Knowledge Management in an Integrated Design and Engineering Environment

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ABSTRACT: Organisations and / or disciplines in Building and Construction projects are usually working in their own design and engineering environments and using their own Building Information Models (BIM). The discipline models are merged into a project BIM which is mainly used to check for interferences or other flaw geometrical interface conditions. The checking is based on the skills and experience of a few individuals and usually performed as a verification afterwards.

An important assumption is that many non-conformances can be avoided or at least detected easier and earlier in the project if knowledge and information between the disciplines is shared and all designers and engineers are working on an integral product model right in the primary process. The result will be based on the experience and skills of many collaborating individuals in different disciplines and checked during execution of the individual tasks.

Knowledge, i.e. tacit knowledge, is what is in people's minds. This knowledge has to be captured and transformed into explicit knowledge so it can be used by many others. This knowledge, for example documented in models, drawings or instructions, has to be integrated with the product data of the related physical objects and kept up to date. Otherwise it will be lost. Also explicit knowledge on processes and procedures has to be stored and maintained.

The paper explores the relationships between the available knowledge in the project (people), the use of an integral product model in the primary process or a BIM (both repositories) and the management of all product lifecycle information (Configuration Management). Known principles like Collaborative Engineering and Concurrent Engineering are discussed as methods to share knowledge. They are also used to assure the highest reachable level of quality, prevent failure costs and bring value added changes earlier in the project to save time and costs. Attention is paid to the role of ICT, e.g. product lifecycle management (PLM) and social media.

The textbook of Dalkir 2011[2], an acknowledged guru on Knowledge Management, is used to cover the discipline of Knowledge Management. Several further references are taken from Dalkir[2]. The publication of Anumba[1] is studied for more details of Knowledge Management in Building and Construction.

Keywords : Knowledge Management, Configuration Management, Integrated Product Model

1 INTRODUCTION

An important reason for current interest in Knowledge Management is the loss of knowledge caused by massive retirement of the baby boom generation from the late forties of last century. This paper however will look into the impact of Knowledge Management on the daily challenges in Building and Construction, i.e. failure costs. The basic underlying assumption (by applying Configuration Management) so far is that the result of an activity is good if the input consists of an order referring to all needed documents to do the job and that all these input documents are good, meaning clear, concise, consistent and valid. (Guess 2002[4], Reefman 2011[11]). Besides the input documents the actor has libraries, repositories, for product and procedures. Skills and experiences is in this case taken as granted. Considering the fact that a knowledge worker, and our actor is a knowledge worker, finds only 15-20% of the needed knowledge to do his job in formal documents (Dalkir 2011[2]), it may be questioned or the basic assumption regarding Configuration Management is enough.

Another underlying statement in Reefman 2011[10] is that the quality of the Building and Con-

struction is improved if ideas and opinions of colleague engineers are shared early in the process, i.e. in the Post phase of the document or model lifecycle and when colleague engineers will see preliminary results and have the opportunity to comment. The Post phase is a formal phase of the release process proposed by Reefman 2011[10]. The effect is increased by using an integrated product model in the primary process (Reefman 2011[11]). Within Knowledge Management these knowledge workers are sharing knowledge which is one of the major processes in Knowledge Management [2].

This paper discusses the role of Knowledge Management to let our designer or engineer delivering the best possible result to the project.

Note that a document in this article includes text documents, models, instructions, movies etc.

2 THE KNOWLEDGE MANAGEMENT LIFECYCLE

2.1 *Knowledge Management and Configuration Management*

The relations between Knowledge Management and Configuration Management (CM) have not yet been studied very much. Both professions do not really know what the mutual position is.

Dalkir 2011[2] does not go deeper than single documents. Even if it is mentioned that so called explicit knowledge has to be organised and structured there is no mentioning of a configuration in which documents are related with product - or business items. These items, also called objects, are usually structured as a hierarchical tree. As argued by Guess 2002[4] and Reefman 2011[11] document Management, as commonly applied in building and construction, is not enough. It is necessary to apply Configuration Management to keep the document versions defining the product consistent with each other in case of a change. (A document management system contains an unrelated set of documents and does not deal with consistency between those documents. This means that if you are going to change a document you don't know which other documents you have to change to keep the system consistent.) Many PLM systems can apply Configuration Management.

Within a PLM environment often only documented knowledge is discussed, sometimes the PLM system is used to store additional documents in the product structure (Matta 2011[6], Lindow 2011[5]) and sometimes information is extracted from a PLM system to be stored in a Knowledge Management System (Teng 2011[15]).

This article will research the position of Knowledge Management in an integrated design and engineering process and its logical structure or relationship with Configuration Management.

2.2 *What is knowledge?*

There are many definitions of knowledge. The following definition is given by Davenport and Pusak 1998[3]:

"Knowledge is a fluid mixing of framed experiences, values, contextual information and expert insight that provide a framework for evaluating and incorporating new experiences and information.

It originates and is applied in the minds of those who know. In organisations it often becomes embedded not only in documents or repositories but also in organisational routines, processes, practises and norms."

Dalkir 2011[2] distinguishes three sources of knowledge:

- The knowledge within an individual;
- The knowledge within a group of individuals;
- The knowledge within an organisation.

It is assumed that the knowledge within a group is larger than the sum of knowledge within all individuals. The only permanent knowledge in an organisation is the knowledge that is transformed from what is in peoples mind into documents, from tacit knowledge into explicit knowledge.

Considering a building and construction project this knowledge is about:

- KNOW WHY, the reasons behind choices;
- KNOW WHAT, what is the product, how is it produced, operated, maintained;
- KNOW HOW(processes and procedures to do the job).

From these the "KNOW WHY" is the most difficult to formulate because it is for a for a great deal tacit knowledge and also based on unconsciously used individual and socially shared basic assumptions or mental models.

2.3 *Knowledge Management Lifecycle Phases*

Considering an organisation or project, the author comes to the following lifecycle phases for knowledge:

- Defining the needs for knowledge;
- Acquire people for the organisation with the required competences and / or create knowledge;
- Share the knowledge within groups and organisation;
- Capture the knowledge from people's minds, from individuals and groups;
- Codify the captured knowledge into documents of whatever type (explicit information);
- Store these documents in accessible repositories;
- Maintain and manage these repositories;

- Acquire explicit knowledge and use it for the job to do;
- This creates knowledge and the loop is closed.

Dalkir 2011[2] states that Knowledge Management is a developing science which mean there are many definitions and also many models and lifecycles. To stay within an accepted and defined framework the author chooses to use the basic lifecycle of Dalkir in which all earlier mentioned phases or processes can be found or have to be positioned. The Knowledge Management lifecycle of Dalkir is presented in figure 1.

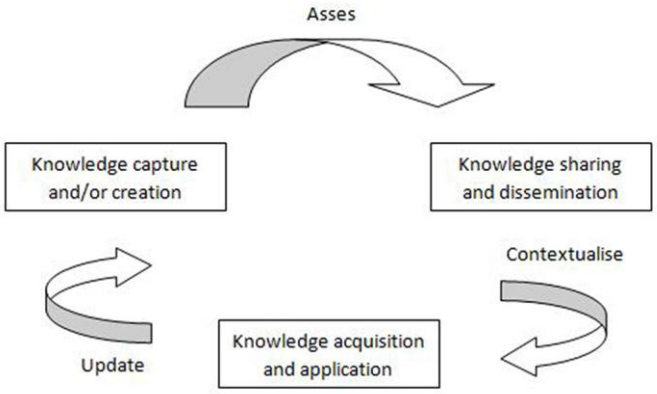

Figure 1. Dalkir 2011[2] Knowledge Lifecycle

1. Knowledge capture and or creation

Before doing anything the organisation has to define its needs regarding knowledge, meaning competences and experience . It has to acquire these individuals on the market or educate them. The knowledge in the minds of people has to be captured and codified in any form of documentation.

2. Knowledge sharing and dissemination

The main purpose of knowledge management is reuse and innovate and because the knowledge of a group, for example a community of practise, is larger than the knowledge of the sum of individuals sharing of knowledge is of great importance. Sharing of knowledge will require often a culture change of the organisation, because it requires the appreciation of sharing above individual results.

3. Knowledge acquisition and application

Codified knowledge is in principal unordered information often fragmented and without a proper context. This codified knowledge can be considered as data which has to be interpreted, analysed, reformulated and / or refined. The results have to be validated and stored as explicit knowledge in a repository. Individual knowledge workers will assess this knowledge and interpret it, transferring this explicit knowledge as tacit knowledge in their minds. This is acquisition of knowledge by an individual. By applying this acquired knowledge to his job he reuses existing knowledge and creates new knowledge which should again be captured and shared.

Another quite often referenced lifecycle is the so called knowledge spiral of Nonaka and Takeuchi. (1995)[8]. See also Nonaka (1994)[7] This lifecycle is given in figure 2 and copied from Dalkir 2011[2]. It shows the increasing knowledge by going through the lifecycle time after time.

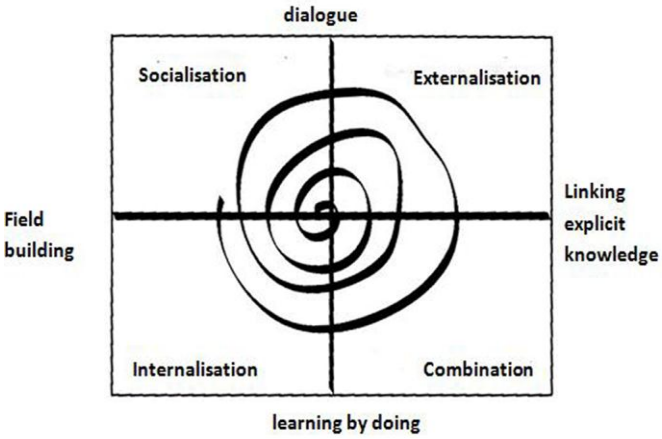

Figure 2. Increasing the knowledge level by closing the knowledge lifecycle time after time.

2.4 *Knowledge Management*

All processes of the knowledge lifecycle have to be defined, controlled and managed. The management of all these processes involved is Knowledge Management.

A more formal definition can be found in Dalkir 2011[2]:

"Knowledge Management is the deliberate an systematic coordination of an organisation's people, technology, processes and organisational structure in order to add value through reuse and innovation."

The Knowledge spiral of Nonaka and Takeuchi is showing that Knowledge is increasing if it is managed well. This means that also the company knowledge or the explicit knowledge about product as well as processes and procedures is increasing all the time. Or in other words the representing document versions are changing continuously. This means managing explicit knowledge is managing change.

In the following chapters the knowledge life cycle will be applied to an integrated design environment as was proposed by Reefman 2011[11]. The article starts the knowledge lifecycle with the designer or engineer internalising the input documents for his job and creating new knowledge.

3 THE KNOWLEDGE WORKER IN HIS JOB

3.1 Introduction

This chapter will discuss the knowledge lifecycle in the context of the job of an individual designer or engineer. His task is to produce a document version based on an order referring all needed input documents. He is supported with tools, libraries or repositories regarding building - and construction items and procedures. The knowledge he brings into the job is his skills and experience including the cultural context of individual and shared basic assumptions and values or in other words his tacit knowledge. A diagram of the job is given in figure 3. Figure 3. differs from the activity diagram presented in Reefman 2011[11] that the knowledge brought in is this time not taken for granted.

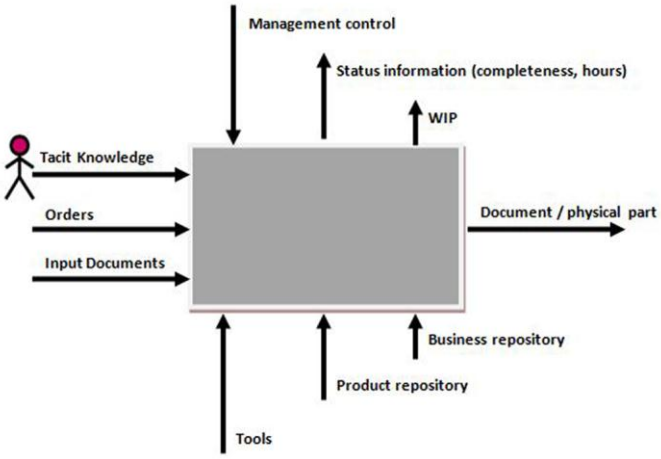

Figure 3. The job with its input, control, support and result

3.2 Creation of Knowledge

Before discussing the position of the individual knowledge worker in the knowledge lifecycle a few basic assumptions are made. These are:

- Knowledge Management is fully implemented;
- Knowledge sharing is appreciated and rewarded above individual application;
- Order and Input documents are clear, concise, consistent and valid as are all documents from used libraries or other repositories;
- Configuration Management is fully implemented;
- Integrated Design Environment and using Integral Product Model (Reefman 2011[11]);
- The statement of Dalkir 2011[2]is true: Only 15 - 20% of the needed knowledge to do the job is covered by the content of the documents.

An Integral Product Model is a well managed digital product model in which all engineers of all disciplines and parties perform their design and engineering together, independently from their location. It is situated in the middle of the primary process in an integrated design and engineering process.

The statement of Dalkir means that a lot of solutions, choices and decisions made to get the wanted result are mainly based on individual knowledge. This raises the interesting question: "How important is the quality of the used documents for the quality of the result of the task?" This question however is not answered in this article.

Our knowledge worker starts with internalising the input documents. This means he is merging this information in his mind with his basic assumptions and values. He is transforming the offered explicit knowledge to individual tacit knowledge.

In the process of creating new knowledge he is using his tacit knowledge and may consult or reuse explicit knowledge from the product repository. This new knowledge is especially product knowledge like requirements, models, drawings, but he might also have questions and remarks about followed processes and procedures as given in the business repository.

In the creation process he is sharing knowledge with individuals and communities. Within Knowledge Management one speaks about CoPs, Communities of Practise.

Our knowledge worker exchanges knowledge in the form of questions and remarks mostly in conversations but also by "industrial" media like Enterprise 2.0.

He is exchanging knowledge with:

- The individual authors of the input documents;
- Specific individual project members which are structurally, as a part of the lifecycle of the document version under creation, invited to supply comments, which is more effective if all designers and engineers are working in an integral product model(Reefman 2011 [10],[11]);
- Specific individual experts which are structurally, also as a part of the lifecycle of the document version under creation, requested to approve or reject the results (Reefman 2011[10], [11]);
- The community of knowledge workers in his discipline or profession, colleagues working in other projects;
- The community of knowledge workers within the project usually from other disciplines and in building and construction projects usually from other companies as well.

As a consequence of this knowledge sharing it is expected that the results of the job are of a higher quality and earlier mature.

The result of the job is new explicit product knowledge. This is knowledge about the Know What and will be automatically saved for the project and organisation because it is part of a managed configuration in the product repository.

3.3 *Positioning of Concurrent Engineering, Engineering Collaboration*

The creation of knowledge is an interactive process in which the result gets more and more mature. Knowledge sharing plays an important role. Concurrent Engineering and Engineering Collaborations are special forms of knowledge sharing.

Reefman 1995[9] defines three phenomena of Concurrent Engineering:

- Mutual involvement, i.e. seeing what colleagues are doing as in Post phase of release process;
- Working at the same time in the same phase of the design and engineering process and in the same space of the integral product model or BIM, e.g. architect with walls - and a mechanical engineer with pipe layout.
- Working at the same time in different phases of the design and engineering process, e.g. in the design phase and in the detailed engineering phase. This means detailed engineering is deliberately working with non-released information, circumstances under which good configuration management is a must.

The author found in Wikipedia the following definition of Engineering Collaboration: the interactive process of engineering collaboration, whereby multiple interested stakeholders resolve conflicts, bargain for individual or collective advantages, agree upon courses of action, and/or attempt to craft joint outcomes which serve their mutual interests.

From above it may be concluded that Concurrent Engineering is a structural way of sharing of knowledge in the design and engineering process of an identified project.

Engineering collaboration will be seen as informal knowledge sharing outside the formal design and engineering process. Both types of knowledge sharing are important and part of Knowledge Management.

How to deal with Concurrent Engineering and Engineering Collaboration is part the company Know How thus part of described processes and procedures!

3.4 *Acquire and use of Know How*

So far our knowledge worker had to acquire and use Know What knowledge. Learning and creating new product knowledge is part of his job. His mental model or basic assumptions and values are not subject to change. Therefore transfer and use is expected to take place smoothly. Acquiring and using new Know How knowledge is different.

Suppose our knowledge worker has always been producing a concept drawing which was released after it was approved by his manager and now he has to play a role in a process of sharing information with other stakeholders and playing an unknown role in a different release process. This process is in severe conflict with his way of live, his mental model or basic assumptions and values. He will unconsciously and automatically resists because his mental model has to change.(Dalkir 2011[2]. Implementing new processes and procedures takes time and effort.

Shelburne 2006[13][14] implemented new processes and procedures in the following way. His starting point was that procedures and or processes have to be "lived" by the people executing them, documentation is not enough. So he trained all people who had to apply the new procedures and processes. He also mobilised the knowledge of the trainees by listening to their ideas and adapted the trained procedures and or processes accordingly. After an agreement between management and work force these new adapted procedures and processes were successfully implemented.

The best Know How is with the knowledge workers doing their jobs and for this reason many companies believe they should keep the documentation of processes and procedures to an absolute minimum and leave it to the people themselves how to do their job. From a standpoint of Knowledge Management this is not recommended for the following reasons:

1. The company does not really know what happens on the floor and is losing its Know How when the people are leaving.
2. There will be hardly any innovation because old habits stay forever.

3.5 *Capturing Knowledge*

Because the larger part of the product knowledge is still tacit knowledge only, it will be lost for project or organisation unless it can be captured. Within his job the knowledge worker may also have remarks about the processes and procedures he has to follow. For example he has a better idea to use the BIM model for his job.

According to Dalkir 2011[2] a lot of capturing tacit knowledge is done by interviewing and focused on lessons learned and best practises. These lessons learned and best practices are usually dealing with Know How.

An integrated design and engineering environment is supposed to deliver product innovations. The normal result is product information (Know What) which can be managed well by Configuration Management. The Know Why is often missing. Therefore capturing knowledge in a design and engineering environment has to focus on Know Why. This is difficult because many hidden unconscious assumptions may play a role.

Interviewing during a running project is usually not accepted, not even in a mature Knowledge Management organisation. Easy to use checklists (like

the author proposes in table 1) and briefings by exception for example by extra ordinary checklist results, serious failures, missing tacit knowledge, missing information or unexpected changes might be a better idea. Interviews and briefings are done by officers from the Knowledge Management organisation. This officer might be called a knowledge management journalist.

When using industrial media the capturing of knowledge becomes easier because data is kept in the system. In the Netherlands companies are experimenting with "My Portals" in which community members can upload profiles and documents and search and view each other's information. However capturing knowledge is still not easy. In Reefman 2012 [12]a proposal is formulated to use a smart Question and Answer system to capture knowledge.

A smart Q&A system is a system that can process the questions and answers. For example it fulfils following requirements by handling a question:

- Looking for similar questions and presenting the related answers as well, which would generate extra knowledge for the requester;
- Counting the appreciations of the given answers, which would lead to natural experts;
- Labelling the questions with specifics like order ID, Object ID and or Process ID related with the question? This would relate knowledge to concrete situations.

Such a system could deliver captured data suitable to be analysed, interpreted and codified into explicit knowledge that can be released and stored in appropriate repositories, for example the product configuration or business configuration. A business configuration will be explained in section 4.3.

Checklist Document version reference	Yes	No
Was the Input Documentation "GOOD"?		
If not, this was due to:		
1. Information not clear?		
2. Information not concise?		
3. Information not consistent?		
4. Information not valid?		
Is the job rework?		
Missing knowledge?		
Knowledge shared with individuals?		
Knowledge shared with communities?		
Knowledge sharing had large impact?		
Knowledge sharing had medium impact?		
Knowledge haring had low or none impact?		
Problems in executing job?		

Table 1. Checklist for designer or engineer.

3.6 *Contextualisation*

The acquired knowledge from the captured data has to be codified into documents. Before these documents are allowed to be stored, they have to be submitted to a validation or release process like other results of the design and engineering process. This validation is done by acknowledged experts in the organisation.

The captured knowledge is a bulk of data which has to be analysed, ordered and interpreted by knowledge management analysts. By using their skills and experience, their known and unconscious basic assumptions they will transform this data, this codified knowledge, into explicit knowledge by giving it a context within the organisation. Dalkirk 2011[2]speaks about contextualisation.

Explicit knowledge is the only form of permanent knowledge of an organisation. Tacit knowledge of individuals will disappear eventually. The above created explicit knowledge has to be stored in a structural and accessible way otherwise it will never be applied.

This explicit knowledge will be distributed over three repositories:

1. Product repository containing Know What knowledge;
2. Business repository containing Know How knowledge;
3. Innovative repository containing ideas for innovations and improvements.

Once the tacit knowledge is captured and contextualised it can be disseminated and used by all other people in the organisation. By internalising this contextualised knowledge and using it to create new knowledge the knowledge lifecycle is closed.

3.7 *Capturing knowledge from data sources*

The So far this discussion is about capturing and codifying tacit information. There are many other data or information sources which can be used to capture knowledge. For example refinement, deeper analyses of already created explicit knowledge or sources with measurement data. But this is considered out of the scope of this article.

4 KNOWLEDGE MANAGEMENT, ORGANISATION AND CONFIGURATION MANAGEMENT

4.1 *Tacit knowledge*

The management of tacit knowledge is a social interaction. This social interaction has to be structured and managed. Knowledge is the most important as-

set of the company which means there has to be a line manager in charge for the Knowledge Organisation. Under direction of this Manager HRM will execute Company's Knowledge Policies.

Knowledge Management is at this moment not a common competence and not mature which means that HRM departments have to be made competent to execute and or facilitate Knowledge Management processes.

The HRM Knowledge Management Department will get the following tasks:

- Executing Knowledge Management Policies;
- Define needed knowledge, i.e. competences and experiences;
- Acquire and keep people with needed competence and experience;
- Establish an internal knowledge organisation, e.g. roles and responsibilities for knowledge management officers like journalists, analysts, experts;
- Define and manage knowledge processes and procedures, e.g. communication, certification of competences, interviews and briefings, capture of knowledge, transfer of codified knowledge to Configuration Management, exchange with external parties like project partners and educational institutes.

4.2 *Explicit Knowledge*

The work of the Knowledge Analyst is to transfer Tacit Knowledge into Explicit Knowledge, i.e. documents. The created document versions are becoming part of configurations, part of structures or systems and it looks logical to transfer the Knowledge Management Lifecycle from this point on to Configuration Management. Configuration Management get the following tasks:

- Analyse and codify the captured knowledge into documents;
- Initiate and manage validation process of above documents and store them in the appropriate information sources, configurations;
- Maintain the information sources by managing the change process of its document versions;
- Manage the verification process to assure that the real life business and product objects are conforming their descriptions.

4.3 *Configurations as repositories*

In section 3.6 three repositories are mentioned, for product, for processes and procedures and for innovation and improvements.

In section 2.1 it is argued that the product repository must be a configuration. By considering Configuration Management as the primary product lifecycle process within an integrated design and engineering process the relationship of Knowledge Management and Configuration Management comes naturally. The configuration is the repository of explicit product knowledge and this information is managed as other product lifecycle information. So document versions are related to existing items within a product configuration. It makes sense to put this information (Know What and Know Why) in a PLM system and link it to these items (as for example in Lindow 2011[5]and Matta 2011[6])).

Processes and procedures are part of a business approach a business system described by document versions. These document versions, representing the Know How of the company, are as knowledge increases subject to change. It makes sense and there are business standards, like PAS55 for maintenance and utility sectors, requiring that all these business documents are to be kept consistent. This means again a document management system will not do the job. As is suggested by Guess 2006[4] businesses can be modelled in a same type of architecture (configuration) as a product. This configuration will contain a hierarchy of the following items:

- Mission;
- Strategic plans;
- Organisational policies
- Operating plans;
- Knowledge Management Processes;
- Operating Standards;
- Enabling tools;
- Supporting procedures.

These items are, like product items, described by document versions which are subject to change. Once having a business configuration it can be managed similar to the product configuration. This means that PLM systems can be used to manage business document versions related with items from the business configuration. So, in other words explicit knowledge related to the business architecture can be put in a PLM system and be linked with the appropriate item.

Knowledge stored in the first two repositories, operational repositories, will be automatically applied when related items are used or studied.

But not all acquired explicit knowledge can be assigned to items in these two operational repositories. Examples are:

- Ideas for new alternative product solutions;
- Ideas for new or alternative processes or procedures (lessons learned, best practises);
- Generic knowledge.

There is no structure and thus no configuration management possible. Practise shows that this repository is inaccessible and will not be used. To save the knowledge it has to be transformed into new

knowledge in the two operational repositories. It is the main property of this knowledge that people have to be assigned to apply this or to do something with this knowledge. This knowledge should lead to improvement proposals, change requests for existing items or initiatives for new developments. The handling of change request will be subject to standard procedures (Guess 2006[4], Reefman 2011[11]).

4.4 *Knowledge Management and ICT, a few remarks*

Knowledge resides in people's minds and only a part is captured and codified into documents. This means sharing of information is very important. ICT offers a number of possibilities to support the sharing of knowledge, like video conferencing and social media. Smart Q&A systems are considered to be important because they can support capturing knowledge. An example of a smart Q&A system is QATO.

PLM systems are delivering manageable structures to manage explicit Know What - and Know How Knowledge. Examples of PLM systems are Windchill, Teamcenter and ARAS. BIM has to grow to a mature PLM system or must be an integral part of it.

A Knowledge System has to be found or developed to handle unfinished business like product ideas and lessons learned in order to assure that change requests are created and submitted to the organisation.

5 CONCLUSIONS

It looks like well implemented knowledge management can have a tremendous impact on the results of the organisation. Dalkir 2011[2]gives some impressing success stories. Knowledge Management is a must considering the fact that only a fraction of the Knowledge is explicit. The major part is in the mind of people and they will leave at the end.

Knowledge Management is of direct practical use in a integrated design and engineering environment to maximise the use of available knowledge and bring changes to happen earlier in the process when changes are still cheap to implement. The application of explicit product knowledge is expected to happen more or less naturally. The application of new procedures and or processes is expected to be a large effort because it requests a cultural change, meaning the change of peoples mental models.

A conventional (hierarchical) product structure is a logical structure to store explicit product knowledge. This structure is also suitable to model a business configuration and store explicit Know How knowledge. So a configuration forms the repository for explicit knowledge, the result of the Knowledge Management lifecycle. Configuration Management maintains this knowledge and handles the change requests arising from new product ideas and learning lessons.

Configuration Management is needed for explicit Knowledge Management to keep the Product System as well as Business System consistent in case of changes.

The research also raises the question: "What is more important for the results of design and engineering GOOD input documents or GOOD Knowledge Management?".

Quantitative analyses and reference projects are needed to know more about the business value of Knowledge Management.

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