A context ontology does not differ significantly from any other knowledge-representation system. Each context contains a set of concepts that describe the basic terms used to encode knowledge in the ontology.

In addition to these basic functions, the role of context ontology places a number of further requirements on the representation language. Several semantic specification languages such as RDF and OWL [20], provide potential solutions for context modelling (especially for the future pervasive computing environment where contextual information should be provided and consumed anywhere, and at any time). The logical foundations of OWL and examination on how this modelling language can be used to express a user's situation has been carried out [21].

III. RESEARCH APPROACH

The present research focuses on two ontologies in order to support PSS design in machine industry, namely the PSS ontology and a so-called user-centric ontology.

To effectively support the PSS development processes in manufacturing industry, the engineering tools have to be semantically enriched by a PSS ontology allowing for effective knowledge (re)use.

On the other hand, context sensitivity is achieved by real time extraction of context under which the user is currently using different tools in the engineering environment. In order to achieve context sensitivity of the tools and environments to the users' actual needs, the context model is needed to reach high adaptability of these tools. This allows for easier use of the tools in the collaborative PSS development. The context model is defined by a set of ontologies which describe various (static and dynamic) situations (collaborations), in which the tools and engineering environment are used. Therefore, the context model includes:

- the PSS ontology (as static part, representing the PSS concept dependencies)
- the user-centric ontology (as dynamic part, referring to the user-tool interaction)

The structuring of the context model into static and dynamic part is done from the point of view of the users of the tools. The static part (PSS ontology) includes concepts (classes) which also dynamically change but normally not in the time frame when a user is interacting with the tools.

A. Development of PSS Ontology

The purpose of PSS ontology is:

- to allow for better communication among various stakeholders in the PSS development process, and
- to allow for semantic connections among the tools (e.g., easier search for knowledge in various systems and especially manufacturing intelligence), annotation of information/knowledge is used by tools.

The PSS ontology proposed can be seen as an application ontology which is to be used as a reference ontology in the manufacturing domain. As explained in [12], "an Application Ontology is an ontology that is created to accomplish some specified local task or application, while a Reference Ontology is an ontology that is meant to be canonical, comprehensive representation of the entities in a given domain that is developed to encapsulate established knowledge of the sort that one would find in a scientific text book".

PSS ontology is the set of concepts (and their relations) relevant for PSS development. The main criteria for selection of the concepts that should be included in the PSS ontology followed the general recommendations on ontology building [22], such as: (1) to include all concepts relevant for the PSS design, (2) to keep the number of concepts at minimum to allow for effective use and maintenance of the ontology, and keep the number of concepts on the top abstraction level at minimum, to define an optimal structure of the ontology, and (3) to try to re-use, as far as possible, already existing and widely accepted ontologies (e.g., on products, processes etc.).

The ontology structure adopted comprises three layers: generic, sector-specific and company specific ontology, making it, therefore, extensible for different sectors and companies. The process for the definition of the PSS ontology included the following steps:

- Analysis of the literature on ontologies relevant for PSS was carried out. The most elaborated solution found, was the PSS ontology developed in [11].
- Definition of use cases based on three industrial companies-representatives of the medium-sized machine industry in Europe, located in Italy, Greece and Germany. The use cases describe the PSS design processes in these industries, the interaction among various stakeholders and the use of existing and potential new software tools to support PSS design. The use cases describe both actual PSS design processes and the targeted improved design processes.
- Based on the analyses of the use cases, as well as the literature, the first set of concepts (entities) relevant for the PSS ontology in machine industry were proposed. This list was reviewed by five industrial companies, both machine industry and software houses developing tools to support PSS design, and four research organizations in Europe. Specifically, three manufacturing companies analyzed the proposed concepts, in relation to the defined use cases and the description of their PSS design processes.
- Based on this expert feedback, the selected entities were reviewed, and an updated version of the ontology was created.

The objective is to keep the ontology as simple as possible to allow for "easier harmonization" with other ontologies and to easer establish relations between universals (types of classes) and Basic Formal Ontology (BFO) classes (see [12]), as well as to establish relations to Reference Ontologies in Manufacturing Domain. As explained above, the intention is to contribute to the establishment of a standard ontology for PSS in manufacturing, therefore, the intention is to harmonize the ontology with ontologies for PSS under development in other research initiatives. Thus, the number of concepts at the top level are reduced to the minimum, and subclasses of several classes are included. All concepts are related universals or roots of the BFO classes [12].

The approach adopted follows the (majority of) best practice guidelines in definition of ontologies as proposed in [12], such as: formatting terminology (e.g., ensure univocity of terms, i.e. it is needed to ensure that the terms have the same meaning on every occasion it is used, distinguish the general from particular), principles of definitions (e.g., provide all non-root terms with definitions, use Aristotelian definitions etc.), principles for taxonomies (e.g., structure every ontology around a backbone *is_a* hierarchy, ensure asserted single inheritance etc.)

An analysis of the existing open-source ontology-modelling solutions is carried out and Protégé, as a common used application, was decided to be used for the PSS ontology modelling. The initial version of the ontology is introduced in Protégé (see Fig. 1).

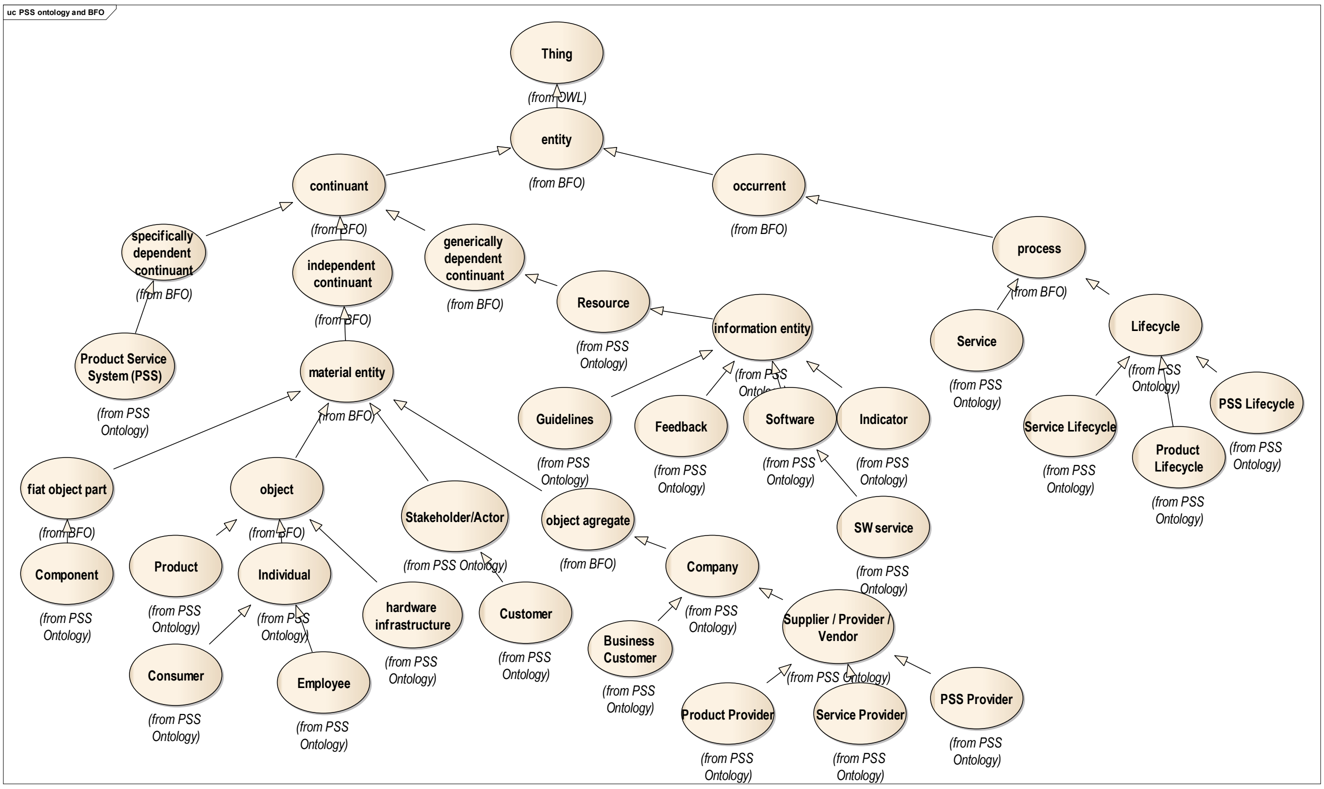

Fig. 1 PSS ontology (generic)

The detailed description of all concepts included is provided on [23]. This is the initial version of PSS ontology, which will be further refined/improved. As indicated above, the PSS ontology includes three layers. The above presented layer is the generic one, while Fig. 2 presents a draft version of sector specific ontology made for a specific company, i.e. manufacturers of machines for shoe industry.

The adopted iterative approach led to the definition of the key concepts in the proposed PSS ontology: Product and Service, Process (which includes PSS Lifecycle), Hardware Infrastructure, Individual (with subclass Consumer and Employee) and Company as subclasses of Stakeholder, as well as Feedback provided by a Stakeholder. Based on the above described approach, it was concluded that these concepts describe in general the PSS development. The Company concept includes (Product) Vendor/ (Service) Provider/ Supplier and Business Customer. Obviously, Product Vendor and Service Provider may be the same company, but in a general case these can be two or more different companies.

The main characteristics of the proposed PSS ontology is that it is built based on the baseline of use cases relevant for the machine industry. The sector-specific layer of the ontology includes, therefore, concepts relevant for the machine industry and their specific needs to build PSS. Besides the standard concepts such as products, services, stakeholders, PSS etc., the ontology clearly distinguishes the concepts of products made by the machine industry itself (e.g., machines, equipment, control systems, etc.), from the so-called final products which are those manufactured by the machines (e.g., shoes). Similarly, besides the generic concept of Business Customer, which include customers of machines the ontology distinguishes the concept of Consumer who buys the Final Products. This is of specific relevance for machine industry, as in designing of PSS (including various services around their products – machines), they need to get feedback from both their direct Customer, for whom they build PSS, and from the Consumers of the Final Products in order to adapt/prepare their products (machines) and services to the future requirements of the Consumers.

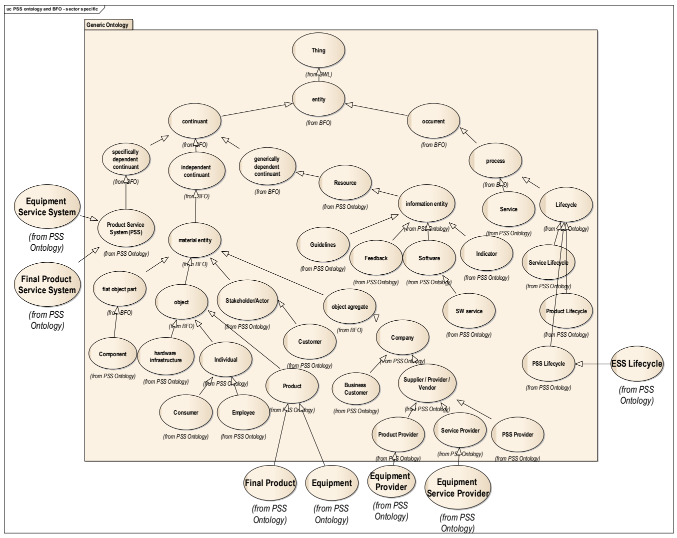

Fig. 2 Sector specific PSS ontology (machine sector)

B. Context sensitivity – User-centric Ontology

To support context sensitivity in the developed PSS design tools, the suggested approach uses also the user-centric ontology, which models the dynamic part of the context related to the user. The key assumptions regarding the dynamic aspects of context sensitivity to support PSS design are [15]:

- The context sensitivity allows for observation of changes in circumstances in which the PSS design is carried out, which in turn allows for a dynamic adaptation of the tools to support PSS design to these varying conditions (e.g., the tool used in the company site or at the customer's site).
- "Normal/Nominal" tool/environment must operate without context sensitivity.
- Context sensitivity "only" improves the tool performance by better adapting it to dynamically changing situation.

As a consequence, context sensitivity is useful for tools operating in dynamically changing conditions. However, the tool must have a "nominal situation" under which it operates without context sensitivity (e.g., a search functionality should be able to provide the user with the information/knowledge (s)he asks for, and additionally, context sensitivity may be used to "adapt" a search query to return primarily the information/knowledge that matches the current situation in which (s)he is working).

Regarding context definition, Dey K.A. [24] defines context as "any information that can be used to characterize the situation of an entity". For example, in order to support using various tools for PSS design, the context can be defined as any set of information that can be used to characterize the situation by which the software environment and tools is used for PSS development. Such a definition, leads to several research questions: (1) Where is a border between "normal/nominal" tool and the context? Which information should be used within "normal/nominal" tools and which for "context model"? The proposed research approach is as following: all what is needed for the operation of the tools in "normal/nominal" (non-dynamically changing) situation, or with "normal/nominal" user, should be associated to a "normal/nominal" system (e.g., use all information which are needed for serving a "normal/nominal" user), and all information which describe changes in the circumstances under which the tool is being used can be associated to the context model. (2) Which information should be associated with context model, as according to the definition, any information can be context? The proposed research responds to that as: it depends exclusively on the purpose of the context, i.e., to which changes in the circumstances it is requested to adapt the tool (e.g., if it is not required to adapt a tool depending on a current weather conditions, then weather conditions should not be a part of the context and vice versa).

Consequently, it can be concluded that there is no unique context model for a specific tool. For the same tool one can define different context models depending on the purpose of context sensitivity. The purpose of the context sensitivity in the research presented in this paper is to support PSS design in machine industry and to enrich the outputs of a tool to better suit its users (e.g., allow adaptation of a tool to the user's needs in a specific use-case situation). Therefore, for each company/user of the tool one can define different sets of information which constitute the respective context, depending on what kind of adaptation of the tool is required. For example, if a tool for collecting feedback from customers about a product has to adapt depending on the season when it is used, such as which shoes are carried in the winter or summer, then the context model has to include a set of information describing season, etc. The context modelling includes, therefore, the identification of the set of features that determine the context and, consequently, identification of the set of information sources to be monitored depending on the tool. This includes a definition of the structure of a semantic description of processes/products/services, as well as of qualitative features and a definition of the relationships between the corresponding ontologies which have to be included in the context model. The next step is to refine the relationship between different ontologies and mapping between specific elements of the context model and ontologies.

In this approach, OWL-based ontologies are being used to represent the extracted information as explicit machine interpretable knowledge. These ontologies serve as a base for context extraction, refining and reusing. For the user-centric ontology, the basic principles adopted are:

1) To support description of the main context. As discussed above, the context could be very broad. The context model should consider those most related factors according to the requirement of context sensitivity.

2) To model the context that is easy acquirable. Those context factors considered should be identifiable and acquirable, whether provided through computer monitoring automatically, or by user input explicitly.

3) Trade-off between investment of context modelling/extraction and effects of context sensitive knowledge management. Intuitively, if we could model as much context factors in as much details, the accuracy of context will be higher. However, this does not come for free. On the one hand, more time and effort on context modelling is needed, and on the other hand, more information sources should be integrated and more computing recourses are needed to extract and handle the context, which will may bring deficiency to the knowledge management process.

The key approach for context sensitivity to support PSS development process is identified [23]:

- A single approach for the context sensitivity of the PSS development environment and all (there included) tools is applied, aiming at high adaptability of those components to the users' actual needs. This approach allows for easier use of the engineering environment in the collaborative PSS development.
- The purpose of "context" is to allow for enhancement of the outputs of a component to better suit users (to allow the component to adapt to the user's needs in a specific situation in which she/he is using tools for PSS design).

- The context models describe the possible contexts of the users, using the PSS development tools. The services for monitoring and extraction observe various sensors in the users' environments, and based on the data from these sensors and the context models, try to identify the context in which the user is currently using the tool. The identification of the current context and the defined context model is based on raw sensors-data. The objective is to get data automatically and not require the user to provide additional information on her/his current situation. Based on the identified current context, the tool adapts its functionality.

As context models describe the situations under which a company and their partners collaboratively develop PSS, they may vary from company to company, as well as they may vary from tool to tool. This means that in the setup phase of the PSS engineering environment and tools, the context model(s) for the specific company and their partners, as well as for each tool, have to be defined and implemented.

While the intention is to define the PSS ontology which will contribute to the standardization of the PSS ontology in the domain of manufacturing, the user-centric ontology is application oriented. The process to identify the concepts relevant for user-centric ontology was the same as for the PSS ontology (see section "Development of PSS Ontology"). In order to define this dynamic part of the context, the concepts/aspects relevant for the context sensitivity of the users in the three companies mentioned above, are identified based on use cases describing various contextual situation information under which PSS is designed.

According to the above listed principles, the initial set of concepts is identified, but it is still subject to change. The user-centric ontology includes dynamic aspects to describe the current user situation, such as:

- Actor/stakeholder (user of the tool)
- Current activity of the user
- Current geographical location of the user
- Time (e.g., time zone, time of the day, but also time in relation to the project phase etc.)
- Infrastructure (e.g., mobile device used or standard computer)

These concepts are related to various concepts/classes in the PSS ontology such as Stakeholder/Individual/Employee. PSS, Product, Service), PSS Lifecycle. The top level of the proposed user-centric ontology is presented in Fig. 3. Sub-classes of this top-level ontology will be introduced for each tool. These subclasses have to be adapted to the specific company. For example, under Employee may come various company-specific roles which an employee may have in PSS development, or other activity.

The detailed description of all concepts included is provided in [23]. However, this is the initial version of user-centric ontology and will be further refined. Therefore, the main concepts in the user-centric ontology are Activity, Time and Location. The other concepts are shared with PSS ontology. Each of those concepts, can be extended with another new or existing ontologies for defining a more detailed context model.

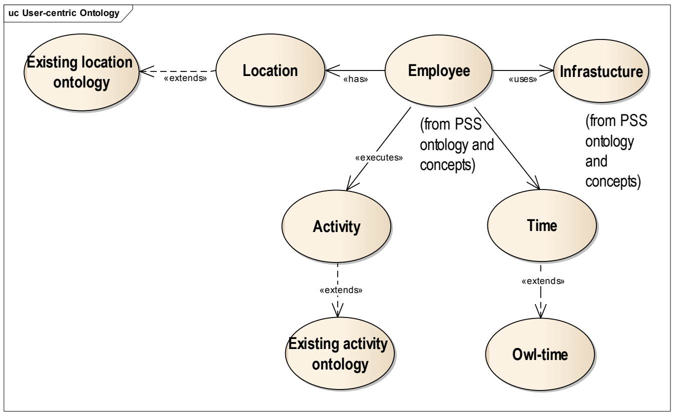

Fig.3 User-centric ontology

Activity is a concept that represents a knowledge-based activity and is very generic to include any sort of work in an industrial domain. Each activity is performed by a group of human beings (employees), which is modelled as a person concept in the ontology and can be imported from the *foaf (friend of a friend): Person* ontology. An Activity is related to itself as a sub/super activity to represent hierarchy, as well as a precedence/subsequence activity to represent time sequence. The concept Activity can be made domain specific by extending it into a more specific concept that may vary from case to case. Furthermore, each of these sub classes can be further extended to sub-sub classes, but this can be done for each specific company, depending on their specific needs. Every Activity has some physical circumstances associated with it, like Location and Time, and is performed by one or more Individuals/Employees. The people who participate in an Activity are modelled using the concept Individual. The object property "executes", defines the relationship between the Individual/Employee and an Activity. The domain and range of "executes" is Employee and Activity respectively. For extending the Activity entity, the ontology, entitled Activity-Centric Collaboration Ontology (ACCO), already used in the previous K-NET and Self-Learning projects, allows for representing the context of collaborative work situations in the form of explicit machine interpretable knowledge [25]. ACCO is implemented using the Web Ontology Language (OWL) 2 (OWL-RL or OWL-DL profiles) [25, 26]).

The *Time* concept can re-use existing ontologies such as the Time Ontology in OWL. In the version ontology of temporal concepts, OWL-Time (formerly DAML-Time) is described by referring to the temporal content of web pages and the temporal properties of web services. The ontology provides a vocabulary for expressing facts about topological relations among instants and intervals, together with information about durations, and about date time information. A time zone resource in OWL is developed for the entire world, including the time zone ontology, the US time zone instances and the world time zone instances. The time aspects may have different influences upon the current context of the user of the PSS development tools (e.g., time zone, time of the day, etc.).

The *Location* concept can re-use existing ontologies such as OWL-based location ontology for context-aware services, [27] France Telecom, R&D Division, Technologies/ONE/Grenoble, and/or Location Ontology WSML sources ontology.

As explained above for the PSS ontology, the context model adopted includes three layers: Generic, Sector-specific and Company specific context model. Therefore, the model is extensible for different sectors and companies. It allows modelling various contexts (various abstraction levels) depending on specific requirements for each company. This facilitates efficient adaptation/customization of the tools to the needs of different sectors and companies, and extents their application.

IV. FINDINGS - APPLICATIONS

As indicated above, the main purpose of the PSS ontology is to serve as a bond between the formally captured knowledge in different documents/data bases, including PDM/PLM systems, and experience based knowledge, since both are of highest relevance for effective PSS design. To examine this bond, the initial versions of both ontologies were first examined in use of various tools to support PSS design.

As a first step, the ontologies were tested to support search of information/knowledge captured in companies, in different systems needed by the PSS developers in various phases of PSS design. The use of the PSS ontology is tested at the machine manufacturing companies for searching information included in product design documents/data, or captured within social software. The PSS ontology specifically, plays an important role in the PSS lifecycle management. To support capturing of experience-based knowledge and knowledge generated within cooperation among various stakeholders involved in the PSS design, social software solutions, such as Semantic Mediawiki, are being used. For this purpose, both design documents and wiki pages were semantically enriched using the defined PSS ontology. The tests demonstrate high efficiency in the provision of the required knowledge, both formally captured (in documents/structured data basis) and experience based (wiki).

In order to test effectiveness of the user-centric ontology, as a part of the proposed context model, the testing of search with and without sensitivity on dynamic contextual aspects (dynamic part based on user-centric ontology) has been carried out. The context models for the PSS developers in several phases of the PSS design, have been developed (e.g., in PSS conceptual phase and in ramp-up phase). The context sensitive search, using the developed context extraction services and the user-centric ontology, identifies at run-time the PSS developer's current context (e.g., her/his current activity and role) and provides the required knowledge fitting to her/his current context (e.g., provides requirements documents and CAD data, if the developer is designing a concept of PSS, or provides experience knowledge on previous problems in the ramp-up phase, if the developer of PSS is acting in installation phase etc., or provides a set of KPIs if the user has the role of PSS Designer as opposed to being Manager). Further tests on the use of both PSS and user-centric ontologies in manufacturing companies are being carried out, to examine their applicability on various tools for PSS design, such as PDM/PLM systems, or tools for provision of lean design rules and definition/measurement of KPIs [23].

V. CONCLUSIONS – FUTURE WORK

The research presented is one of the few attempts found to define and effectively use a PSS ontology, as well as a user-centric ontology in order to support the PSS design process in manufacturing, and specifically in machine industry. The initial version of the ontologies is defined in collaboration with several industrial companies and research centers, using the BFO as upper level ontology. The initial tests with industrial companies indicate the key benefits which can be expected from the application of the ontologies: (1) improved efficiency in search of knowledge relevant for the PSS design, (2) improved communication/collaboration among the stakeholders involved in the PSS design, (3) increased (re)use of knowledge from previous PSS design processes, by at least 60% and throughout the PSS lifecycle, (4) reduction in time and efforts needed for PSS (re)design.

The ontologies will be further explored with various tools addressing the PSS design, and refined based on further defined use cases in the industrial companies, as well as by further modelling various contextual situations. It is planned to involve a number of other actors to further refine the concepts and their relations in the two ontologies, such as research institutions and industrial companies through User Interest Groups in several countries, as well as through clusters of several current European research projects working on PSS topics. The approach selected to apply the BFO as upper level ontology is likely to support collaboration on further refinement of the ontology. One of the mid-term objectives of this work, is to contribute to the definition of a standardized ontology for PSS design in the manufacturing industry.

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