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CHALLENGES FOR EXPERIENCE FEEDBACK IN ENGINEERING DESIGN

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ABSTRACT

In this paper empirical finding from a study conducted at an aerospace company is compared to theory regarding Experience Feedback (EF), Lessons Learned (LL) and Decision Making (DM). The purpose with the study was to examine how EF within the organization was conducted and what problems and possibilities that was seen. A qualitative approach was taken and interviews and a workshop was conducted. The empirical findings show that EF exist on different levels within the organization but current feedback processes are currently leaning more towards archiving and storing than knowledge sharing and learning. Also passive dissemination approaches are mostly used whereas active dissemination within the correct context is needed. The aim with this paper is to discuss issues and empirical findings that should be considered when creating work methods and systems that support learning by EF and LL dissemination.

NOMENCLATURE

CAD – Computer Aided Design
DMS – Document Management System
DM – Decision Making
DS – Decision Support
ED – Engineering Design
EF – Experience Feedback
ERP – Enterprise Resource Planning
KBE – Knowledge Based Engineering
KE – Knowledge Engineering
KLC – Knowledge Life-Cycle
LL – Lessons Learned
PD – Product Development
R&D – Research and Development

INTRODUCTION

Industry is experiencing an increased competition making it challenging to stay ahead by technological advantage, and opportunities ending up in business with smaller margins. As a strategic shift industry is turning towards competing with knowledge and extended offerings [1] in order to ‘do faster, do better, do correct’ and gain advantage over competitors [2]. In the past, industry focused a lot to make the manufacturing process faster, better and more robust. One of the issues was to increase productivity with maintained or increased quality of the final product. To achieve this, methods have been developed to make the design and manufacturing more effective and faster. Not being able to compete solely with production effectiveness, the race has turned to make the products and offerings more innovative.

Innovative design creates new demands both at the product development process but also on the manufacturing process. Thus, novel ideas regarding manufacturing processes have to be developed simultaneously.

Future manufacturing systems have to be developed and adapted for rapid and agile production due to that innovation have become more common from project to project. That is, many projects starts afresh, calling for deeper insights in what is similar to previous projects and what is really new, and how customer value is addressed. The increased pace of innovations between project-to-project makes it important to reuse knowledge and experience. This means that efforts to improve process efficiency focus product development and research and development (R&D) processes, rather than production processes, by managing knowledge and experience from ongoing and previous projects making it available throughout the development process and beyond. Hence competition based on knowledge and competence in early development and innovation has come into play [3].

The idea is that experience feedback and lessons learned systems increase efficiency, by ‘knowing what we know’ [4] so that project start-up time can be reduced and that the solution space increase while at the same time avoid repeating problems [5]. However this is hard to do. The tendency, to not be able to reuse knowledge and experiences between projects creates an increased pressure on the way employees work through out the product life-cycle. New tools and technologies have been developed over the years to help shift the work environment for the designers from physical to virtual environments, e.g. Computer Aided Design (CAD) and analysis software but also documentation and communication tools. However, the actual process of transforming information into knowledge, i.e. the thinking process has not been transformed.

There is a need for increasing the effectiveness of the innovation process, by capturing some of the aspects of experience based knowledge. One-way of doing so is to raise the knowledge baseline for the employees. A way to raise the baseline is to take care of knowledge and experiences that employees have regarding their profession, work environment and the products and services they are developing, and then communicating it to others that are in need of this kind of knowledge. The reuse of knowledge as-is is one aspect but also important is to be able to reuse parts of the knowledge so that it can be applied in a similar or new context. LL are one way of doing this. This includes both explicit but also tacit knowledge [6].

The aim with this paper is to discuss issues and empirical findings that should be considered when creating work methods and systems that support learning by EF and LL dissemination.

THEORY

In Engineering Design (ED) [7]; Knowledge Engineering (KE) [8]. approaches have been used extensively to increase the efficiency of the design process. Creating a design is not a problem, i.e., creating a design and disseminate the change through out the organization. But to know what, how and why a certain design or solution is the way it is and feedback it to current or next generation of products or processes is. This shows the difference between storing documents and organizational learning. The information stored range from product-, process- and business models, documents, analysis models and results, research data, communication, presentations, pictures, video, LL and design recommendations. In this paper documentation regarding LL and experience is in focus.

The data stored in documents etc. is just data until it have been interpreted as information, which in turn require some background knowledge and understanding [9]. Documents often contain knowledge that can be easily expressed, i.e. explicit knowledge, whereas tacit knowledge is not as easy to formalize into clear and understandable documentation. LL has been used as a way to capture and store knowledge and experience for later assessment and reuse. As most other things existing in the world, knowledge also has a life-cycle. The

knowledge life-cycle (KLC) described by Blessing [10], Stokes [11] as well as Nuzzo [12] show similarities with the Lessons Learned Process stated by Weber [13].

- Blessing → Capture, Learn, Store, Retrieve, Use, Generate, Outside sources (between Use and Capture)
- Stokes → Identify, Justify, Capture, Formalize, Package, Activate
- Nuzzo → Identify, Capture, Store, Access, Share, Use, Learn, Generate and Acquire
- Weber → Collect, Verify, Store, Disseminate, and Reuse

What they have in common is the formalization of explicit and tacit knowledge into formal models [5], design rules [11] or design recommendations that may be implemented in computerized systems, such as LL- [14], KE-[15] or Decision Support (DS) [16] systems. Stokes [11] focus more on the capture, formalization steps of the KLC when creating Knowledge Based Engineering (KBE) systems, whereas Blessing and Nuzzo also focus the more human issues such as learn, generate and acquire. Formalizing knowledge and experience and storing it within computerized systems is done with the purpose to make it available and accessible, independent of both place and time. However, experience is communicated in natural language, that is, speech (synchronous) or texts (asynchronous) [17], which introduce a problem with computerized knowledge and experience collection due to that text is hard to retrieve (computationally with algorithms etc.) with precision and recall [13]. Here precision means that many non-relevant lessons are retrieved and recall means many relevant lessons are not retrieved. The reuse of knowledge and experience is also hard due to that before an experience or lesson (documented in textual form) is really understood the documents (essentially data) have to be assessed for relevance and also interpreted, which in turn require knowledge of that domain. Interpretation also involves subjective opinions and the intent with the document can be misunderstood.

A LL process of organizational knowledge contains the phases [13].;

- Collect
- Verify
- Store
- Disseminate
- Reuse

However at the same time “A knowledge-intensive environment cannot rely on a knowledge use-cycle [...]”;

- Capture
- Store
- Retrieve
- Reuse

[...] *Reuse is too limited because it suggests that the knowledge being used does not change*” [10]. This introduces a dynamical problem with EF and lessons reuse. That is, captured and stored lessons have to be managed, validated for relevance, checked for redundancy and eventual changes have to be updated and disseminated within the organization.

Another problem with LL systems is that most of them are stand-alone architectures [13] that forces lessons to be disseminated and reused outside the usage context or environment. The standalone architecture also makes the user responsible for lesson dissemination, which puts the following assumptions about the user [13]:

- The user has to know that repository exist
- The user have to believe that the system will offer useful lessons
- The user have to believe that lesson reuse is beneficial
- The user have to know where and how to access repository and
- The user have to have the time to access it and learn how to use it

Categories of different types of dissemination sub-processes where users search for lessons in standalone retrieval tools exists;

- Passive dissemination
- Active casting
- Broadcasting
- Active dissemination
- Proactive dissemination
- Reactive dissemination

Dissemination where the system remains passive is the most common type while active, proactive, reactive dissemination has only been tried out in research projects [14].

Conducting Product Development (PD) projects involves taking a lot of decisions, hopefully, based on facts either created afresh (as in completely new PD) or from previous experience in either tacit or explicit form. Decision Making (DM) theory, as presented by Mintzberg [18], suggest that there exist three approaches to DM; thinking-first, seeing-first and doing-first.

Thinking-first, which possess the characteristics of “the verbal” and “facts” is more or less explicit knowledge [6] and experiences that can be easily translated into rules and design recommendations, i.e., documentation that can be captured and stored easily both in written and in more technical formal formats [5].

Doing-first, has the characteristics; experience, which involves “...*experimentation – trying something so that you can learn*”. Doing-first involves;

- Enactment – (doing various things),
- Selection – (which works, making sense of that) and,
- Retention – (repeating successful behaviors while discarding the rest.).

Seeing first involves four steps of creative discovery;

- Preparation - involves deep knowledge developed over the years.
- Incubation - means that the unconscious minds “digest” the information.
- Illumination - involves seeing something that triggers the mind into a flash of illumination or insight.
- Verification - the logical mind returns to verify the insight and make logical arguments, which can take time.

Although Mintzberg is talking about DM from a business perspective the ideas regarding thinking-first, seeing-first and doing-first is also applicable in product development where designer make decisions all the time. But can thinking-first, seeing-first and doing-first be applied to LL and EF?

METHOD

Industrial Context

The research has been performed at a company that is developing and manufacturing capital-intensive products and services in the aerospace industry for a global market. Commonly, there is a difference from product development as presented in literature in terms of the processes. That is, the early phases as presented in the literature are part of the overall development process. In this company the early phases are separated from ‘development’. Due to the company providing high-tech solutions for the aerospace industry, innovations and new and not verified or validated technologies and methods are managed in a Research & Development (R&D) process. In the real case, product development is ‘production’ and national and international laws regulate the documentation and ‘traceability’ of information as well as certification of the technologies being used. That is, if information is needed it is documented and can be found. But, as this study highlights, the retrieve processes does not support everyday work. Here the need for more effective processes is found. To achieve this development projects are part of the work at R&D. Each development project has an internal Teamsite [19] that is used for storage of project documents and as a communication area. The projects also have access to an external site called Teamplace [19], here personnel involved in research or extended enterprise work (for instance affiliated partners and academia) can access and store files. Several different systems for documentation and archiving purposes are used, both digital and ‘physical’, e.g., binders and drawings, storage are used. The digital systems are large propriety systems developed by external companies (off the shelf systems). The IT-department at the company is responsible for maintenance and updates of the systems, but they also occasionally perform some customization of the systems.

Data generation

A novel manufacturing method and its application has been used as a case for the study. The studied case is currently in the

R&D phase but is soon to be deployed into production, which is the reason why it was chosen as suitable case for studies within the topic of EF and LL.

In general, data for the study presented in this paper has been generated during informal and formal meetings with the manufacturing company. Besides semi-structured interviews [20], participatory observations, i.e., observations in combination with questions [21], have been performed. This has made it possible to generate data about how engineering work is conducted today and, also, provided for an understanding about manufacturing processes used in the study. For this study, the company has been visited on three different occasions, in addition to a workshop session. In the workshop the topic was 'experience feedback'. Six people representing capabilities in the final manufacturing process from the company participated in the one-day workshop. The workshop was inspired by a 'future workshop' [22]. The group in a future workshop should include people who will get in direct contact with the tool that is going to be developed. Accordingly, people from the development department represented industry. A future workshop runs in three phases, critique (of the present), fantasy (wishes for the future) and implementation (what is possible today), however here the phases in the company workshop was adapted into the phases 'now', 'wow' and 'how' [23]. In general this approach is in line with a 'future workshop', but is performed as a creative session where the participants actively work with Post-its', interact and build on each others' ideas. Further, the implementation in a future workshop and the how phase differs, the how phase is designed to provide for solutions to be initialized and grounded in the participants own ideas. In my view, the implementation phase in a future workshop focus on categorizing and ranking the gap that has been found between the critique and the fantasy phase. Hence not providing for enhancement of the ideas from the fantasy phase.

EMPIRICAL FINDINGS

The study has shown that there are different levels of EF. The three levels can be categorized as

- Within projects
- Between active projects
- From previous projects

Within projects is categorized by personnel working close together in teams often in an open workspace where there is awareness and knowledge of who does what, when and why etc. Personal contacts and face-to-face discussions are dominant in the way knowledge and experience is transferred.

Between active projects is characterized by formal and informal meetings, phone calls, mail conversations and a typically detached situation. Knowledge about where to find information about an active project is characterized by personal networks in the first, second and third hand, where knowledge on company processes is key.

From previous projects means looking in archives or reading white papers regarding an ended project. The teamsite that was once used is closed so awareness of who was involved in the project almost becomes a necessity in order to find information. The time lag makes it apparent that staff turnover creates a possibility for knowledge loss since people from previous projects might have quit or forgotten details of the previous work that was not stored formally.

Projects here mean different R&D projects, but knowledge and experiences from previous projects are also documented in reports, white papers and LL. As described earlier, each different project within the R&D environment has its own teamsite where documentation regarding the R&D project is stored, in a file structure that change between projects. The intranet can be used to search for available projects but respondents feel that systems are hard to use and complete documentation cannot be accessed without access permissions from teamsites of interest, which also may be restricted by contracts. When workshop participants talked about the current way to find information in the systems available to them they said:

"We call it "go fish", when you have to try to find something in it."

"If you're looking into all the development projects going on right now, I don't know how many sites exists today, internally? I have no clue if there are 300 or 1500. And there are sites added all the time."

The respondent are talking about that it's not the lack of information rather it's how to search and retrieve the information that they are interested in that is a problem. Another interpretation of this is that people use the archiving systems but find them hard to use, both to enter and to retrieve documentation. Instead of searching in the systems for information they get fed up because the 'search and find' functions don't work well or that functionality is lacking. At the same time the systems seems satisfactory if something goes wrong and the documentation have to be back traced. For knowledge and information sharing and day-to-day communication the system functionality seems inadequate, but if the timeframe is long enough and personnel have the time to really assess the information available in the systems they function quite well and offers adequate traceability options.

The general feel during interviews and workshops is that personal contacts and networks are dominant and almost a necessity in order to find the information that is necessary to be able to conduct the work. This tendency was seen within development projects and between projects (ongoing) but also seems to be the general notion when looking back at experiences from previous (ended) projects. It's easier to search for the person name or role that has written the document (within the systems), if you are aware of who was responsible of writing and filing the document, than to search for "keywords" or content within the document. This limits

personnel to information created within their personal network of their knowledge. The following quotes are mentioned:

"If you have to use the systems we're supposed to use then you get fed up pretty quickly, due to the fact that you already know it so hard to find and retrieve things from it."

"Then you start looking for someone to talk too, preferably"

"Knowledge and experiences are reused for sure but it's often personal related. The knowledge and experience we have gained we carry with us"

"Documented experiences and information exists, in large quantities, but to find it you still have to been involved in it (previous project) or heard that it exists from someone else."

"You don't search in databases, or such, so much."

Regarding systems for EF they say that they don't have any systems for that. The closest they can come to EF are the LL they are supposed to document. They say that if any problems occur they solve it at the best of their abilities and LL are documented. However at the same time they state that there is no one responsible (at least to their knowledge) for making sure that the LL are disseminated within the organization or even to the people that was involved with solving the problem. There also seems to be indifferences to how LL should be written.

"A lessons learned document, as I see it, answers the questions 'has the lesson been learnt?' and 'who has learnt the lessons?', is it just myself or the organization? Has the company learnt its lesson? It's not just documentation about what went wrong but also in what way it has been secured, updated or corrected so it won't happen again[...]I want to make a difference between lessons learned and a report about what has happened. The fact that a report has been written doesn't mean that the organization or yourself have learnt your lesson."

"For me lessons learned are more of what we did and what happened and what was the result. But to take care of the experience and make sure that the organization learns from it, I think it's excellent"

"How do we avoid the same problem again? In the next project we're following exactly the same design recommendations as we did before due to that the design recommendations haven't been updated."

"You create a process that says that this kind of information shall flow in this way."

"I think dissemination is a pedagogical issue. To create a process for it is good but it's also important to spread the word about WHY we are doing it, which is, so that we can learn."

The different viewpoints on LL can also lead to that systems and lessons within them are not used because no one knows if they are up to date. They are aware that the work practice has to change in order to make things work. But they don't know how to change it. They understand that communication and how they work with information and documentation are essential issues to deal with but if time isn't put aside for this change no one have the time or the will to do their ordinary work and in addition implement work practice changes.

"We have to change the way we work. If we continue to work as we do and then add things on top of that we won't be able to keep up. We have to make our way of work at least 30% more effective."

"You're used to a certain way of work but you have to be able to step outside and find new ways. That is development. If you don't get the time for reflection you don't figure things out."

Informants agree upon that it's not only way of work and systems that have to change but an equally important part is company culture.

"We have to have that kind of culture, where everyone is sharing problems and insights and everyone is looking at the same place to make things visible for others"

"... a lot of it is culture. Culture is as important as having the right tools available."

DISCUSSION

Relating the empirical findings to the five issues that Weber [13] mentions that have to be taken into concern at least four of them are empowered in a negative way.

The user has to know that repository exist

- They are aware of where to look within projects, when they are using the teamsites. However searching for other projects and previous ones may be more difficult due to the fact that it's hard to know what projects are available. If an interesting project is found it may be restricted by contract, which effectively restricts knowledge and experience transfer between projects.

To address the above issue more visual aids that support the seeing-first approach could provide an overview of how projects relates to each other as well as the competencies and capabilities within the projects that are available could bring awareness to the users.

The user have to believe that the LL system will offer useful lessons

- This is a major issue due to the fact that people think that the systems and tools they are offered as EF and documentation tools don't work to their preference or satisfaction. People are not using it due to the same issues, which also creates mistrust to the lessons available, due to the fact that before a lessons is "believed" as true and correct they first seek personal contact with the author to the document or to someone who was involved with the same project.

To increase the trust into the provided lessons learned or experience feedback levels of maturity or readiness could be attached as well as who provided the lesson.

The user have to believe that lesson reuse is beneficial

- They do see the benefits and that it's important but perhaps it is not the same within the whole company. However the mistrust from the previous issue can affect this issue negatively. As respondents also describes it is important not to only implement technology or new work methods without changing work culture and justify why they are implemented.

The user have to know where and how to access repository

- They do know where to find the systems but lack of knowledge of how to use them to its full extent, both as input and output systems, was not common knowledge according to the empirical findings. The teamsites are working as everyday archiving and the Enterprise Resource Planning (ERP) and Document Management Systems (DMS) as long term archiving. However the amount of separate projects put awareness of people involved in focus in order to find information and projects available. Awareness of where to find needed knowledge and experience is essential, thus systems should be completed with charts, that points out where colleagues with completing skills are working. This can also stretch across company borders if partnership in an extended enterprise (or such)

The user have to have the time to access it and learn how to use it

- This is one of the major things that have to be taken into concern and also one of the major things that are lacking according to the findings. People are so stressed and overwhelmed with workload they don't have the time to learn from the past. Often because it's hard to search for information or that the information is not assessed before a project starts when time is critical. Learning is also a keyword here. Most of the LL systems are still focusing store and retrieve but none of them have focused different "learning" processes other than white papers and text.

Weber describes in [14] and [13] that LL systems are highly focused on capture and storage of experience or lessons

in textual form. Capturing and Formalizing knowledge and experiences into lessons that may become recommendations or design rules connects well to thinking-first, which is characterized by facts and the verbal and works best when issues are clear, data reliable, context is structured etc. This can be interpreted as text. The two other steps in Mintzbergs theory; seeing-first and doing-first are used during development and in product development processes in combination with thinking-first. However, seeing-first and doing-first are not seen anywhere in the lesson or EF dissemination process according to the empirical findings. Thus it should be noted that approaches that enhance the seeing-first and doing-first effect are issues to consider when realizing EF and LL systems.

Reuse of LL and EF is only performed using passive dissemination when using system support but before that personal contacts and networks are used extensively. To some extent active dissemination can be used if design rules and recommendations are implemented in a way so that system interacts and explains to the user if design boundaries have been crossed. These kinds of system are rare and mostly implemented in KBE systems where standardization of the design process is high and the diversity in concepts is low [11]. However, only creating systems, such as KBE design support tools, to enable automated design processes doesn't necessary mean that knowledge implemented are spread through the organization. In order for that to happen rules implemented have to have transparency, e.g., be connected to the rationale of how they came to be as well as to who created the rule. Although, KBE systems enhance the doing-first effect in that the user learns that design choices have a certain effect.

Seeing-first, with its four phases; *preparation*, *incubation*, *illumination* and *verification* can to some degree be implemented into the lessons creation and dissemination. Preparation involves deep knowledge developed over the years, which can be seen as experience, which you gain putting knowledge into action (doing-first). The sole purpose with EF and LL are that the knowledge baseline (deep knowledge) should be raised within a short time frame (thus reducing "developed over the years") so that problems are avoided or success repeated. Seeing first characteristics are; art, visioning, imaging, visual and ideas. This means incorporating other more visual ways in the LL or EF systems to enhance or speed up the illumination effect. Incubation can be hard to affect though.

LL and EF only focus the 'thinking first' phase. But what happens when you can't think it up nor draw a picture of it. Then you have to experience it. Connecting the doing first to LL and EF creation and dissemination raises the question "how to document something (processes, activities) so that someone else can experience its behavior and then draw conclusions from that?". Here models come in. If something is so complex that knowledge about it and its behavior cannot be described in words (tacit knowledge) then perhaps making a model of it that people can manipulate and "play games" with can be useful. Remember that a model is only a description of reality, that is, a different kind of documentation. However creating a model can be hard and may involve competencies that most people don't

possess. Using a bottom-up approach the model can be developed and enhanced over time, which also enables people to document or formalize things as they go on. Agent-based modeling offers such an approach. This also addresses issues in the empirical findings that people don't have time to document things twice, e.g., first personal notes and then formal reports. By just doing it people can get into the mode of formalizing the activity they are performing by creating models that other people can assess to create an understanding for them selves. Creating models also involves different graphical tools used that may enhance the seeing-first effect.

Regarding LL; If there are no standards for how a LL structure will look like the LL that have become documented only becomes dead documents in a file structure. It becomes impossible to know which lessons that are valid and not without assessing every LL that have been filed. There have to be some kind of structure in order to update LL and design practice documents in order to avoid redundancy. What Weber is referring to, as formal method is a format or structure that makes lessons easier to search and find with precision and recall. This is an enhancement but doesn't affect the users learning process due to that the lesson is still in text format.

As a final remark, if the efficiency in the EF and LL processes are enhanced it may also affect the rate of innovations due to the effect that previous unknown knowledge can be disseminated and used in other areas that it was not designed for in the beginning. New knowledge applied in different context.

CONCLUSIONS

In a comparison between the five issues regarding LL dissemination at least four of them are mentioned in the empirical findings. The user knows where to find information but system functionality and lack of knowledge on how to use them affects documentation and dissemination processes. They do believe that EF and lesson reuse is beneficial but lack in system functionality and knowledge about how to use the systems introduces reluctance with using them in everyday work. Also due to update issues with LL people have problems relying on the lessons that are in fact stored making them turn to personal networks for verification. Knowing where to find information from different projects can be difficult due to access permissions. Even though information is found and retrieved personnel seems to be lacking the time to access all information that would be beneficial for their work and reflect upon it.

Lessons retrieval in combination with the time it takes to interpret and understand the information available and the fact that texts only support the thinking first suggests that other formats or types of documentation that also support seeing-first and doing-first should be implemented. Creating active models with methods such as KBE, or Agent-based modeling offers support to both if care is taken to create transparency in the rules created. In addition to that other "learning" formats have to be supported. Here visual and interactive methods and media should be used to a greater extent. Also other dissemination

sub-processes than passive dissemination should be considered where such environments could be offered, e.g. computer aided tools or other virtual environment tools.

Documenting knowledge and experiences about processes or activities in active models that other person can access and reuse can be beneficial both for work efficiency by the person documenting and also for the learning process of the person assessing the model. Seeing-first suggest that pictures, schematics, animations and videos could be used as media to speed up and enhance the learning process as well as dissemination in the EF and LL process.

With today's processes regarding EF and LL thinking first is in focus whereas seeing first and doing first also should be supported.

EF and LL can exist on several planes, that is within, between and from previous projects. As the empirical findings show people document and look for information and knowledge in different ways depending on project situation. This suggests that tools for knowledge and experience dissemination should be designed to support these different categories and also that tools that are created should support seeing- and doing first in addition to current thinking first.

FUTURE WORK

It would be interesting to investigate how lesson reuse and EF or actually the learning process would be affected if seeing-first and doing-first would be more integrated in the way lessons are created and assessed.

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REFERENCES

- [1] Shehab, E.M. and Roy, R., 2006 of Conference, "Product-Service Systems: Issues and Challenges", in *Proceedings of 4th International Conference on Manufacturing Research (ICMR2006)*.
- [2] Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Locket, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., and Wilson, H., 2007, "State-of-the-Art in Product-Service Systems", *Journal of Manufacture Engineering*, 221(B), pp. 1543-1552.
- [3] Nonaka, I., 1991, "The Knowledge Creating Company", *Harvard Business Review*, (November-December 1991), pp. 96-104.
- [4] Davenport, T.H. and Prusak, L., 1998, *Working Knowledge: How Organisations Manage What They Know*, Harvard Business Press, Boston, MA.

- [5] Kamsu Foguem, B., Coudert, T., Béler, C., and Gensete, L., 2008, "Knowledge Formalization in Experience Feedback Processes: An Ontology-Based Approach", *Computers in Industry*, 59(7), pp. 694-710.
- [6] Nonaka, I., Toyama, R., and Konno, N., 2000, "Seki, Ba and Leadership: A Unified Model of Dynamic Knowledge Creation", *Long Range Planning*, 33, pp. 5-34.
- [7] Cross, N., 2000, *Engineering Design Methods : Strategies for Product Design*, Wiley, Chichester.
- [8] Schreiber, G., Akkermans, H., Anjewierden, A., de Hoog, R., Shadbolt, N., Van de Velde, W., and Wielinga, B., 2000, *Knowledge Engineering and Management: The Commonkads Methodology*.
- [9] Bergmann, R., 2002, *Experience Management: Foundations, Development Methodology, and Internet-Based Applications*, Springer, pp. 393.
- [10] Blessing, L. and Wallace, K., 1998, "Supporting the Knowledge Life-Cycle", in *Proceedings of IFIP TC5 WG5.2 Third Workshop on Knowledge Intensive CAD*, 161, pp. 21-38.
- [11] Stokes, M., 2001, *"Managing Engineering Knowledge - Moka: Methodology for Knowledge Based Engineering"*, Wiley Chichester.
- [12] Nuzzo, P. and Lockwood, F., 2005, "Knowledge Enabled Solution Components State of the Art – Version 2", VIVACE 3.1.2/BAES/T/05031/1.0, V.C. Members, V. WP3.1,
- [13] Weber, R., Breslow, L., and Sandhu, N., 2001 of Conference, "On the Technological, Human, and Managerial Issues in Sharing Organizational Lessons", in *Proceedings of Fourteenth Annual Conference of the International Florida Artificial Intelligence Research Society*.eds, Menlo Park, CA, pp. 334-338.
- [14] Weber, R., Aha, D.W., and Becerra-fern, I., 2001, "Intelligent Lessons Learned Systems", *Expert Systems with Applications*, 20(1), pp. 17-34.
- [15] Kendall, S.L. and Creen, M., 2007, *An Introduction to Knowledge Engineering*, Springer, pp. 287.
- [16] Turban, E., Aronson, J.E., and Bolloju, N., 2001, *Decision Support Systems and Intelligent Systems*, Prentice Hall International, Upper Saddle River, N.J.
- [17] Ellis, C.A., Gibbs, S.J., and Rein, G.L., 1991, "Groupware: Some Issues and Experiences", *Communications of the ACM*, 34(1), pp. 39-58.
- [18] Mintzberg, H. and Westley, F., 2001, "Decision Making: It's Not What You Think", *MIT Sloan Management Review*,
- [19] <http://www.microsoft.com/Sharepoint/default.aspx>, February 27, 2009.
- [20] Mason, J., 1996, *Qualitative Researching*, Sage Publications, London.
- [21] Patton, M.Q., 2002, *Qualitative Research & Evaluation Methods*, Sage Publications, USA.
- [22] Kensing, F. and Madsen, K.H., 1991, "Generating Visions: Future Workshops and Metaphorical Design. In Greenbaum, J. & Kyng, M., *Design at Work: Cooperative Design of Computer Systems*, Lawrence Erlbaum Associates, UK",
- [23] Bergström, M. and Törlind, M., 2008 of Conference, "Towards Virtual Co-Location in Functional Product Innovation", in *Proceedings of eChallenges e-2008, Collaboration and the Knowledge Economy : Issues, Applications, Case studies.*, P. Cunningham and M. Cunningham.eds, Stockholm, Sweden, 1, pp. 806-814.