K-MORE - A METHODOLOGY TO MANAGE DOCUMENTED KNOWLEDGE FOR REUSE

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Abstract

The reuse of documented knowledge still represents a challenge for engineering design companies. Most of the research and practice in knowledge management has focused on the systematic collection, storage, and transfer of knowledge, assuming that if those actions are performed, the knowledge will be reused automatically. However, this does not seem to be true. We conducted a research in order to understand how the reuse of documented knowledge during the design process can be supported and based on that, we developed the k-MORE methodology (Knowledge Management for Optimised REuse). k-MORE is structured in six phases, in which methods and guidelines are suggested for the planning of the complete knowledge reuse cycle. Especial focus is on the impact of each phase of the cycle on the moment of knowledge reuse, which had been traditionally disregarded in research. All the planning is conducted under consideration of the specific company's situation and the individual needs and behaviours of its employees. We illustrate the industrial application of the methodology on the case study of a video camera development company.

Keywords: Knowledge management, Information management, Design management, k-MORE methodology

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1 INTRODUCTION

The reuse of documented knowledge still represents a challenge for companies. Despite the fact that companies are reasonably good at acquiring knowledge, this resource is often wasted due to an ineffective dissemination and low reuse levels (McShane and Von Glinow, 2010). Most of the research and practice in knowledge management has focused on the systematic collection, storage, and transfer of knowledge, assuming that if those actions are performed, the knowledge will be reused automatically. However, this does not seem to be true (Schacht and Maedche, 2016).

In the field of engineering design, aspects like high number of stakeholders, high number of documents or changing designed products make the reuse of documented knowledge even more challenging.

We conducted a research in order to understand how the reuse of documented knowledge during the design process can be supported and based on that, we developed the k-MORE methodology (Knowledge Management for Optimised REuse). Section 2 presents the state of the art of knowledge management and reuse. Section 3 explains our research methodology. The requirements for the support and the proposed support are presented in section 4. Results of the methodology application in an industry case are presented in section 5. Contributions and limitations of the methodology are discussed in section 6 and we close the paper with the conclusions and further work in section 7.

2 STATE OF THE ART

2.1 Knowledge Management

The goal of knowledge management (KM) is "to improve organizational capabilities through a better use of the organization's individual and collective knowledge resources" (Probst, 1998). Figure 1a shows the main activities of KM. The terms are not well-established in literature, what leads to finding different authors referring to the same activity under different terms (e.g. knowledge acquisition can also receive the name of knowledge creation or knowledge capture).

There is also no consensus on what the term knowledge represents in the context of knowledge management and it is often confused or indistinctly termed as information or data. Ameri and Dutta (2005) refer to data as "unorganized and unprocessed facts" and to information as “the aggregation of processed data which makes decision making easier”. Knowledge is defined as "evaluated and organized information that can be used purposefully in a problem solving process". However, the boundaries in practice are not easy to define: Is the description of a method knowledge or information? Is a CAD model knowledge, information or even data? Davenport and Prusak (1998) state that "knowledge originates and is applied in the minds of knowers". Following this idea, we consider that trying to classify documents or files as knowledge, information or data is irrelevant. No matter which content is provided to a person in a document (knowledge, information or data), if it is the right person, he or she will originate knowledge from it, which will support the decision-making during the design process. For this reason, we do not make a distinction between the terms in our methodology and we will just use the term knowledge from now on to avoid confusion.

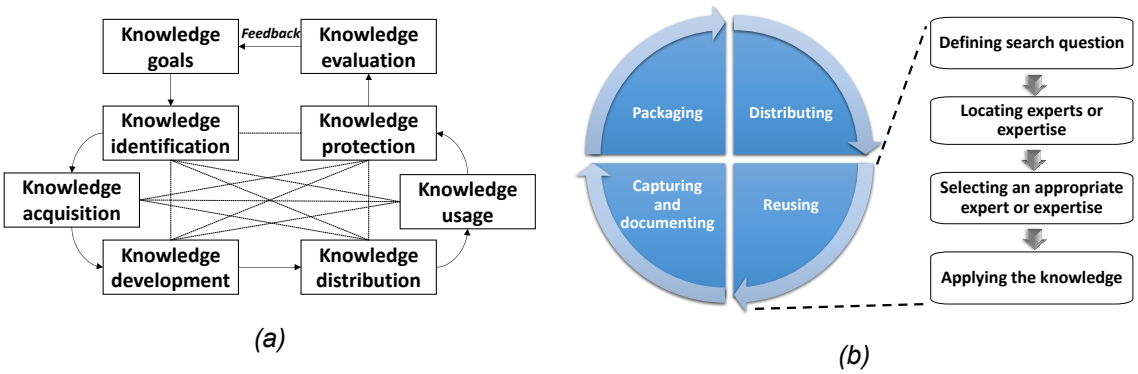

Figure 1. a) Activities of knowledge management (Probst, 1998); b) The knowledge reuse cycle (Markus, 2001)

There are two approaches for KM: the codification approach that attempts to manage documented knowledge (with e.g. knowledge management systems); and the personalization approach that focuses on the transfer of non-documented knowledge between persons (with e.g. methods like communities of practice). The two approaches are not exclusive but they can complement each other.

2.2 Knowledge Reuse

The term knowledge reuse can receive two interpretations. The first one is equivalent to the knowledge usage of Probst (1998). It only refers to the moment in which an individual performs the reuse. Markus (2001) describes this moment as a process with four steps: 1) defining search question, 2) locating experts or expertise, 3) selecting an appropriate expert or expertise, and 4) applying the knowledge. Fruchter and Demian (2002) distinguish between internal and external knowledge reuse. Internal reuse relays on own experiences and personal memories acting as knowledge repository. On the contrary, external reuse occurs when the knowledge is provided by an external source. The reuse that Markus (2001) describes and that KM literature addresses corresponds to external codified knowledge, which is stored in knowledge repositories. This limits the term knowledge reuse to codification approaches within KM.

The second common interpretation of knowledge reuse is to consider it as the complete knowledge cycle instead of only considering the concrete moment of reuse. Markus (2001) herself depicts this paradox by describing the knowledge reuse cycle divided in four stages, in which one of the stages is also called reusing (see Figure 1b): 1) capturing or documenting knowledge; 2) packaging knowledge; 3) distributing or disseminating knowledge (providing people access to it); and 4) reusing knowledge.

2.3 The Research Gap

A survey conducted by COVEO in 2014 reports that 67 % of the knowledge workers asked have trouble with finding the information they need. In a survey conducted by Milton (2010), more than 50 % of the companies that attempt to collect lessons learned recognised that they do not use them efficiently. In our own research, in year 2015 and 2016 we approached ten big to medium-sized companies in informal meetings and semi-structured interviews in order to investigate their reuse of knowledge during the process of product design. We observed that most of them do not have a systematic strategy for knowledge reuse. In some cases, they implemented methods of KM like wikis with search options but the processes to use them systematically had not been established. They admit that their knowledge reuse is inefficient and when it occurs, it is basically a "matter of luck". They also claim that more knowledge reuse would have a positive impact for the company in terms of increasing the time available to perform valuable new tasks and increasing the product quality. Those facts expose that effective knowledge reuse in industry generally and especially during the design process is still a goal to achieve. There are several approaches in literature to support knowledge reuse in the field of product design. However, they do not seem to have been implemented in industry. Vijaykumar and Chakrabarti (2008) suggest that the reason may be the lack of understanding of the knowledge needs of designers. Lauer (2010) points to the lack of target-oriented knowledge supply. Schacht and Maedche (2016) argue that the problem is the lack of consideration of the individual behaviour of designers during the reuse cycle. It seems that the reasons may be various and they are still unclear.

The main shortcoming of most of the approaches that claim to support knowledge reuse in engineering design literature is that they do not address the support of the reusing stage. They assume that if knowledge is documented, stored, and distributed, it will be reused automatically. But this is not what actually happens (Schacht and Maedche, 2016). There are few approaches that actually consider to some extent the support of the reusing stage. However, those approaches do not consider other relevant aspects like the ones exposed in the previous paragraph.

Summarizing, the reasons for the lack of implementation of knowledge reuse approaches within the design process in industry are not well understood and there is currently no approach that addresses all possible failure factors already identified in the literature at the same time. More understanding of the factors influencing knowledge reuse is needed, as well as an adequate support to increase the reuse of codified knowledge in engineering companies.

3 RESEARCH METHODOLOGY

Considering the aforementioned research gap, we initiated a research with the aim of increasing the knowledge reuse from repositories of the companies during engineering design and the goal of developing adequate support for that. The research was conducted following the Design Research Methodology (DRM) of Blessing and Chakrabarti (2009). The DRM consists of four stages. In the following lines, we explain the goal of each stage and the methods we used to conduct it:

- Research clarification (RC): This is the stage, in which researchers identify the need to develop support. In our case, a literature review was performed and our observations from industry in form of informal meetings and semi-structured interviews confirmed the need. The main results are presented in section 2.3 of this paper.
- Descriptive study I (DS I): This is the stage, in which researchers gain understanding of the phenomenon they want to support. In our case, we performed an extensive literature research, three workshops with industry partners, and we conducted two exploratory experiments. The main results of this stage are presented in section 4.1 of this paper.
- Prescriptive Study I (PS I): In this stage the support is developed. In our case, we developed a methodology to prepare the stages of the knowledge reuse cycle based on a synthesis of the findings from the DS I. The methodology is presented in section 4.2.
- Descriptive Study II (DS II): In that stage the developed support is evaluated. In our case, the methodology proposed has been partially evaluated on an industrial case study, which presented in section 5 of this paper. Further evaluation is part of the outlook.

4 SUPPORTING KNOWLEDGE REUSE

4.1 Requirements for the Support

The requirements for the support are derived from the findings of the DS I. Table 1 presents the main findings obtained from each method applied in this research stage and the requirements for the support than can be derived from these findings.

Table 1: Requirements for the support derived from the DS I

Method	Hypothesis (H) or research question (RQ)	Result	Implication for the support
Workshops	RQ: What are the reasons for the lack of knowledge reuse in industry?	There is no overview of the knowledge of the company. It is unclear in which situations during the design process reusing knowledge is beneficial and when not. If in doubt, people decide not to reuse.	The support should facilitate the knowledge acquisition and visualisation. The support should enable the identification of situations of design, in which reusing knowledge is beneficial.
Literature research	RQ: What are the influencing factors for knowledge reuse?	Individual needs and behaviours are not considered enough in current approaches. Habit is the major influencing factor common to all individuals.	The support should enable the analysis of individual needs and behaviours of designers. The support should foster the implementation of habits and routines.
Exploratory experiment I	H: The awareness of knowledge availability does not assure knowledge reuse.	H confirmed. The formulation of a search question seems to be the major challenge for designers.	The support should facilitate the formulation of a search question.

Exploratory experiment II	H: Designers involved in a design project prefer searching freely for knowledge related to the project in which they have worked, whereas designers external to the project prefer target-oriented search methods.	H refused: The approach to search in a knowledge base does not depend on the participation or not in previous projects but on individual characteristics of the person.	The support should provide individualized solutions independently of the participation of designers in previous projects.

4.2 The k-MORE Methodology

We developed a methodology in order to fulfil the abovementioned requirements. The methodology's name is k-MORE, which stands for Knowledge Management for Optimised REuse. In the following sections, the concept of the methodology and its phases are presented.

4.2.1 k-MORE: the Concept

k-MORE is a methodology to support the implementation of knowledge reuse during the design process. In order to do that, methods and guidelines to prepare the stages of the knowledge reuse cycle described by Markus (2001) are proposed (phases 3 to 6 of the methodology in Figure 2). Previously to the preparation of the stages of the knowledge reuse cycle, methods to acquire, visualise, and analyse the company's knowledge are proposed (phases 1 and 2 of the methodology). The innovative aspect of the methodology is the individualized analysis (company-specific and individual-oriented) of the influencing factors for knowledge reuse that is performed in phase 2. The results of the analysis in phase 2 influence the upcoming phases of the methodology. The goal is to assure that the reuse cycle is prepared in a way that better fits the company, the designer's preferences, and the situations during the design process.

In the k-MORE methodology, the preparation of the stages of the knowledge reuse cycle takes place in the opposite direction of the reuse cycle as of Markus (2001). The reason for that is that the methodology is not created to support the reuse cycle itself but the planning of it. The planning takes place backwards by first defining the goal to achieve, i.e. the conceptual design of the knowledge base (phase 3) and then establishing the processes to fill it (phase 4), use it (phase 5), and promote its use (phase 6).

The users of the methodology are managers or KM practitioners. Designers are the users of the results obtained after going through the methodology.

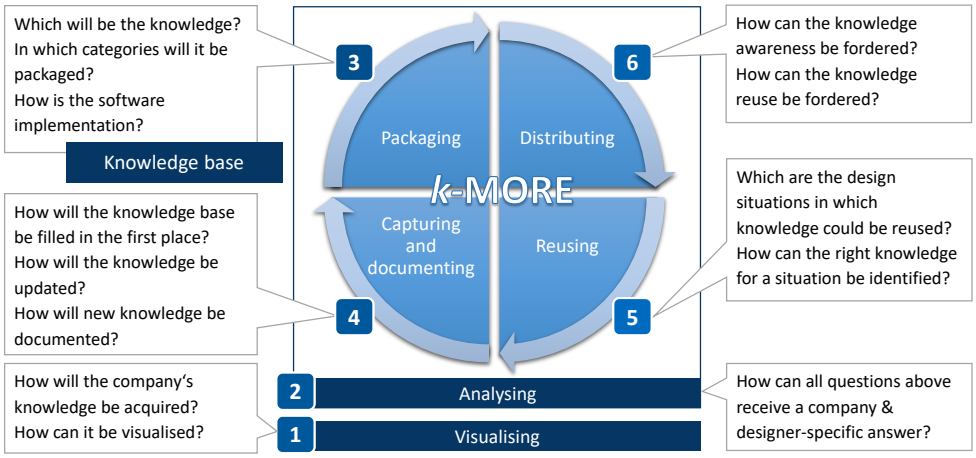

Figure 2. Overview of the k-MORE methodology

4.2.2 Visualising

The initial situation of companies that want to improve their reuse of documented knowledge is that they lack an overview of the knowledge they possess, its documentation status, and its owners or storage places. These aspects can be visualised by means of a knowledge map. We propose a knowledge map with five connected elements (person, task, document, competence, storage place) as presented in Figure

3. The description of tasks depicts the link to the activities of the design process. The differentiation of knowledge elements into competences and documents allows the understanding of what is documented and what not. Furthermore, the roles of the documents for the task (inputs or outputs) are depicted through the directional edges "is used in" and "generates". The storage place in the company of each document is also visualised.

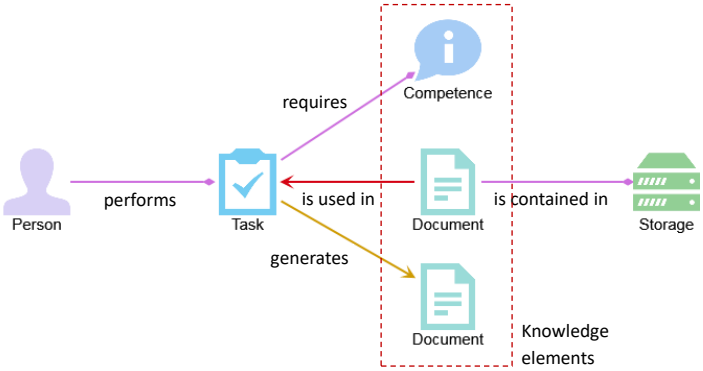

Figure 3. Metamodel of the proposed knowledge map

For the acquisition of the current knowledge, the employees describe their tasks and the associated elements in template tables within workshops or individually. Improvement suggestions for the documentation of the named documents are also collected. The consistency of the elements is achieved in the workshops through common agreement or one person must be in charge of continuous check.
Not all employees or knowledge elements must be contained in the knowledge map. Each company should conduct a needs analysis first, in order to determine their goals for knowledge reuse. Based on those goals, the company identifies the relevant persons to ask in order to obtain the knowledge map.

4.2.3 Analysing

Two analyses are carried out in parallel within the analysing phase:

1. Analysis of the individual influencing factors for knowledge reuse. The goal is to prioritize the factors that should be considered to plan the knowledge reuse of the company. Therefore, we propose to conduct a survey with the employees, based on the 21 influencing factors for knowledge reuse described in the Worker-Centred-Model (Carro Saavedra et al. 2015, Fernandez Miguel et al. 2016). The survey provides two main outcomes: which factors are more relevant from the point of view of the employees and which factors are less considered by the company. Analysing those results points the factors to focus on in upcoming phases of k-MORE.
2. Analysis of the knowledge map. The goal is to define the company-specific knowledge base and to determine focus groups to consider in the upcoming phases of the k-MORE methodology. We propose seven rules to analyse the knowledge map. The rules are exposed in Table 2.

Table 2: Rules to analyse the knowledge map

Rule	**Implication for KB and upcoming phases of k-MORE**
Knowledge element number of edges	Knowledge elements with high number of edges define the knowledge categories of the KB (to consider in phase 3 "Packaging")
Knowledge element number of common terms	Most common terms appearing in the knowledge elements define the knowledge subcategories of the KB (to consider in phase 3 "Packaging").
Clustering	Clusters represent groups of people that intensively exchange documents. Credentials to the KB in the cluster and from outside the cluster are defined as well as measures to promote knowledge transfer between the clusters (to consider in phase 6 "Distributing").
Storage number of edges	Storages with high number of edges define the storages of the KB (to consider in phase 3 "Packaging").
Person number of input edges	Persons with high number of input edges are the focus group for reusing (to consider in phase 5 "Reusing").

Person number of output edges	Persons with high number of output edges are the focus group for documentation (to consider in phase 4 "Capturing and Documenting").
Knowledge element number of edges	Knowledge elements with low number of edges tend to be documented for own purposes, which is a shortcoming for knowledge transfer. How to document them with the adequate knowledge breath will be considered (to consider in phase 4 "Capturing and Documenting").

4.2.4 Packaging

The main element to plan the reuse cycle is the knowledge base (KB). It is defined by Milton as a "centralized repository of information used for knowledge dissemination" (Milton 2007). The main elements of the KB are the physical storage place of the documents and the visualisation of its content. We propose a KB concept with three visualisations (A, B, C) of the knowledge contained, as presented in Figure 4. Visualisation A is the knowledge map obtained from phase 1 "Visualising" of k-MORE. Visualisation B is an overview of the knowledge categories related within a hierarchy. The knowledge categories are the result of the analysis of the knowledge map conducted in phase 2 "Analysing". Visualisation C shows the workflow of the development process connected to the documents generated in each phase of the design process. The combination of the three visualisations pursues the goals:

- Provide multiple options of free search for documents, so each employee can conduct an individualized search depending on his or her preferences and understanding.
- Facilitate access to experts (contribution to personalisation approach for knowledge reuse) through the identification of them in Visualisation A.
- Provide the context of knowledge generation in Visualisation C.

The software implementation requires graph-visualisation tools, which should provide direct access (and control accessibility) to documents.

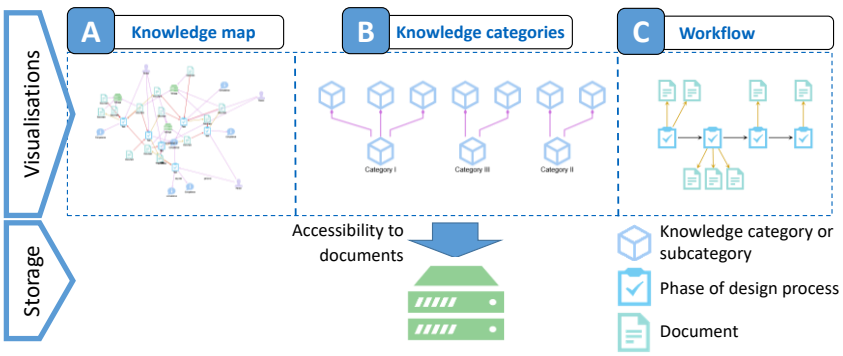

Figure 4: Knowledge base concept with three knowledge visualisations

4.2.5 Capturing and Documenting

Once the concept for the company's KB and its implementation is defined, the first filling of the KB takes place. The KM practitioners using k-MORE go through the suggestions to improve the documentation collected in phase 1 "Visualisation" in order to define the not documented knowledge that should be documented and the documented knowledge with needs for improvement. It is also suggested to elaborate standard templates for the knowledge categories of Visualisation B.

The results are discussed within the company and the actors that work on the improved documentation are defined through the links in the knowledge map. Especially relevant in the discussion are the identified persons with a higher number of output edges in phase 2 "Analysing". The three visualisations of the KB are prepared by the KM practitioner. The storage of the documents can be done by the KM practitioner or the employees.

In order to keep the KB updated, the processes for documentation during the work are defined. The definition of the documentation processes is company-specific under consideration of three aspects: 1) integration in the working process; 2) automatization; and 3) clear definition of roles.

4.2.6 Reusing

We propose two methods to conduct this phase, which can be combined according to the individual preferences and situation.

One method that we propose is suggesting the potential knowledge for reuse in a design situation without need of formulating a search question. Several characteristics of design situations influence the type, amount or representation of the knowledge which should be considered for reuse in such situation. An example of characteristic of the design situations could be the "designer's level of experience". There are studies that point out that more knowledge can be provided to experience designers because due to their experience, they are able to identify the relevant knowledge in considerable amounts of knowledge, whether novice designers get lost in the amount of information and cannot handle it. We postulate the hypothesis that for the same situation (characterized by the same characteristics), the same documented knowledge may be useful to be reused (Carro Saavedra and Lindemann, 2015). We propose eleven characteristics of the design situation (e.g. design phase or level of product complexity), which can be extended for each company. The documents are characterized by their metadata (e.g. design phase of document generation or type of knowledge representation). The patterns between design situations and documents can be derived from the daily work using artificial intelligence methods like artificial neural networks. The characterization of the design situation (CDS) by the designer is easy and it substitutes the formulation of a search question, which seems to be a shortcoming for reuse (see section 4.1).

The second method is a free search using the visualisations of the KB. The search for documents can be done looking for persons in Visualisation A, knowledge types in Visualisation B or process phases in Visualisation C. The user can navigate through the different visualisations to get a bigger picture for his or her search. Oriented searches can be conducted through the visualisations to reduce the search scope. If required, the formulation of the search question can be supported using existing methods like C-Quark, a question-reasoning method develop by Ahmed and Wallace (2004).

4.2.7 Distributing

Communication and training are the foundations for knowledge distribution. A training plan to learn how to use the KB should be company-specific designed. Suggestions from the survey of phase 2 "Analysis" are considered. The roles identified from the analysis of the knowledge map are used to define the communication measures with which knowledge generators will assure the awareness of knowledge existence for knowledge users.

5 INDUSTRIAL APPLICATION

The methodology was partially applied to a middle-size electronic company. In this section, we present some results of this application in order to illustrate how the methodology works in industrial contexts. The results are generalized in order to preserve their confidentiality.

The application of k-MORE started with the needs analysis. The company lacks on understanding which documented knowledge is available and where. Its strategic goal is to be market leader in innovation and its operational goal is to achieve structured knowledge documentation. Considering those goals, the focus for reuse is the technical product knowledge and market knowledge. This knowledge is mostly possessed by three departments (product management, quality management, research and development). Those departments were the focus for knowledge acquisition in phase 1 "Visualising" of k-MORE.

The knowledge acquisition was done by survey using excel templates for documentation. In order to assure consistency, three survey rounds asking 10, 25 and 85 employees per round were planned. After each round, we check the responses, we add predefined elements to the template tables of the next round, and we review the terms with managers. Plausibility checks between stated knowledge providers and knowledge users are conducted to verify the responses and thus, the knowledge map.

In phase 2 "Analysing", it was conducted the analysis of the 21 factors for successful knowledge reuse proposed in the Worker-Centred-Model. It shows that for this company, perceived risk of reusing knowledge and use of knowledge as power are the less relevant factors. Infrastructure factors are the ones with more room for improvement. Figure 5 shows the survey results for the factors influencing the knowledge understanding. The four factors are considered relevant for knowledge reuse with learning aptitude being the most relevant one according to the employees of this company. They consider that the company is not performing bad handling these factors but there is room for improvement for all of them. Knowledge affinity has more room for improvement and it should be considered especially in

phase 5 "Reusing" of k-MORE. Also interesting is that the opinions of the employees regarding knowledge breath differ considerably. A deeper analysis could be conducted to understand this difference. The knowledge depth is a factor to consider when planning the knowledge documentation in phase 4 "Capturing and documenting" of k-MORE.

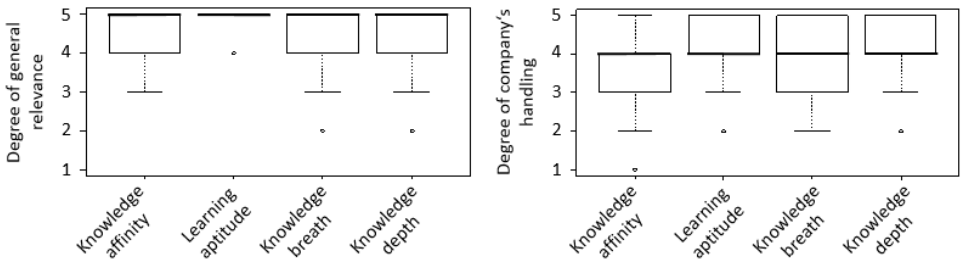

Figure 5: Boxplot of survey results for the influencing factors for knowledge understanding

The analysis of the knowledge map with the rules of Table 2 shows knowledge categories like tests or software, and knowledge subcategories like sensor or optic. These categories and subcategories constitute the Visualisation B of the KB (see Figure 4), which corresponds to the phase 3 "Packaging" of k-MORE. The analysis of the knowledge map with the rule "storage number of edges" showed that the company stores numerous documents with SharePoint (web based application for document management and storage). SharePoint has the functionality of visualising workflows and graphs. Thus, in this case, SharePoint is proposed for the implementation of the KB and no new software is required. Clusters can be seen for this company's knowledge map depending on the working country, especially in the case of the quality management (QM) department. As consequence, a measure for phase 6 "Distributing" is planned: temporarily exchange of employees between the countries to increase the awareness of the knowledge of the colleagues in the other country.
For phase 4 "Capturing and Documenting" it is decided to create templates to document the tests on different video camera components. For the phase 5 "Reusing", the possibility of rating the documents usefulness as metadata of the document is proposed, since the importance of recommendation was highlighted in the comments of the employees' survey conducted in the phase 2 "Analysing".

6 DISCUSSION

k-MORE provides support to prepare all phases of the reuse cycle of Markus (2001) with a focus on industrial application and consideration of individual needs of company and employees.
The knowledge acquisition and visualisation are proposed with templates for the employees and a knowledge map. Selecting the employees and achieving the consistency of the knowledge elements of the map are key aspects within these phases. Starting the knowledge acquisition from scratch allows a broad industrial applicability, since having a knowledge overview seems to be a need for most companies. Thanks to the various visualisations of the documents contained in the KB, designers get a big picture of the available knowledge so they can identify more situations of design, in which reusing knowledge is beneficial. Furthermore, more documents can be identified through the characterization of the design situation. The method of characterizing the design situations (CDS) pursues the goal of facilitating the search for knowledge while avoiding the formulation of search questions. An aspect to clarify in future research is how replicable the patterns of design situations are matched with the knowledge to reuse in those. Another open point is the feasibility of a passive (computer-aided) acquisition of the parameters of the design situation during design work, so designers do not have to define the parameters themselves and receive suggestions for knowledge to reuse automatically.
The individual needs of the company and its employees are collected and analysed based on the factors of the Worker-Centred-Model (Carro Saavedra et al. 2015, Fernandez Miguel et al. 2016). We selected this model because it synthesises the factors influencing knowledge reuse for individuals, but it limits the analysis to the factors considered on it. Other models or factors could be used at this phase. The interpretation of the results of the analysis is company-specific and understanding the implications of the results for upcoming phases of k-MORE can be challenging. Several case studies should be conducted to provide hints on which are common results and their implications.
k-MORE promotes habits and routines with standards like the KB and templates for documentation, as well as the definition of processes for documentation and reuse. Various solutions for the reusing stage

are provided in order to allow an individualized choice of solution. The definition of the specific parameters of the design situation provide the individualization in the method CDS.
The phases 1, 2, 3, and 5 of the methodology are generally applicable and systematic. Phases 4 and 6 are highly dependent on company's structures. Guidelines are provided for those phases.

7 CONCLUSSION AND FURTHER WORK

k-MORE is a methodology to prepare the reuse of documented knowledge during the design process. The methodology supports the reusing stage, which is traditionally disregarded, and it considers how to plan the complete cycle to enhance knowledge reuse. All of that is conducted under consideration of the specific company's situation and the individual needs and behaviours of its employees.
The next step is to complete the evaluation of the methodology within the Prescriptive Study II of the DRM. The application of the methodology to the industry case will be finalized and design experiments will be conducted to evaluate the feasibility of the CDS approach for phase 6 "Reusing".

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