Exploring Lightweight Knowledge Sharing Technologies for Functional Product Development

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Abstract

Moving away from offering just physical artifacts to becoming providers of functional products, or Product Service Systems (PSS), implies inevitable changes in the way engineering knowledge is identified and shared in a cross company environment. Capturing downstream knowledge assets and making them available to cross-functional teams becomes crucial to approach ill-defined problems in PSS design. The purpose of this paper is to investigate how Web 2.0-based knowledge sharing technologies may be used to support the design of functional products. The article, drawing on data from several industrial development projects in various segments, introduces the concept of "lightweight technologies" as a means to lower the threshold related to the sharing of downstream engineering knowledge assets. The paper points out potential benefits and challenges related to the adoption of a lightweight approach and provides examples of how tools like wikis, blogs or social bookmarking may be used to support functional product engineers.

Keywords

Product Service Systems, Functional Product Development, Knowledge Sharing, Engineering 2.0, Lightweight technologies, Cross-functional teams.

1 INTRODUCTION

In a traditional manufacturing situation, companies deal with the development, production and sales 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. In this context, production costs, timely delivery and technical quality are seen as main competitive factors. However, the emerging globalisation and the increasing market competitiveness are pushing companies to reconsider their business model, shifting from offering merely physical artefacts to introducing product-service combinations to able to satisfy increasingly sophisticated customer needs [1]. The basic principle of the Product Service Systems (PSS) [2] paradigm is to bring added value to the customer by offering the "functionality" or "performance" of the physical product as a mix of goods and services [3]. It also implies that the ownership of the physical product remains with the manufacturer or with the joint venture delivering the PSS [3], meaning that the function provider retains the extended responsibility of the product in the later life-cycle stages [4].

Brännström [5] defines functional products as combination of hardware, software and services. His study expressed a need for the companies integrating the development of hardware, software and services into complete offers, or functional products. In many discussions the least common denominator for the definition of a functional product is "improved performance through available ability" [6]. The current trend of offering this "functionality" leads to refer the development process as 'Functional Product Development' (FPD) [5-7].

Moreover, a single company rarely has all the knowledge required to deal with the development and supply of the mixed offer, therefore the development of functional products [7] is typically done in an Extended Enterprise (EE) [8-11] or Virtual Enterprise (VE) [8, 12-13] setting. Hence, FPD or PSS lead to a more complex organizational structure [14] with involvement of external stakeholders and multidisciplinary teams from the beginning of product planning to the development stage. This aspect radically changes the scope and objectives of the design activity [4,15]. Engineers and designers are requested to increasingly work in highly cross-functional, cross-disciplinary, cross-cultural, cross-located, and cross-organizational environments, thus these enterprise-wide teams have need of developing closer interactions with external stakeholders to gain a better understanding of the desired function to be developed. This new way of working demands engineers to make their knowledge available to a larger audience, as well as to use knowledge from more sources, compared to traditional product development situations. Such enterprise-wide teams, however, 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 [15]. To provide effective support for knowledge identification, codification and sharing is a key objective to achieve successful PSS partnerships.

The design of functional products requires an enhanced understanding of the full range of life-cycle demands and needs in the earliest possible phases [7]. In this context, the availability of downstream knowledge, i.e. knowledge from the later life-cycle steps, becomes crucial to improve early-stage decision-making. This knowledge, however, is mainly tacit, owned by a wide range of people and dispersed in the extended organization. Making it available for the engineers, i.e. providing tools to capture, model, simulate and share this knowledge across organizational and departmental boundaries, represents a main issue in the design of PSS.

This continuously changing market context raises the interest of those companies participating in PSS development to create better knowledge sharing technologies that could allow them to stay ahead of the competition. A more lightweight, bottom-up approach to knowledge codification and sharing shows a serious potential for the creation of a collaboration environment where knowledge can flow smoothly and informally across functions and organizations [16-17], thus helping in building new communities, growing common understanding on the PSS concept and leveraging innovation capabilities and creativity across the corporate boundaries.

2 PURPOSE

Moving from the consideration that Web 2.0 technologies have shown to greatly enhance interactive information sharing and collaboration among communities on the World Wide Web, this paper aim to investigate how such methods and tools can complement existing knowledge engineering technologies and support better information management and knowledge sharing in an Extended or Virtual Enterprise context. The paper initially introduces the concept of “lightweight technologies” as a means to lower the threshold related to knowledge identification, codification and sharing of such downstream engineering knowledge. Further, it points out the potential benefits and challenges related to the adoption of this approach, providing examples of how tools like wikis, blogs or social bookmarking may be used to improve the knowledge flows across organizational and functional boundaries.

Although many contributions in literature describe how bottom-up lightweight technologies may be useful for education [18-19], human resource management [20, 35-36] innovation [21-22] and knowledge management [23-28] there are no clear statements about the benefits of using such technologies to support cross-functional teams designing functional products. The bottom-up approach shows potential in many domains; nevertheless no clear vision exists on how it may be beneficial for the design of e.g. an aircraft engine going to be sold as a function rather than merely a product. The following sections discuss principles, opportunities and challenges within the area of functional product development [7], thus outlining how a Web 2.0-based approach may enhance creativity and innovation in PSS or functional product design.

3 METHOD

This research is based on industrial case studies rather than in theory. The research strategy combines a case study approach [29] and ethnographic methods [30] to verify the approach close to technology and product development activities in industry. The paper draws on data from several industrial development projects related to products in various industry segments – ranging from the development of manufacturing tools and industrial drive systems, to aircraft engines and armoured terrain vehicles. The discussion has evolved in close collaboration with industrial companies and accessing empirical cases. A case study approach has been considered a good means to render a map of barriers, thus the key themes for the research. Several kinds of 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. In the detailed data-gathering step, the researchers have explored the knowledge problems by means of in-situ observations, group interviews, in-depth interviews and through the analysis of working documents. The data gathering activity has involved about 50 people at different hierarchical levels, which include engineers, managers, and project leaders with knowledge on these projects, both from academia and from industry. The data collected from multiple sources allow the authors to integrate different perspectives and analyse the data under the lens of Web 2.0 to outline drivers and barriers related to the adoption of a more bottom up and lightweight approach in knowledge engineering to support functional product engineers.

4 KNOWLEDGE SHARING POTENTIAL OF THE LIGHTWEIGHT APPROACH

Traditionally, manufacturing industries have been using technologies like Product Data Management (PDM), Product Lifecycle Management (PLM), and Knowledge Based Engineering (KBE) systems for knowledge acquisition, knowledge sharing and intellectual property formalization. These technologies are characterized by a top-down structure, i.e. a centrally-controlled structure growing from a pre-defined concept that is refined in greater detail, adding additional subsystem levels, until the system is reduced to base elements. However, in a functional context, engineers are working to a lesser extent with pre-defined concepts and to a larger extent with ill-defined concepts, where they need to figure out what the “problem” actually entails. As they do so, they need to move back and forth between problem solving and prediction, collaborate with a multitude of actors across the value chain, and work in a network of loosely coupled companies and stakeholders that collaboratively interpret and define what customer value is and how it could most effectively be provided in the form of a PSS offer. A drawback of the “traditional” PDM/PLM approach when approaching this kind of issues may be found in these systems’ intrinsic rigidity and their relatively slow and resource-consuming development and deployment, partly due to the fact that the structure is defined “a priori” by the domain experts [31]. Furthermore, these tools normally lack support for the interaction process between the employees and are relatively ineffective in situations when instant feedback is needed during the knowledge creation process, thus not adequately supporting engineering teams when facing wicked design problems in a PSS situation.

For example, to design and produce an aircraft engine requires many organizations, customers, suppliers, research centres 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 dynamic, multi-cultural, and highly unpredictable environments, using a diverse set of IT systems and collaborative technologies [15]. During the design and production stages, these virtual engineering teams need to collaborate consistently to share design information, know-how, and stakeholder feedbacks, etc. In the traditional way, the virtual engineering teams usually capture and store all the design information and knowledge in databases that are categorized by a predefined 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, aggregate knowledge flows in the organization, search and retrieve quality information, and most importantly, 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 [32].

Hence in functional product development settings, it is fundamental to develop information systems with fully integrated and social interactive features that support collaboration and sharing of both formal and informal knowledge to provide added value for an organization [31]**.** The authors believe that lightweight technologies show a promising potential in this context with a focus on connecting people, synthesizing information, and supporting both formal and informal communications.

The shift towards the functional aspects of a product, seeing it as a value carrier as opposed to hardware, adds complexity and knowledge intensity to the design activity. The capabilities to make superior product development are derived from their ability to create, distribute and utilize knowledge throughout the product development process in a new and more efficient way [33].

Developing highly successful new products is possible through the integration of abilities of both upstream (e.g. innovation and design engineers) and downstream knowledge workers (e.g. manufacturing, maintenance, and field-service engineers) [33]. Here the issue is to capture the tacit knowledge that comes from the experiences of the individuals. This could be considered as the most powerful form of knowledge, but this kind of knowledge is difficult to articulate formally, difficult to communicate and share, shared only when individual are willing to engage in social interactions within the extended organization.

According to Bell [34], 80% of organizational knowledge is stored in people's heads, 16% is stored as unstructured data (Office documents, network folders, files and e-mail, internet sites) and only 4% stored as structured data (databases, data warehouses, cubes, XML data). These results indicate how important it is for an organization to capture and share tacit knowledge from their employees, and to deal with unstructured data in more effective ways.

This highlights the need for a different approach able to merge traditional technologies, with emergent social software technologies. These tools show completely different characteristics compared to corporate databases. Their structure evolves over time, they support a bottom-up approach and informal communication, they are flexible in nature and transfer the control to the users, and their development is quick and inexpensive [31,35]. These technologies with their underlying social features like co-authoring, people finding, tagging and community building, may provide easy and better conditions for knowledge sharing between virtual teams [32]. Furthermore they may support and encourage virtual engineering teams to engage [36], participate, cooperate and share their ideas, experiences, and feedback to simulate the knowledge flow and social networks across the organizations. Moreover, these technologies are relatively lightweight, if compared with the traditional ones, in terms of cost, time for implementation and maintenance.

External participation and knowledge sharing of corporate knowledge in virtual environments can yield benefits that include higher customer satisfaction, greater customer loyalty and reduced support costs, and continuous refreshment of knowledge [37]. Many organizations are starting to acknowledge the sharing potential of the lightweight approach, and believe that these technologies certainly support the traditional tools, like PDM, PLM and KBE systems, for effective virtual collaboration and knowledge sharing, and further they could help fill the social-technical gap in the organizations.

A recent initiative started by PTC to integrate a Social Product Development approach with PDM tools to be able to provide interaction and collaborative features among global design teams [38]. Some other examples of adoption of lightweight methods come from IBM, using Dogear social bookmarking, and Microsoft, using the Quest internal communications system, which includes a wiki system for effective knowledge codification and sharing in the organization [31].

5 CONTEXT AND MEANING OF THE LIGHTWEIGHT PARADIGM

Lightweight technologies [15,18-28, 31-32, 34-45, 47-48, 51-54] are intended as systems that require little time and effort to set up, learn, use, and maintain, i.e. aiming to lower the threshold for adopting. Moreover, they are intended to let the structure evolve over time and to support informal communication also in absence of physical proximity [15]. Lightweight technologies are built on the basis of technologies such as blogs, wikis, tag clouds, mashups, RSS, and social networks. They are not intended as a replacement for traditional heavyweight technologies, instead they aim to complement them, dealing with new problems in new way as required in the development of functional products or PSS. The following sections describe some of the major terms in the "lightweight" domain, followed by a detailed discussion of Engineering 2.0 opportunities and challenges.

5.1 Web 2.0

Web 2.0 is a term coined by Tim O'Reilly of Tech publisher O'Reilly Media in 2005 [39]. Web 2.0 represents the second generation in the Web's evolution that shows a significant move in the way people engaged on the web can create, store, edit, access, share and distribute the content to larger audiences compared to the first generation of web, Web 1.0.

Web 1.0 refer to static web pages, written solely in HTML, that only allowed users to read, and there was an hierarchical organization of producer/user, and lack of support for two-way communications [40]. In contrast, Web 2.0 refers to dynamic web pages that allow users to write, contribute, add value and act as co-developers, and this approach further facilitates creativity, collaboration, and sharing between users.

The O'Reilly Radar team [41] formulates Web 2.0 as *"…a set of economic, social, and technology trends that collectively form the basis for the next generation of the Internet—a more mature, distinctive medium characterized by user participation, openness, and network effects.".* Some of the most common Web 2.0 applications are blogs, wikis, social networking, tagging, RSS, mashups, podcasts, bookmarking, media sharing and collaborative editing, etc. O'Reilly stated that Web 2.0 does not have hard boundaries, but relatively have a gravitational core which specifies seven core characteristics of Web 2.0 [39]. These characteristics can be grouped into three areas: the use of the Web as a platform, the Web as a place to read and write rich content, and the social and collaborative use of the Web [42]. Web 2.0 is revolutionizing the World Wide Web in favour of a bottom-up and collective sense-making approach to knowledge sharing. Functional product or PSS design also require a more open approach to knowledge sharing, hence these tools are particularly interesting to be implemented in an industrial setting.

Strengths	Weaknesses
Facilitate virtual collaboration,co-ordination, co-operation. Capture “unstructured data” across the organization. Allow informal (tacit) knowledge capturing and sharing. Easy access to experts and network building. Leveraging open and bottom-up innovation. Simplified store, search, retrieval and access information. Allow for exchange of ideas with control access. Cost-effective, easy to set-up, use and maintain. Collective intelligence approach to knowledge creation.	Older workforce could resist adopting new technology. Ambiguity and misunderstanding in knowledge modelling. Proper maintenance is required, otherwise become vague. Demands active participation. Consistency on regular usage of tools. Management policies and organizational control. Possibilities for making mistakes in social interaction. Ineffectiveness in case of lack of consensus. Degree of transparency.
Opportunities	**Threats**
Collaboration among multi-disciplinary virtual teams. Shared knowledge base in enterprise-wide teams. Facilitate innovation practices and promote innovation. Build long term relationships and community building. Lightweight knowledge enabled engineering system. Incorporate social collaborative features to traditional systems. Improve knowledge baseline for new PSS projects.	Privacy of organizational knowledge assets. Losing control of intellectual property. Sharing confidential information with unauthorized persons. Security. Espionage.

Table 1: SWOT analysis of lightweight technologies adoption in an engineering context.

5.2 Enterprise 2.0

Many organizations have started to use Web 2.0 technologies in their working environment. McAfee [43] summarizes the rising interest in the use of these 2.0 tools for generating, sharing and refining information in the companies with the term Enterprise 2.0 [43]. Enterprise 2.0 is defined as “*the use of emergent social software platforms within companies, or between companies and their partners or customers”* [43]**.** McAfee uses the acronym SLATES to specify the six underlying components of Enterprise 2.0 technologies that guide the creation of Enterprise 2.0 software: Search, Links, Authoring, Tags, Extensions and Signals [43]. SLATES forms the basic framework for Enterprise 2.0, however it does not deny the higher level of Web 2.0 design patterns and business models [44] since it takes some of the prominent ideas of Web 2.0 like user generated content and peer production. The most common Enterprise 2.0 platforms are blogs, wikis, social networking, instant messaging, and mashups.

Several organizations are driving towards Enterprise 2.0 to enhance real time communication, community building, collective intelligence, and knowledge management. The major differences with new social tools from the traditional ones are that they can change enterprise knowledge flow by making it more open to public and more sociable [44]**.** It can create value by extracting the knowledge from various sources in the organization. A recent survey from McKinsey reported that 69 % of 1,700 executives perceived that their organizations gained measurable business benefits, including more innovative products and services, more effective marketing, better access to knowledge, lower cost of doing business, and higher revenues [45]. Another report on enterprise adoption of Web 2.0 tools in the workplace shows that between a third and one half of businesses are either already using or will soon be deploying Enterprise 2.0 tools in the workplace for better communication and collaboration practices [44].

5.3 Engineering 2.0

Functional product development is something different from traditional engineering and product development: The organization is different, the team composition is different, the objectives are different, and the responsibilities are different, since it is done in a virtual enterprise setting involving many industrial partners and external stakeholders. A major challenge is how to support knowledge workers to collaborate across the many boundaries of the virtual enterprise. The traditional CAD/PDM/PLM technologies, although playing a strong role in virtual enterprise collaboration, show some inefficiency in terms of time, cost and quality of knowledge sharing.

Larsson et al [15] coined the term Engineering 2.0 to indicate the use of Web 2.0 technologies in the fields of engineering and functional product development. These technologies specifically target globally dispersed engineering teams working in business-to-business situations of the VE kind where the available technology support for knowledge sharing still centers heavily on comparably heavyweight technologies like CAD, PDM, and PLM systems [15]. In this paper authors like to explore a set of Engineering 2.0 tools that could potentially enhance better knowledge sharing in functional product development. Blogs, wikis, social networks, RSS feeds, tagging, microblogs, instant messaging, discussion forums, social bookmarking, and mashups are few examples of these technologies. Some of these technologies might be positioned in between Web 1.0 and Web 2.0, but authors consider them because they believe that these technologies can help cross-functional virtual engineering teams in the context of functional product design. For example, microblogging can provide combination of synchronous and asynchronous communications, while instant messaging could provide an effective channel for immediate assistance, and a quick way of sharing files and triggering video/audio meetings.

5.4 Opportunities and Challenges of the Lightweight Approach

Lightweight technologies can provide easier platforms to connect virtual engineering teams through sharing their ideas, know-how and corporate knowledge with the support of existing enterprise artefacts. But achieving the benefits of these technologies will require cultural and behavioural shifts within an organization as described earlier. Hence, the adoption of a lightweight approach could create both pros and cons in internal and external environments of the enterprise. The authors use SWOT analysis to explain and summarize the opportunities and challenges of such an approach in a cross-functional engineering context. There are many different interpretations of a SWOT analysis, and in this paper authors considered Strengths and Weakness as a Now (or As-Is) situation and Opportunities and Threats as a Future (or To-Be) situation of a lightweight approach in an engineering context [46]. Table 1 below shows the outcome of the SWOT analysis on the application of lightweight tools in an engineering context.

6 ENGINEERING 2.0 FOR FUNCTIONAL PRODUCT DEVELOPMENT: A SCENARIO COLLECTION

This section discusses some of the most common Web 2.0 technologies from an engineering perspective, trying to outline how such technologies can be adopted in a PSS development context to support engineers in the knowledge sharing activity within the above-mentioned constraints and barriers. The main scope of this section is to point out how these technologies can be useful in a PSS context presenting examples of To-Be usage scenarios coupled with the issues and challenges related to their utilization. These scenarios are drawn both from observing real industrial cases through case study approach and theoretical findings from the functional product development or PSS research.

One of the most common Web 2.0 technologies is the **blog**. From a PSS perspective they show potential to be used as a platform for early feedback from external stakeholders and employees and allow them to engage in the discussion [22] on product and service offerings. On one hand, new ideas and findings on innovation projects could be presented to a larger audience as an entry in the weblog. On the other hand, stakeholders may easily comment and express their opinions, in a very informal mode. Such a two-way communication channel may be developed in a way that could make it possible to network and exchange knowledge between the organization and a larger customer base, thus allow capturing customer usage patterns, their needs and demands. The low level of formality associated with the tool may possibly 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.

Wikis have gained popularity in recent times as a means to gather collective knowledge about a topic and to share it with a large audience. Wikis have demonstrated good potential regarding knowledge sharing in an enterprise setting [47] and successfully used in several parts of the organization as a platform for both internal and external collaboration. From a PSS perspective, the benefits of the open authorship approach can be further leveraged, e.g. as a supporting tool that allows the different PSS stakeholders to gather and collaboratively define and refine best practices and lessons learned from the different life-cycle phases. Wikis can also be used as a space to collaboratively grow ideas for future products, letting stakeholders propose innovations and changes directly building from the ideas of the others. Its asynchronous nature, bottom-up and informal approach [47] may facilitate idea and experience sharing among the stakeholders, building a sort of informal corporate memory [48]. An alternative usage scenario for the wiki is in the area of service provision. They may be used as a shared platform to collect and manage knowledge on customer use, requirements, maintenance demands, know-how and more.

Social networks. Within a single company it is rare to find all the competences needed to develop real PSS combinations, since it requires a deep investigation of topics that are typically outside the technical horizon of the engineers [49]. As far as the complexity of the problem space increase, it becomes more important to involve people with different expertise in design, i.e. knowing who knows [50]. Very often, in fact, the problem related to the lack of specific knowledge in a given topic is addressed by networking with experts working in different enterprise contexts to raise the knowledge baseline and this is often done by merely relying on the "social ties" people in the PSS design team may have developed in their carrier. Social networking, in particular, may support newcomers in exploiting the network of connections that typically distinguish more experienced engineers, finding expertise inside and outside the company or, alternatively, stakeholders with similar interests across the organizational and functional boundaries, thus giving the possibility to form a work group and discuss ongoing issues and learn from each other [22]. It can ultimately foster collaboration among staff and external stakeholders allowing sharing of new ideas, needs, opportunities and updates on products and services.

RSS feeds allow employees to subscribe to their choice of content resources to get regular updates in a standardized format, which facilitates the pulling of relevant information to the employees instead of pushing it to them [51]. Organizations in a PSS context include many geographical dispersed teams functioning simultaneously and updating key information from projects, themes, and discussions into various databases, blogs, wikis, and forums. This may lead to information overload and difficulties to overlook and consolidate the updates from several vital sources. RSS feeds, with its Interactive and dynamic nature, can help employees in getting the right information at the right time in the right place [51]. Organizations of the VE kind may create RSS pages to accumulate all updates from various databases that are specifically customized for the employees' needs and can help them to get an overview of the hot topics in the organizations. Alternatively, they could allow updating of stakeholders on issues of their interest that can enhance decision-making in between organizations. In addition, it can potentially reduce email overload [51] and save time by speeding up the dissemination of information among staff and external stakeholders.

Tagging enables the generation of user-generated taxonomies (i.e folksonomies) that basically categorizes the content with keywords or tags for easy searching and retrieval. In a typical PSS environment, different organizations have different ICT policies and databases, forcing engineers to store documents in a formal and restrictive hierarchical system that does not allow flexibility in modelling complex information and knowledge [31]. This can cause misinterpretations and ambiguities when other staffs tries to retrieve the information from traditional databases since they neither have the same technical background, nor a shared history of working together. Using tagging practices, PSS engineering teams can organize their content or documents in the most comfortable way for the teams likely per customers, competitors, projects, product types, maintenance and service offerings. This can help other engineering staff and business partners to locate and fetch information or documents easily by referring their tags or by a tag search function. Additionally, it is possible to retrieve specific content from different sources tagged in the same way. Tags can be used in internal blogs, wikis and collaborative portals of the organizations for easy retrieval and sharing of information. From a PSS perspective, this practice can leverage the collective wisdom of engineers and improve the way information and knowledge sharing takes place among employees and external stakeholders. Further, organizations can consistently update their taxonomies based on the popular tags from tag clouds, hit ratios and context [52].

Social bookmarking is a method to store, organize and share bookmarks of web content with the help of metadata in the form of keywords or annotations. Engineers in a PSS context often deal with complex problems, and functional related research topics. They frequently require saving their search information for easy access and retrieval in the future. Furthermore, they need a shared platform for collective knowledge sharing among multi-disciplinary teams to come up with innovation solutions. From a PSS perspective, social bookmarking enables global engineering teams to possibly search and find the experts on specific product related topics based on informal browsing of bookmark collections for external help in problem solving. It also facilitates to locate the people with similar interests in the projects, enabling them to group as a team, and outline shared bookmarks by a group tag. In a PSS context, engineers may get informed of significant new content with RSS feeds that allow easy subscription of a bookmark collection belonging to a specific tag, keyword or individual. Research engineers from various organizations can share their research with peers that allow others to rate and review to decide on usefulness of resources [19]. All these practices nurture communities of practice [53] between enterprises, thus could improve information and knowledge sharing in functional product development.

Microblogs allow users to share brief text updates, web links, photos or audio clips to a restricted group by the user choice. As mentioned earlier, engineers in the PSS context take part in multi-disciplinary teams working at different locations around the world. Engineers with similar interest in a specific subject can group together and share innovative sources of ideas, quotes, and links that may allow others to give focused and concrete feedback. From a PSS perspective, microblogging may act as an informal communication channel for collaborative work that can yield communication productivity and lower the threshold for knowledge sharing compared to email, instant messaging and forums [54]**.** Its people-centric nature can facilitate virtual discussion on ongoing issues or functional requirements among business partners that possibly nurture the relationships among employees, customers and partners. On the other hand, it can help engineers to locate and follow experts in a VE setting, to allow them to ask questions and get answers that can create a learning experience and foster professional connections.

Instant messaging is a text-based communication medium for connecting users in real-time. The PSS context includes different organizations and external stakeholders, and since engineers in a PSS context deal with complex problems in their everyday work, they often need to engage in real-time communication to get quick access to help, suggestions or feedbacks. From a PSS perspective, engineers in the virtual enterprise network can use instant messaging for short one-to-one conversations and to escalate immediate queries and clarifications [54] on technical difficulties, functional needs, etc. It can enhance the sense of community and accessibility that facilitate collaborative learning environments [19] across PSS engineering teams. Moreover, it can helpful for coordinating unstructured group meetings and scheduling tasks of engineers within a company or with external parties. Although microblogging provides both synchronous and asynchronous ways of communication, instant messaging, by adding more enterprise features, can enhance virtual collaborative learning environments among PSS engineering teams.

Discussion forums allow users to post questions for debate to find helpful answers. PSS engineering teams require long-term commitments throughout the product lifecycle. They need easy-to-use platforms where to discuss certain issues over a prolonged period. From a PSS perspective, forums could allow engineers to discuss on certain critical issues among business partners in the early stages of product development, and they could also be useful for heavily moderated topical conversations over a prolonged period [54] for the internal and external arguments. Using forums in the PSS environment can create opportunities to come up with new solutions to the problems or get feedbacks from technical experts in the various life phases of the product. Furthermore, forums may be helpful for bottom-up innovation with regard to new products and services that can possibly build cooperation and association among organizations and business partners to enhance collaborative knowledge exchange [28].

7 CONCLUDING REMARKS AND FUTURE WORK

This paper has taken an important step towards exploring the application of Web 2.0 technologies in the area of Functional Product Development, introducing and exemplifying the concept of Engineering 2.0, intended as a more bottom up and lightweight knowledge sharing approach, able to complement CAD/PDM/PLM systems in the early product development stage when dealing with the design of a product-service combinations in a cross-functional and Virtual Enterprise setting.

The research work has outlined that existing knowledge sharing systems are not supporting in an adequate way the capturing, codification and sharing of cross-functional knowledge in PSS design. The authors believe, therefore, that adding social features to these technologies may improve the knowledge sharing potential of existing “heavyweight tools”. Lightweight technologies can add further support to the heavyweight systems, hence leveraging global communication and collaboration in a functional product development or PSS context.

Although such technologies, methods and tools look promising to leverage the knowledge baseline of functional product innovation projects, their uptake in industry is limited. The discussion with the industrial partners has outlined several issues that have to be addressed both from a process and tool perspective before a wide adoption of such tools may be achieved:

Active user participation. Web 2.0 tools are intended as spaces where people may grow their knowledge and understanding through interaction with other people sharing the same interests on a topic (rating, commenting, replying to feedbacks). The lack of user participation in the discussion will eventually spoil the innovative power of the technology.

Leakage of proprietary knowledge. Letting the information flow across the organization in such an open mode can have negative consequences on a company’s proprietary and core knowledge, thus strict policies concerning dissemination of sensitive, proprietary information outside the company may be required. Using RSS feeds, for instance, confidential information can be pushed to unknown subscribers.

Information quality. One of the major problems relates to information quality. Web 2.0 tools are typically dominated by the loudest and most persistent voices, leaning towards personal opinions and interpretations rather than verified facts.

Lightweightness. Over time, as far as the information and knowledge managed by the lightweight platform increases, noise and spam increases as well, leading to a situation where the system is no longer lightweight, but rather cumbersome to navigate and poorly reliable. The risk of duplicated information is also relevant and may generate confusions and errors if not accurately managed.

From a process perspective, future research need to consider the importance of lightweight technologies in PSS or FPD context in considerations to industrial obstacles and defining the kind of working modes that these technologies able to support cross-functionality.

One of the advantages related to the bottom-up approach is that it can allow to overcome the traditional symptoms – a corrective actions working mode – moving towards an approach where problems can be avoided by recognizing in advance the root cause of the problems.

Eventually, the capability to turn tacit knowledge into explicit, and to make it available across functions and projects is still to be assessed. At this point, an Engineering 2.0 demonstrator is under development, in collaboration with the Swedish manufacturing industries, to collect feedbacks on the use of bottom-up and lightweight technologies for cross-functional knowledge sharing in a cross-company design situation.

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