COPING WITH THE KNOWLEDGE SHARING BARRIERS IN PRODUCT SERVICE SYSTEMS DESIGN

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ABSTRACT

This paper analyzes the knowledge sharing process that characterizes Product Service Systems (PSS) design, drawing on data from an in-depth study in the Swedish manufacturing industry. It categorizes and describes the most relevant knowledge sharing barriers affecting early PSS development phases, discussing them in terms of capabilities to be included in a knowledge engineering system to fulfill the increasing need for knowledge in product-service design. To cope with these barriers, the authors introduce the concept of Engineering 2.0, which borrows the general Web 2.0 concept and translates it into engineering terms, going into the details of how functional product development may benefit from the possibility to integrate bottom-up and “lightweight” knowledge sharing techniques with traditional PLM/PDM/CAD solutions, and highlighting the most relevant challenges for the Engineering 2.0 research.

KEYWORDS
Product Service Systems, Virtual Enterprise, knowledge engineering, Engineering 2.0, bottom-up knowledge sharing

1. INTRODUCTION

In a traditional manufacturing situation, companies deal with the development, production and sale of goods in the form of physical products. When a product is sold, a company transfers its ownership to the customer and retains limited or no control over the later product life-cycle phases, except for sporadic maintenance interventions and for spare part replacement. Nowadays, to cope with an increased market competition, companies have started to offer capabilities, rather than products, to increase profit opportunities [1], selling Product Service Systems (PSS) [2] [3] contracted on the characteristic to provide “functions per unit” instead of merely hardware. “Functional” means that products and services are merged together in a way they may bring added value to the customer (i.e. offering power-by-the-hour or thrust-on-wings instead of selling a jet engine), allowing companies to decrease the competition in the aftermarket [4]. Hence, a long-term commitment has to be established between the customer and the provider, while economies of scale can be gained by networking with other industrial partners in an Extended or Virtual Enterprise scenario [5][6].

The need to integrate hardware, software and services asks for increased capabilities to manage knowledge across different groups, departments and companies [7]. Designers are requested to increasingly work in highly cross-functional, cross-disciplinary, enterprise-wide teams, and to develop closer relationships with customers and suppliers, making their knowledge available to a larger audience and to use knowledge from more sources than before, to better understand the desired “function” to be developed and to optimize its availability.

Since crucial decisions have to be taken early in the development process of a functional product, the availability of high-quality and up-to-date knowledge becomes a crucial factor for the final product success. Identifying, formalizing, storing, accessing, sharing and using such heterogeneous assets becomes more complex than ever, much because the people involved in the design of PSS have different backgrounds, competencies and communicational skills.
2. MOTIVATION AND OBJECTIVES
On the authors’ advice, traditional knowledge engineering solutions, centred on Computer Aided Design (CAD), Product Data Management (PDM), or Product Lifecycle Management (PLM) systems, do not adequately support knowledge identification codification and sharing under the PSS paradigm.

The main purpose of this paper is to contribute to the development of more effective knowledge sharing methods and tools for product-service development. Focusing on those downstream knowledge assets that normally would not be considered until a design concept has already been selected, the objective of the work has been to identify and describe those barriers that prevent PSS design teams in reaching a full effectiveness in the way tangible and intangible knowledge assets are exchanged within and across functions and organizations.

From such list of barriers, the paper derives and discusses a set of capabilities for a knowledge engineering system aiming to improve the ‘knowledge baseline’ of PSS projects in their early stages. The paper finally introduces the concept of Engineering 2.0, as a means to fulfil such demand for capabilities, and exemplifies how Web 2.0-based technologies may address the knowledge sharing barriers previously identified.

3. RESEARCH APPROACH
This paper is based on an in-depth company study in the Swedish manufacturing industry. The starting position of this research is, therefore, in a real industrial case rather than in theory. A case study approach [8] and ethnographic methods [9] have been applied to gather data close to technology and product development activities in industry.

Several multi-day workshops, virtual meetings, and company visits have been performed during the data collection phase. Semi-structured interviews have been initially conducted with the scope of picturing the State-of-Practice in industry and to provide a solid context for the later data analysis stages. Semi-structured interviews have been preferred at this stage because allow the respondents to talk without restraints, thus letting them to diverge and spotlight supplementary topics and areas.

In the detailed data-gathering step, the authors have further explored the knowledge problems by means of in-situ observations, group interviews, in-depth interviews and the analysis of working documents. The interviews have been facilitated and moderated by the researchers to uncover topics that were not anticipated beforehand [10] and to build on the findings from previous studies.

The data gathered have been formalized in a set of process models, depicting the knowledge flows and the interactions between the design stakeholders in the different PSS projects. These models have been further analyzed and collaboratively discussed with the key design process stakeholders to define the list of knowledge sharing barriers and to highlight the limitations of the currently in use knowledge engineering tools.

The data gathered during the in-depth study have been complemented by observations from other industrial development projects related to products in various industry segments, ranging from the development of industrial drive systems, to aircraft engines and armoured terrain vehicles [11]. Also in these projects the discussion has evolved in close collaboration with industrial companies and accessing empirical cases.

The data gathering activity has involved about 50 people with knowledge on these projects, both from academia and from industry.

4. KNOWLEDGE WORKERS IN THE FUNCTIONAL ORGANIZATION
Product Service System design raises the knowledge sharing problem to a new level. In the new paradigm, in fact, design teams are increasingly requested to face not-well-defined problems, to move back and forth between problem solving and predictions, to nurture creativity and to encourage radical thinking.

The decision to maintain, upgrade or radically re-design a product has to be grounded on a different knowledge base than it was before, and knowledge elements of interest may be often found outside the traditional boundaries of the product development teams (i.e. knowledge about how customers use the products, or about best-practices in various application domains). The availability of such “downstream” lifecycle knowledge in an early phase is critical to realistically forecast future customer needs and to guide decision makers in prioritizing different scenario alternatives.

Then, functional product development is typically carried out in networks of an Extended or Virtual Enterprise kind, where, in spite of the contractual obligations between the partners and of the
willingness to contribute in sharing [12], effective knowledge flows are very difficult to be established, mainly because people do not normally have a shared history of working together, neither a shared knowledge base nor methods/techniques to create, store and share information and experiences.

In this context, the problem of understanding “what knowledge to share”, “how to share it” and “whom to share with” is even more challenging than in traditional product development. Engineers and designers are requested to become “knowledge workers” and “knowledge brokers”, interacting with several product stakeholders at a time, in spite of different organizations, department and functions [11].

For example, the development and production of an aircraft engine requires many organizations, customers, suppliers, research centers and external partners to collaborate and share each other’s knowledge, core competencies, and experiences in VE or EE settings. Typically, these geographically dispersed engineering teams operate in a dynamic, multi-cultural, and highly unpredictable environment, using a diverse set of IT systems [13]. During the design and production stages, these virtual engineering teams need to collaborate consistently to share design information, know-how, and stakeholder feedback. In the traditional way, the virtual engineering teams usually capture and store all the design information and knowledge in databases where all the pieces are categorized according to a predefined and top-down structure. These databases mainly cover formal (structured/explicit) communication such as internal corporate information, project documents, design drawings, lessons learned, best practices records, etc. However, they show limitations when a new engineer or another co-located team requires authentic information, expert help, or when there is a need to share ideas and knowledge for collective decision making, to aggregate knowledge flows in the organization, to search and retrieve quality information, and to capture informal (unstructured/tacit) knowledge that comes from the knowledge workers’ own experiences. This often leads to misunderstanding and ambiguities in facilitating knowledge sharing among global virtual engineering teams [14].

5. KNOWLEDGE SHARING BARRIERS IN FPD

Drawing mainly on the data gathered from the in-depth case study, the aim of this section is to outline those “individual” and sometime “subjective” barriers - here listed in alphabetical order - that inhibit the effective flow of knowledge across the organization in the early PSS development phases.

The theoretical basis for the definition of such a framework is found on previous works dealing with knowledge sharing inhibitors in traditional product development settings [15-19]. Here the focus is on those dimensions found to be more crucial under a product-service development perspective in the company investigated, They are also intended as the ones that best outline the limitations of traditional knowledge sharing tools in product-service design.

5.1. Acceptability and self-censorship

In PSS design, diversity of opinion and lack of consensus may represent important drivers for innovation, rather then obstacles towards the achievement of the design targets. Harnessing the intelligence of people not “officially” in the team, not “supposed” to have an opinion and not “familiar” with product development, can release unexpected forces and synergies [20] and may ultimately suggest radical and unexpected designs, able to greatly increase the customers’ perceived value [21].

Acceptability and self-censorship have a deep impact on the way tacit knowledge is captured and shared, as already observed in many traditional product development situations, e.g. in the establishment of effective Communities of Practice [22].

In PSS, where cross-functional teams rarely even share a common ground, lexicon and objectives, this barrier is even more evident. The case study has shown that moving out of the traditional organizational pillars is often perceived as a non-acceptable behaviour, meaning that people are usually reluctant to exit their comfort zone and to exchange what they know with other actors through the value chain.

Most of the designers interviewed, especially the less experienced engineers, often consider the information they possess not being important or completely accurate from a product-service development viewpoint. Similarly, the acceptability barrier has been found to inhibit communication and collaboration among those product stakeholders, such
as customers, end users or managers, who possess knowledge regarding the later product lifecycle stages.

People outside the traditional design team boundaries tend to consider their knowledge too specific or too well known, and lack of understanding how their contribution may be beneficial to others. This ultimately boosts self-censorship behaviours, suggesting not to actively contribute to the sharing activity. In such a situation, important knowledge assets risk to remain hidden within a function, pushing engineers to take decisions based on not-enough information.

5.2. Commitment and reward

The lack of commitment in the PSS project has been found as a major inhibitor for effective knowledge sharing. The fear of being part of a cross-functional effort, where competencies are mixed and responsibilities are not well clarified is seen by several of the informants as a major barrier for the effective participation of the team members, impacting the way knowledge is exchanged across the functions. One of our informants has outlined that:

“...people in the team has strong attachment to their home port and have a hard time to loosen up this attachment...”.

Several project responsibles interviewed claim that a significant number of engineers and designers tend to consider important only what concern their specific domain of expertise, not feeling the responsibility of the overall results of a project. As a consequence, the team may lack of exploring the problem space in all its dimensions, e.g. not considering in the concept design phase all those variables that characterize a real world implementation, leading to the generation of sub-optimized alternatives.

Moreover, the analysis has shown that the commitment barrier has usually a little to do with the fear of not receiving the right recognition and accreditation from managers and colleagues, as pointed out by Riege [24], as well as with the unintentional reward for hoarding [25].

5.3. Resignation

In a design situation characterized by wicked design problems [26], with no clear directions to follow and no specific answers to be found, engineers need to keep themselves exposed to many diverse sources of information, which makes difficult to sort out what is relevant and what is not in a particular design situation. The term resignation aims, therefore, to describe the attitude of “giving up” when searching for relevant knowledge outside the designer’s line of sight.

The observations have revealed that most of the information potentially useful for the design of the new product-service offer is typically stored in sectorial databases not accessible outside a specific department, function or company. Looking for specific knowledge elements outside the engineering boundaries, the search may end in plenty of generic inputs, which require additional time for verification. Sometimes it also lead to situations where the search into the “traditional” knowledge management systems, PLM, PDM or CAx, ends in plenty of specific answers, unable to provide useful stimuli for the early PSS design process phases, requiring further interpretation and abstraction. As a consequence, designers tend to base their decisions more on gut feelings and tacit knowledge rather than spending additional time searching for knowledge in the existing repositories.

The problem of codifying knowledge in a way that could be easily reused over time, in different PSS projects, has been often discussed in the interviews. Several informants have indicated the lack of contextual information about the documentation retrieved as a main factor boosting the resignation barrier. This lack of context is seen as something undesirable but inevitable, which makes difficult to communicate knowledge across the functional boundaries and easily reuse it in other projects, since the elements contained in the different repositories, may be almost impossible to interpret without a specific background. Ultimately, it may lead to an under utilization of the existing knowledge assets, spoiling the product-service development activity of much of its innovation potential.

5.4. Time loss

In traditional product development, more than one-third [27] of the time is spent waiting for decision or information, a figure likely to be higher in PSS design, due to the higher degree of uncertainty. Being able to find the right information in the shortest possible time is therefore crucial to reduce the design process lead-time.

The data gathered from the case study confirm that the time dimension plays a central role in the way...
product-service offers are developed, showing that the problem is further complicated by the closer interaction with the other company functions and with the product stakeholders along the all life cycle.

The possibility of reducing the time needed to locate the “right” knowledge for a specific project context is perceived as a major problem dealing with hardware and service aspects. The wicked design problem space, in fact, requires additional time for the identification, access and interpretation of relevant pieces of information, making more time consuming to gather all the knowledge needed to clarify the problem space in a reasonable amount of time. Such inputs has to be found in many different parts of the virtual organization, i.e. in different teams, functions or companies.

Hence, to manage such an overwhelming amount of information, plenty of time is spent just to access all the different knowledge sources and to browse through the knowledge elements. Engineers, however, still have to “do the job” and such a loss of time is perceived as a main inhibitor, asking for more effective means to identify, formalize and share knowledge without stealing too much time from their everyday tasks. As a consequence, people tend to avoid “wasting time” in activities that do not seem to provide benefits in the short term, taking decisions more on the basis of assumptions rather than on documented knowledge.

5.5. Awareness

In product development, engineers seek novelty and innovation, not redundancy. This is particularly evident in product-service design, where the search for breakthrough solutions, able to cope with the “fuzzy” and “wicked” design problems, suggests to move beyond known-item searches, fact retrieval and question answering, i.e. to perform investigative activities able to bring new stimuli and ideas to come out with breakthrough concepts.

The case study has shown that a major problem dealing with PSS design relates to awareness, i.e. with the problem of being aware of where relevant stimuli for the design activity are likely to be found, locating the knowledge assets outside engineer’s main domain of expertise.

The analysis has outlined several dimensions dealing with awareness.

First, the barrier has a spatial dimension, i.e. people are typically not aware of what other people outside their reference domain or outside their function do or know, as well as of people that have knowledge that can influence their own decisions (“knowing who knows” [11]).

Second, awareness has a temporal meaning, i.e. engineers and designers may not be aware of what is going outside their reference group at a given point of time, lacking of up-to-date information regarding current activities in other projects or functions.

Third, in the design of complex systems, product stakeholders might not be aware of people and processes that may be affected by the decisions they take. In this sense, optimizing certain sub-system features may be counterproductive from a system perspective, reducing the overall performances.

Fourth, the awareness barrier is also related to the low realisation of the value and benefit of possessed knowledge to others [24], i.e. “knowing who should know”, pushing information to the people who might be potentially interested in it.

5.6. Language and models

In PSS design, engineers need to keep themselves exposed to as many diverse sources as possible, and participate in groups that range across hierarchies [3]. Moreover, the development of a product-service offer raises the language barrier to a new level, because of an effective communication with the customers is crucial to understand the desired function to be developed.

The lack of a commonly understood language, as well as the lack of a shared format to communicate information and knowledge between the product stakeholders is perceptible in the case study investigated. The analysis shows, in fact, that the different functions involved in a PSS project tend to express what they know by using means that, although coping with the specific task characteristics, are undecipherable in other contexts. Most of the stakeholders tend to keep using their own form of expression, making difficult to communicate the real meaning of the information exchanged across the boundaries of their discipline.

Communication issues, however, are not only concerned with language. They also refer to the problem of providing a common understanding on the data shared, since contextual information regarding the knowledge stored in the different parts of the organization is typically missing. Similarly to what described by Grudin [28], databases and
repositories containing most of the structured content produced in previous projects have been found to be almost undecipherable for those team members with poor connections with the project, as well as difficult to interpret for those who joined the project in a later phase and even for the original project members after some time had passed.

5.7. Trust

Knowledge-sharing activities are characterized by the fear of exploitation [15], which “starts with the premise that I will only share my knowledge with you if I think you can give me something in return” [29]. A feeling of trust is therefore an important prerequisite for a successful knowledge sharing activity [30], both for what concerns the relationship between the design teams members as well as between the provider and the customers.

The authors have observed that, in a cross-functional design situation, trust building among the team members is even more difficult than in a traditional product development situation. The design team, in fact, manages knowledge elements so heterogeneous to raise frequent questions about their quality and consistency, and even the project responsible, sometime, does not have broad enough knowledge to assess the reliability of all the information exchanged in the project. Hence the team tend to play safe with the concepts it cannot fully understand, missing the opportunity of further develop radical designs.

The case study has also shown that customer involvement tends to be confined to those process phases where the risk of knowledge leakage is considered minor, typically in the pre-design and in the testing phase. A closer involvement is often seen as a “loss-loss” situation, where the provider is scared to be drained on knowledge for the advantage of the competitors, while the customer are reluctant to give access to their core know how, because it might be used, in the future, to develop solutions competitors will benefit from.

The companies, and even the individuals, must therefore trust that the counterpart will use the knowledge in an appropriate manner. Building mutual trust between the parties, even at a personal level, is essential for the final success of the agreement [31], since a lack of trust may result in an ineffective decision-making process, based on not-enough information.

6. DISCUSSION

The barriers above describe a set of issues that need to be addressed to better cope with the increasing demand of knowledge that characterize PSS design. In this section, the authors aim to discuss these barriers in terms of capabilities complementing PLM, PDM, CAD and KBE solutions in a way they could further enhance collaboration and sharing of both formal and informal knowledge, and to increase the effectiveness of knowledge flows, between cross-functional teams.

6.1. Acceptability and Self-censorship

Within a heterogeneous design team, knowledge sharing performance gains might be achieved when social identification is strong, as proven by the fact that in many successful design projects, people already know each other from past projects [22]. Satisfying social interactions and experiences with other members of the team, as well as the development a common social identity [33], may have a significant impact on the willingness to contribute to the knowledge sharing activity.

Traditional knowledge engineering tools perform poorly in this respect, in spite of recent initiatives aiming to introduce the social-related functionalities in PLM solutions [34] Hence, enhanced social connectedness functionalities [35] are interesting to be explored to encourage individuals, regardless of their level of functional similarity, to perform more effectively as team members [36]. Moreover, traditional top-down knowledge engineering solutions tend to impose the “language of the engineer” to the “extended” design team. This can be pretty intimidating for people who do not master engineering-related disciplines. Therefore the acceptability barrier might also be reduced by using a communication means that make sense for people, not forcing product-service stakeholders in using formalizations not in their domain of usage.

6.2. Commitment and rewards

As outlined by many authors [37-40] the introduction of a reward system or incentive policies neither have an effect on the corporate culture, nor enhance long term knowledge sharing. Although a formal reward system has proven to be beneficial in the short term to overcome commitment problems [41], the use of encouragement, stimulation or incentives is inadequate in hostile environment [42], suggesting
that any kind of rewards evaporate quickly and do not increase motivation for knowledge sharing.

Moving from what described by Ardichvili [22], who observed that people who are reluctant to contribute when asked to write something for a database are normally willing to share information when asked informally by other colleagues, the authors also found that the social side of design plays an important role in the way people perceive incentives and rewards. The case study has revealed that a proactive knowledge sharing behaviour is usually triggered and nurtured by satisfying social interaction between team members. In such a situation sharing knowledge was seen more as an opportunity for growing and learning, a sort of win-win situation, rather than an extra burden on everyday working tasks.

In a broad sense, the possibility to “judge” and to “be judged” by people with similar interests, and that possess similar knowledge, provides additional motivation to engineers and designers to actively participate to the sharing activity. In a Virtual Enterprise setting, however, satisfying social interactions are difficult to create and maintain. Traditional knowledge engineering systems lack of means to build discussion threads, to comment and to provide feedbacks, thus limiting the opportunity for learning and giving the users the perception that knowledge sharing is something imposed from the top and contrast with their priorities. A more bottom-up approach may potentially facilitate the knowledge sharing activity, raising people’s commitment and motivating product stakeholders in directly contributing to the common knowledge baseline.

### 6.3. Resignation

The case study has outlined three main factors that may potentially lower the resignation barrier.

First, enhanced filtering capabilities, e.g. providing means to assess the applicability of the knowledge retrieved, may help engineers to more intuitively find what might be beneficial for them in a given design situation. Looking at traditional knowledge engineering tools, very few means are given to filter the knowledge assets on the basis of the current user profile, need and task. Context-based applications [44] for the in-context delivery of knowledge are, therefore, interesting to be explored to cope with the problem of providing applicable knowledge to engineers and designers to support the decision-making activity in an early stage.

Second, the identification of relevant stimuli is also dependant by the level to which knowledge elements are linked one each other, thus by the possibility to quickly browse and find connections between a wide variety of topics that makes sense to others. Hence, the knowledge sharing applications should facilitate the serendipitous discovery [11] of knowledge, i.e. the capability to stumble upon relevant inputs for the design activity, such as knowledge that has been accumulated in previous projects or that relates to other domains and disciplines. Providing a means to find something unexpected, out of the usual paths, but related with the ongoing design activity, may stimulate creativity, innovative thinking and inspire radical designs.

Third, more focus should be given to the identification of the knowledge owners, i.e. facilitating the identification of those people who may tell why a model looks exactly what it is, why a certain decision has been taken and under which conditions, in order to make easier to gather those contextual information that traditional systems lack to record and communicate.

### 6.4. Time Loss.

Aggregation is a key factor when discussing the possibility to reduce the loss of time dealing with information and knowledge retrieval. By aggregating several knowledge elements at a time, i.e. gathering different inputs and updates on the same screen/page, it might be possible to reduce the time needed to browse heterogeneous knowledge sources, without being overwhelmed by unnecessary details.

Such an approach may also increase the capability to find innovative solution, stimulating cross-fertilization through association of knowledge elements that are different in nature.

### 6.5. Awareness

Similarly as what discussed regarding acceptability and resignation, the awareness barrier may also be mitigated by focusing more on the social side of design, helping designers in increasing their social ties as a means to find people “who knows” and people “who may help” with a specific problem.

The implementation of social-related functionalities may enhance the capability of the team members to locate where knowledge assets are more likely to be found and to discover contributors also outside the usual network of connections.
To make an example, the level of awareness of more experienced designers is significantly higher than newcomers, mainly because they can count on a wider network of connections developed throughout their entire career. Providing means to help younger engineers to access such connections may potentially leverage their level of awareness, finding design stakeholders who have similar knowledge and share the same interests to solve complicated tasks.

6.6. Language and models

The nature of a PSS project asks for a knowledge sharing approach (methods and tools) that can be accessed, used and understood by all the players. In a functional context, moreover, ideas on how to realize a certain function/product/service originate from different (and sometimes unexpected) areas of the organization.

Imposing a too rigid structure for knowledge codification, e.g. domain-specific templates, models or standards, may inhibit participants willingness to contribute to the knowledge base. Here comes the idea of adopting “lightweight” approach for knowledge codification and sharing, i.e. more intuitive and visual means for sharing information and knowledge across the boundaries. Lightweight in this context refers to methods and tools that can be learned and used by all the potential PSS stakeholders with low effort, and that are low time and resource consuming to install, populate and maintain.

Moreover, not all the knowledge can be captured by product models alone, especially for what concerns service-related aspects. While in traditional mechanical engineering product models aim to contain all the knowledge related to the product, dealing with combinations of hardware, software and services different means have to be found to communicate what the product has to do, and the knowledge engineering solution should be able to incorporate all these different expression into a coherent whole.

6.7. Trust

Among the design team members, trust may have different meanings, such as calculus-based, knowledge-based and identification-based trust [45]. Our investigation has basically confirmed what observed by Ardichvili [22]. In PSS design, in fact, knowledge-based trust, based on recurring social interactions between trustier and trustee, is more effective than other types of trust.

In the case study people have shown to share and trust knowledge more easily if asked by members of their earlier established network. Personalization instead of codification [46] is therefore interesting to be further developed in this context. Codification means that the knowledge is extracted from the people and stored in a database that can be accessed by anyone. Personalization implies that knowledge is shared via person-to-person interaction, meetings or one-to-one conversations. Here again, social connectedness is an important aspect to raise the level of trust of the information exchanged. It is mostly in informal networks that people trust each other, voluntarily share knowledge and insights with each other, and collaborate actively and willingly [24].

From a technological perspective, both the quality and bi-directionality (function-to-function) of the knowledge exchange are important. They both are crucial factors to build interpersonal trust between the participants from the different organizational functions. However, traditional knowledge engineering tools poorly support bi-directionality [47] and complementary approaches have to be explored in order to cope with the trust barrier in design.

7. ENGINEERING 2.0 FOR FUNCTIONAL PRODUCT DESIGN

Moving from McAfee’s [48] concept of Enterprise 2.0, the authors have coined the term “Engineering 2.0” [11], which borrows the more general Web 2.0 concept and translates it into an engineering context characterized by globally distributed cross-functional engineering teams. Engineering 2.0 focuses on the social aspects of design, where the end users add value to the development process around products and services. Such an approach for knowledge engineering is built on two basic concepts: lightweightness and bottom-up knowledge sharing. Lightweight because the purpose is to develop and implement methods and tools for knowledge sharing that require little time and effort to set up, use and maintain. Bottom-up because the approach proposed does not impose a pre-defined structure, but rather lets structures evolve over time as an almost organic response to the activities, practices and interests of the knowledge workers that use these technologies as part of their everyday work.
Weblogs, wikis, social networks, RSS feeds, tagging, microblogs, instant messaging, discussion forums, social bookmarking, and mashups are few examples of Engineering 2.0 technologies.

Weblogs, for instance, might be used as a platform for early feedback from external stakeholders and employees, allowing them to engage in low effort and low time-consuming discussions on product and service offerings. On one hand, new ideas and findings on innovation projects can be presented to a larger audience as an entry in the weblog, in a form easily understandable by the different product stakeholders. On the other hand, customers, users and managers may easily comment and express their opinions in a very informal mode, thus potentially lowering the acceptability barrier. Weblogs may also lower the threshold for the documentation of personal experiences, thus giving people a chance to codify and share their practical and tacit knowledge with others. Indirectly, comments and feedbacks may give indication on the applicability of knowledge elements to a certain context, helping in mitigating the resignation barrier.

From a PSS perspective, wikis might be used as a space to collaboratively grow ideas for future products and to define and refine best practices from the different life cycle phases. Their asynchronous, bottom-up and informal approach [49] may lower the acceptability barrier and facilitate idea and experience sharing among the stakeholders, building a sort of informal corporate memory, where knowledge on customer use, requirements, maintenance demands and know-how are collected and managed. Both weblogs and wikis may facilitate person-to-person interaction and one-to-one conversations, potentially increasing social connectedness and consequently trust among the dispersed team members.

Social networking may support newcomers in exploiting the network of connections that typically distinguish more experienced engineers and in fostering collaboration among staff and external stakeholders. It may also leverage acceptability and commitment, increasing social identification, meanwhile raising the feeling of trust among the knowledge sharing parties.

RSS feeds, can help employees in the Virtual Enterprise in getting the right information at the right time in the right place, creating RSS pages to accumulate all updates from various databases that are specifically customized for the employees’ needs. This not only can reduce email overload [50] and save time by speeding up the dissemination of information, but can also help in increasing people awareness on what is currently going on in the different parts of the virtual organization.

Using tagging practices, PSS engineering teams can organize their content or documents in the most comfortable way for them, such as per customers, competitors, projects, product types, maintenance and service offerings. This could help mitigating the self-censorship barrier, not forcing stakeholders categorizing what they know in a way they do not fully understand and agree. Additionally, tagging practices may possibly raise the awareness on knowledge elements from different sources tagged in the same way, which may facilitate the serendipitous discovery of relevant content in heterogeneous databases.

Social bookmarking may enable global engineering teams to find experts or people with similar interests on specific product related topics, based on informal browsing of bookmark collections, enabling them to group as a team. Engineers from various organizations can also share their findings with peers that allow others to rate and review, to decide on usefulness of resources, impacting on the resignation, awareness and trust barrier.

8. CONCLUSIONS AND OPEN ISSUES

The focus of the ongoing research is on the conceptual design phase of a Product Service Systems design. The main purpose is to understand how knowledge engineering methods and tools may support heterogeneous design teams in eliciting, storing and communicating knowledge elements in a cohesive way across functions and across companies, to support decision-making activities in PSS early design stages.

In line with this aim, mainly drawing on data from an in-depth study in the Swedish manufacturing industry, the paper has categorized and described the most relevant knowledge sharing barriers affecting the early PSS development phases. The barriers identified have been then discussed in terms of capabilities for a knowledge engineering system aiming to cope with the increasing need for knowledge that characterize the new paradigm.

To cope with these barriers, the authors have introduced the concept of Engineering 2.0, which brings the general Web 2.0 concept into the
engineering domain. The analysis of the barriers presented in the paper have outlined, in fact, that a more bottom-up and “lightweight” approach in knowledge sharing has a serious potential when it comes to effectively sharing knowledge between actors partaking in product development across company functions. A more collaborative and user-centred approach in knowledge codification and exchange may facilitate the circulation of knowledge, which, following a more rigorous approach would be very difficult to identify, store and share in a cross-company environment.

It has to be noted that the barriers outlined in this paper, although the most relevant in the specific case study conducted, are not the only ones impacting on the effective sharing of knowledge in cross-functional teams. Other barriers, e.g. related to culture, conflict avoidance and loss of power, have also been identified. However, these barriers have been considered less critical, (and less typical) dealing with a product-service design situation.

The Engineering 2.0 approach is not intended to replace CAD/PDM/PLM systems, rather to propose a new way to deal with new problems that are not likely to be adequately addressed by traditional systems alone.

How, using this new approach, knowledge elements can be elicited, turning them from tacit to explicit, how they can be aggregated and managed along the lifecycle and how their relevancy can be assessed, are questions still to be fully answered, but crucial to verify the applicability of the Engineering 2.0 idea. At this purpose, an Engineering 2.0 demonstrator is going to be developed and implemented in a real industrial situation, complementing traditional knowledge engineering solutions, to collect feedbacks on the use of lightweight and bottom-up techniques in a cross-functional and cross-company design situations.

From a methodological perspective, it will be crucial in the future to investigate how the lightweight approach may increase design teams capabilities to prevent mistakes in design rather than correcting them. The idea is, in fact, that they should not merely support the team in the classical “recognizing symptoms - implementing corrective actions” mode. Backtracking the causes for a failure is just one part of the job. They should support designers in preventing mistakes, helping engineers in performing more effective root-cause analysis.

ACKNOWLEDGMENTS

The research is supported by VINNOVA (Swedish Agency for Innovation Systems), through the FASTE Laboratory at Luleå University of Technology.

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