Increasing the Amount of Knowledge Reuse from Engineering Design Repositories

A Research on the Needs and Behaviours of Novice Designers

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1 RESEARCH PROBLEM

Engineering design is a knowledge-intensive activity, in which designers are constantly learning. The knowledge gained with each new design can be reused in future designs in order to avoid past mistakes and do not reinvent the wheel.

Companies make efforts acquiring and storing their knowledge, but this knowledge is often not reused. 80% of the companies that participated in a survey conducted by (Milton 2010) attempted to collect lessons learned, but more than half did not reuse them efficiently. (Ichijo and Nonaka 2007) also remarked that "despite the growing interest in knowledge management and the initiatives many organizations have taken to manage knowledge, few companies have succeeded in creating a knowledge-based competence to gain and sustain a competitive advantage". Reality is that companies still fail transforming knowledge into actions. Either they do not apply the methods for knowledge reuse or they do not succeed applying them. Therefore, the question is *what is hampering companies in the successful reuse of the knowledge gained during engineering design?*

Numerous studies have been done to identify barriers for knowledge reuse (Chirumalla 2013, Ranjbarfard et al. 2014). Several approaches for knowledge reuse have been also developed. A shortcoming of the existing approaches for knowledge reuse knowledge reuse is that they do not deepen enough in the barriers existing at the level of designers. Individuals are in the end the ones that decide if they reuse or not. (Markus 2001) stated that "each type of knowledge reuser has different needs from repositories" and can experience different problems to reuse knowledge. More understanding of designers' needs and behaviours while reusing knowledge from company's repositories is required. The reuse of company-specific knowledge supports especially novice designers that are not familiarized with specific aspects of the company. Since novices are the main target group for knowledge reuse (Ahmed et al. 2000), they represent the focus of the research.

Early-phases of design are especially challenging for knowledge reuse due to the ill-defined status of the design problems. (Baxter et al. 2007) remarks that most methods for knowledge reuse are focused on detailed design and it should be given more attention to knowledge reuse in early design phases.

2 OUTLINE OF OBJECTIVES

The objective of the research is to increase the amount of knowledge reused from companies' repositories during early-phases of engineering design. In order to achieve this aim, the research is focused on understanding the needs and behaviours of novice designers while reusing knowledge. The understanding sets the basis for the development of support to increase the knowledge reuse.

Subsequently, the research challenges (RC), assumptions (A) and hypothesis (H) that motivate the research are presented. The research questions (RQ) derived from them are also introduced.

A 1: An understanding of the individual influent factors for novice designers to reuse knowledge from repositories is missing.

RQ 1: Which are the influent factors for novice designers to reuse knowledge from the repositories during early-phases of engineering design?

H 2: The identification of reuse situations during the early-phases of the design process is the trigger for knowledge reuse. Authors like (Wallace et al. 2005, Baxter et al. 2007) remark the need of process-based approaches for knowledge reuse.

RQ 2: Which are the situations of knowledge reuse during early-phases of engineering design? How can they be characterized?

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RC 3: Large amount of knowledge overwhelm designers, resulting on a negative attitude towards future knowledge reuse.

RQ 3: What is the relevant knowledge for designers in each reuse situation?

RC 4: Lack of successful support for knowledge reuse. Authors like (Ichijo and Nonaka 2007) and (Milton 2010) highlighted the need.

RQ 4: How can novice designers be supported to reuse the relevant knowledge in the identified reuse situations?

The research is structured according to the stages proposed by (Blessing and Chakrabarti 2009) in their book Design Research Methodology (DRM). The framework of the DRM is depicted in Figure 1. A comprehensive *Descriptive Study I* is being conducted in order to address RQ 1, RQ 2 and RQ 3. The understanding builds the basis to answer RQ 4 during the *Prescriptive Study*. The support will be evaluated during an initial *Descriptive Study II*.

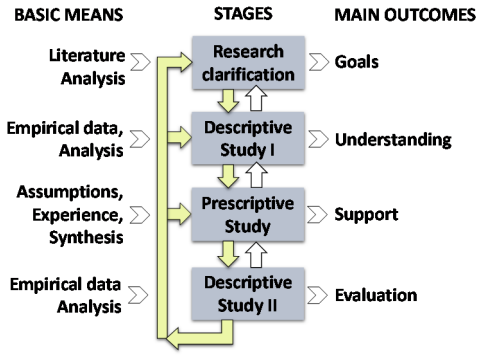

Figure 1: Framework of the research methodology. (Blessing and Chakrabarti 2009).

3 STATE OF THE ART

3.1 Knowledge Management

Knowledge management (KM) refers to the ability of companies in leveraging and applying individual and collective knowledge to help them compete (von Krogh 1998, Alavi and Leidner 2001). Consequently, "KM plays a critical role in efficiency, competitiveness, and productivity of organizations" (Manohar Singh and Gupta 2014).

3.1.1 Activities in Knowledge Management

The main activities of KM were defined by (Probst et al. 1998). They are related to each other since they are part of the process of KM (see Figure 2).

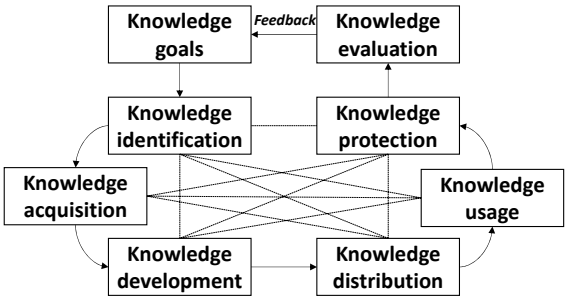

Figure 2: Activities of Knowledge Management (Probst et al. 1998).

According to (McMahon et al. 2004), the activities can be conducted with two focuses: 1) emphasize human resources and communication (personalization approach); or 2) promote collection and organization of documented knowledge (codification approach).

3.1.2 Types of Knowledge

Defining knowledge is a difficult task. The term has received different definitions but any of them has been established. However, the understanding of most authors can be summarized in seeing knowledge as information combined with experience, interpretation and reflection (Nonaka 1994, Davenport et al. 1998, Zack 1999b, De Long and Fahey 2000, Alavi and Leidner 2001).

A common resource in literature to succeed defining such an abstract term is to classify the types of knowledge. Numerous ways of classifying knowledge have been proposed.

(Polanyi 1962, 1966) introduced the two dimensions of human knowledge, the tacit and the explicit. He described tacit knowledge as "non-codified and non-verbalized knowledge that resides in individual's heads". "Explicit knowledge is encodable and transferable in formal language".

(Zack 1999b) classified knowledge into general and specific. "General knowledge is broad, often public available and independent of particular events". "Specific knowledge is context-specific."

(Alavi and Leidner 2001) and (Zack 1999a) also classified knowledge depending on its content as declarative (know-about), procedural (know-how), causal (know-why), conditional (know-when), and relational (know-with).

Some other classifications of knowledge are depending on the origin (internal or external) or the strategic value (core, advanced, innovative).

3.1.3 The Development of the Discipline

Coming from the field of strategic management, the article of (Nonaka 1991) *The Knowledge-Creating Company* represents a milestone in the development of KM as a formal discipline.

Since then, numerous theorists and practitioners have built on the discipline (Nonaka 1994, Grant 1996a, Grant 1996b, Davenport et al. 1998, Zack 1999a, Zack 1999b, Zack 2003, De Long and Fahey 2000). However, the successful implementation of KM is not an easy task. "Despite the growing interest in knowledge management and the initiatives many organizations have taken to manage knowledge, few companies have succeeded in creating a knowledge-based competence to gain and sustain a competitive advantage" (Ichijo and Nonaka 2007). This failure made questioning the effectiveness of KM. (Zack et al. 2009) conducted an empirical study to analyse the organizational impact of KM. They claim that KM practices are directly related to organizational performance and thus, they built the foundation to continue researching on the topic.

3.2 Knowledge Management in Engineering Design

KM is especially relevant to support knowledge-intensive activities like engineering design. Every design project is different, so engineers must come up every time with new solutions and ideas during their work. Past knowledge can support the development of solutions to new design problems (Duffy et al. 1995). The codification approach of KM provides a systematic support during the design process. The knowledge is stored in repositories, also called organizational memory systems (Markus 2001). The challenge is to make the maximum use of the available knowledge by delivering it "in the appropriate form at the right time" of the design process (Blessing and Wallace 2000).

This particular case of supporting knowledge-intensive activities using codified knowledge from repositories receives in literature the name of knowledge reuse (Markus 2001).

3.2.1 Knowledge Reuse from Repositories

(Markus 2001) built the foundations of a theory for knowledge reusability. She defined basic concepts of knowledge reuse and identified four types of situations in which knowledge is reused.

The reuse process consists according to (Markus 2001) of four phases: *capturing and documenting* knowledge; *packaging* knowledge for reuse; *distributing* knowledge; and *reusing* knowledge. She detailed further the last phase (reusing knowledge) in four steps, presented in Figure 3.

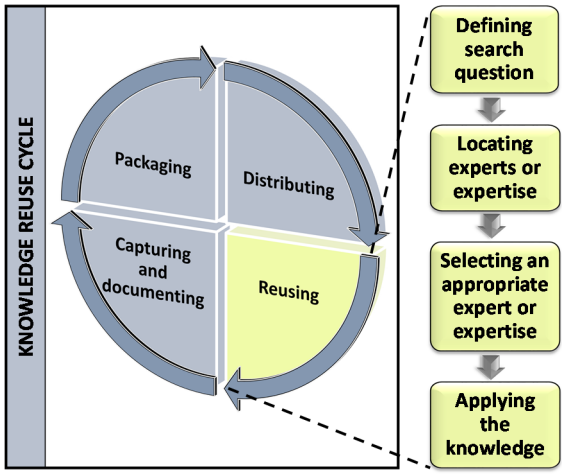

Figure 3: The Knowledge Reuse Cycle and the four steps of the reusing phase. (Adapted from Markus 2001).

(Markus 2001) determined the roles which participate in the knowledge reuse process: the *knowledge producer*; the *knowledge intermediary*; and the *knowledge consumer*. She identified four types of situations in which knowledge is reused depending of the roles of the actors involved in the reuse situation:

- Shared Work Producers: people working together (homogeneous or cross-functional). Producers of knowledge for their own later reuse.
- Shared Work Practitioners: people doing similar work in different settings. Producers of knowledge for each other's use.
- Expertise-Seeking Novices: people with an occasional need for expert knowledge that they do not possess.
- Secondary Knowledge Miners: people who seek to develop new knowledge through analysis of records produced by other people for different purposes.

After presenting the framework, she concludes that the type of repository and the associated KM processes must be designed differently depending on the reuse situation. "Successful knowledge reuse is a matter of designing repositories that meet reusers' needs" (Markus 2001).

3.2.2 Types of Knowledge in Engineering Design

The term design knowledge often refers to knowledge about products' geometry, that is embedded in CAD models and it can be reused using knowledge-based engineering (KBE) tools. This knowledge can be abstracted in form of structural, functional or behavioural models, so it can be reused for any design situation or any physical structure. Generic relations among abstract design elements based on these models are the so called design patterns (Bhatta and Goel 2002).

However, there is more knowledge that can be reused in engineering design, like project-constrain reasoning, problem resolution methods, solution generation strategies, design intent, and supply chain knowledge (Baxter et al. 2007). In fact, knowledge in engineering design can be classified using the types of knowledge described in section 3.1.2. Inside each type the categories can be further concretized for specific fields.

Some authors derived specific categories of knowledge reused in engineering design conducting empirical observations. (Cross and Sivaloganathan 2007) conducted their study within a mobile elevating work platform manufacturer. They determined the following categories of knowledge:

- Country- and market-specific requirements
- Experience, best-practice, tips and tricks
- Product-specific parameters
- Interactions, trade-offs, and design rules
- Knowledge contacts
- Legislation and approval bodies
- Manufacturing process capability and available materials
- Preferred parts and installation requirements
- Stakeholder behaviour
- Stakeholder requirements

(Gainsburg et al. 2010) propose also a classification based on observations in structural engineering companies.

3.2.3 Approaches for Knowledge Reuse in Engineering Design

(Duffy et al. 1995) present a design reuse model consisting of three processes and six knowledge-related components. The goal of the model is formalising design reuse in order to provide the appropriate scope to be supported. The work is theoretical and no evaluation is presented.

(Blessing and Wallace 2000) developed PROSUS, a system to support knowledge reuse during the design process focused in knowledge generation. They identified the generation of knowledge as the consequence of using knowledge. Therefore, the core of the system is a working area for the designer, in which the relevant knowledge during design is generated and stored. They also highlight that the whole knowledge reuse cycle (they refer to it as knowledge-life cycle) must be taken into account when developing knowledge-based support for design. PROSUS does not explicitly address the knowledge-life cycle but it sets the basis to support the entire cycle through the indication of context, which is the basis for understanding.

(Fruchter and Demian 2002) developed a prototype knowledge management system, CoMem, to support the activities that they identified in the process of knowledge reuse: finding reusable items and understanding these items in context. They do not consider knowledge reuse as the complete process (from generating to reuse) but only the last phase according to (Markus 2001), reusing knowledge. It is not explained who or how should the system be fulfilled with knowledge to be sustainable.

(Dani et al. 2006) developed a methodology to support communication, sharing and reuse of best practices in product development. The methodology focuses in capturing, structuring and finding best practices for new projects. The proposal is project-focused instead of process-focused. Best practices to be reused during a new project are identified at the beginning of a new project and there is no method suggested for the retrieval of best practices once the project has started.

(Johansson et al. 2012) propose Matrix-Flow-Charts (MFC) as an approach to support the reuse of knowledge from manufacturing processes during design. Their work is conducted within the field of laser welding technology. Real implementation of MFC or an evaluation are not conducted.

(Chirumalla 2013) developed a methodology to reuse lessons learned (LL) in product development. The LL are captured using templates and videos with storytelling. The videos contribute to transfer contextual and tacit knowledge. The integration of the LL in the development process is not addressed.

3.2.4 The Research Gap

Despite the efforts made in research and the evidence of the benefits of knowledge reuse, reality is that companies still fail transforming knowledge

into actions. Either they do not apply the methods or they do not succeed applying them (Ichijo and Nonaka 2007, Milton 2010). Therefore, the question is *what is hampering companies in the successful reuse of the knowledge gained during engineering design?*

Numerous studies on the barriers for KM have been carried out. The studies identify barriers related to different aspects like people-related barriers, technology-related barriers, organization-related barriers, environment-related barriers or knowledge characteristic-related barriers (Ranjbarfard et al. 2014). These barriers are usually also allocated to the correspondent activities of KM. However, the spectrum of barriers is large and the interdependencies between the activities in KM are high. Therefore, the understanding of the implications of barriers on the knowledge processes and which kind of support can overcome those remains still incomplete.

(Davenport and Prusak 1998) stated that "knowledge originates and it is applied in the minds of knowers". They point out with this statement that the decision of applying knowledge depends ultimately on individuals. Thus, individuals represent the connecting link between KM initiatives and firm performance. A better understanding of individuals' needs and behaviour when reusing knowledge is the key to identify the reasons for the failure in reuse.

Looking at individuals, it can be distinguished between expert and novice designers. Knowledge reuse is especially relevant for novice designers, since it helps to "bridge the gap between novices and experienced designers" (Ahmed et al. 2000), contributing to a faster learning curve for novices.

The approaches presented in section 3.2.3. do not focus on the specific needs of novices or experts. However, the needs and behaviours of both groups while reusing knowledge are different. For example, (Ahmed and Wallace 2004) found that one differential issue between experts and novices is the awareness of knowledge needs. Novices were only aware of their needs in 35% of the cases. They present a method (C-QuARK) to support novice designers in the step "defining the search question" of the reusing stage established by (Markus 2001). However, the integration of the method in a holistic approach for knowledge reuse is missing.

We argue that the lack of differentiation of reusers' (knowledge consumers) requirements, aspect that (Markus 2001) identified as of mayor importance, is the main reason for the low implementation in industry of approaches for knowledge reuse and for the failure in case of implementation. The specific requirements of the individuals involved in the process are not taken into account. Furthermore, the requirements of other stakeholders during the reuse cycle, like knowledge producers and knowledge intermediaries, must be also considered for a system addressing the whole reuse cycle to succeed. Due to the mismatch between system features and stakeholders' requirements, reuse systems are finally not properly used or not used at all, and the knowledge reuse during the design process does not occur.

Since novice designers are the stakeholders that can profit the most from an approach for knowledge reuse, this research proposes to start a deeper investigation on stakeholders' requirements by analysing the requirements for novices and proposing support for them. Thus, the target support would be established and further investigations should consider the integration of the other stakeholders according to their specific requirements in such a support.

4 METHODOLOGY

A research methodology based on the DRM of (Blessing and Chakrabarti 2009) has been designed.

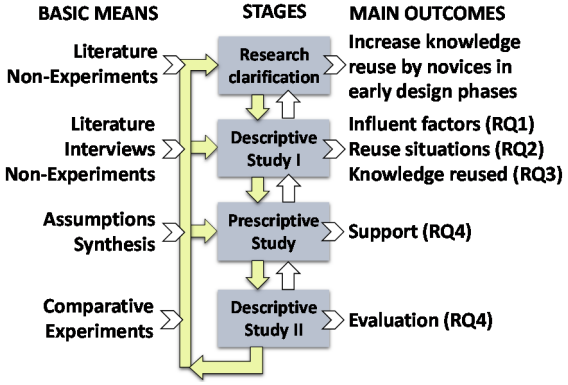

Figure 4: Research methodology.

The *Research Clarification (RC)* has been done reviewing literature and non-experimentation with students in design workshops.

The *Descriptive Study I (DS I)* constitutes the largest research effort due to the current lack of proper understanding on the research topic. There is the need of obtaining empirical data for the analysis. Therefore interviews with novices and experienced designers will be conducted. Also non-experiments with novices to observe and analyse their behaviour during knowledge reuse will be conducted.

An approach for support will be proposed during the *Prescriptive Study (PS)*. The reuse situations and reused knowledge established in the DS I constitute the framework to develop the support. The support should help to overcome the harmful influent factors identified during DS I.

The proposed support will be evaluated during the *Descriptive Study II (DS II)* in comparative design experiments, in which one group of designers conducts a design development without support and the other group does it with the support.

4.1 Research Clarification

Several approaches for knowledge reuse have been proposed in literature. Numerous barriers for knowledge reuse have been also identified. However, the reasons for the lack of knowledge reuse during engineering design are unclear. Setting the focus of the research was difficult under these conditions.

Novice designers were identified as the group with higher potential for support. An approach to understand better the influent factors that affect them during knowledge reuse was to simplify the scene: what if the complex environment of the company (culture, network, time-pressure, etc.), or the technological support were out of the picture? Would in this case knowledge be successfully reused during the design process? With the purpose of answering this question, a non-experiment with three students was realized. A non-experiment is conducted when the understanding of the research phenomenon or the available resources are "not sufficient for permitting strong tests of causal hypothesis" (Cook and Campbell 1979). Non-experimentation is done to observe a phenomenon as it occurs and helps to generate new ideas.

For the non-experiment, the students were considered as "novice designers" and they were given a design problem to solve in three hours. They worked individually and they could ask questions to the "knowledge repository" during their work. The knowledge repository contained useful knowledge for the design problem in form of knowledge pages previously documented and categorized. For simplification reasons, the knowledge repository was a person. The person did not interact orally with the participants and the communication was in written form. The person acted as an "intelligent knowledge retrieval system" providing the correspondent knowledge page to the question written by the participant.

The design process was divided in three phases: idea generation, concept design and detailed design. The participants should provide their output of each phase to the moderator. Their requests for knowledge during the process were documented and the application of the knowledge contained in the knowledge pages was analysed regarding the outcomes of the design phases.

Two main problems were observed: difficulty to articulate questions and difficulty to interpret the knowledge that was received and reuse it successfully. The first problem occurs due to the low awareness of their knowledge needs. The fact that the knowledge is available (explicit set up of the experiment: there is knowledge available for your specific design problem) did not appear to have a significant impact. An interesting observation was that the amount of requests increased as the design process advances. Therefore, the phase of the design process influences the amount of knowledge reused. The request for knowledge is less in early-phases of design. The second problem occurs due to the lack of knowledge contextualization. The knowledge of the knowledge pages was not documented in a way that it was understandable for the participants how they could apply it in their situation.

From the non-experiment is concluded that barriers for knowledge reuse also exist in a simplified environment. More understanding of the phenomenon is needed, especially on early design phases, before support can be developed. A literature review shows that most methods for knowledge reuse are focused on detailed design (Baxter et al. 2007) and it should be given more attention to knowledge reuse in early design phases. Therefore, the research continues in this direction.

4.2 Descriptive Study I

The DS I attempts to answer RQ 1, RQ 2 and RQ 3. In order to answer the questions, an approach based on three methods for data acquisition is proposed: literature review, interviews and non-experimentation. An overview of the proposed methods is depicted in Table 1.

Table 1: Research methods applied during the DS I (√: contribution; √√: main contribution).

	Lit. review	**Interviews** with novices	**Interviews** with experts	**Non-experiments** Novices as participant Experts as analysts
RQ1		√	√	√√
RQ2	√√	√	√	
RQ3	√	√	√√	√

Further details and the expected outcomes of each method are explained in the following sections.

4.2.1 Literature Review

A literature review is being conducted in order to find types of reuse situations and ways of characterizing those (RQ 2), and types of knowledge to be reused (RQ 3). The literature review should provide the major contribution to answer RQ 2 and contribute to answer RQ 3. However, not much information has been found until the moment.

Regarding the identification and characterization of reuse situations, there is the approach of (Markus 2001) explained in section 3.2.1. Sources proposing classifications of design situations (considering those as potential reuse situations) provide also useful insights. (Sim and Duffy 2003) identified the generic engineering design activities in three groups: design definition activities (like abstracting or detailing), design evaluation activities (like analysing or modelling), and design management activities (like planning or prioritizing). (Ponn 2007) suggests three main categories to classify a design situation: design task, designer/designer team, boundary conditions.

Considering the types of knowledge to be reused (RQ 3), the classifications of (Cross and Sivaloganathan 2007) or (Gaingsburg 2010) introduced in section 3.2.2 have been found. Other authors in the field of engineering design adopt the categories presented in section 3.1.2 that can be generalized to other disciplines. These categories seem too general to support the reuse of specific company´s knowledge.

4.2.2 Interviews

Gathering empirical data is necessary to answer the three research questions formulated.

For RQ 1 and RQ 2, interviews with novice and expert designers are proposed as a method to verify/extend the data obtained first by other means. For RQ 3, the outcome from the interviews represent the main source to obtain data.

In the case of RQ 1, the results from the non-experiments refer to concrete cases. The interviews to novice designers are proposed in order to check if the influent factors identified during the non-experiments can be generalized. Interviews to expert designers with the same purpose are proposed. Experts work with novices and from their experience, they can also provide valuable insight about the influent factors for novices.

The literature review to define the reuse situations (RQ 2) does not seem conclusive. Only one concrete classification has been found up till now (Ponn 2007) and its focus differs from the focus of the research at hand. If no further classifications are found, an approach for the classification will be proposed and its validity evaluated by interviewing novices and experts.

Interviewing novice designers about the knowledge they reuse and the knowledge they would like to reuse contributes to answer RQ 3. However, as it was already explained, novice designers are not always aware of their knowledge needs. In order to understand which kind of knowledge is reused, the experience of expert designers is considered a key factor. Therefore, the main contribution to RQ 3 are the interviews with experienced designers.

4.2.3 Non-Experiments

Current literature is not sufficient to identify the key influent factors. Interviews with novice and expert designers may contribute but the factors are difficult to be elicited in interviews. A more realistic approach to identify influent factors is direct observation of the process of knowledge reuse. Non-experiments in form of design workshops are proposed. (Blessing and Chakrabarti 2009) point out that due to the lack of understanding in design "design research usually involves non-experimental and quasi-experimental research, in particular for DS-I". During the non-experiment, novice designers must reuse knowledge, and expert designers support the researches with the analysis of the results.

The non-experiments will be conducted similarly to the one realized during the RC but focused on early phases of design. The intention this time is to conduct them with real knowledge in collaboration with a development company that brings up a realistic design problem. The knowledge repository will be fulfilled with knowledge provided by the company. The participants will be novice designers from the company. Experienced designers from the same company will support the researcher to analyse the results. The effects of the non-use of available knowledge or of the wrong use will be analysed. The reasons for the non-use or wrong use will be identified and the ways to overcome those will be discussed with experts and novices.

A model to support the analysis of influent factors for the participants during the non-experiments has been developed (Carro Saavedra et al. 2015). The model is centred in the individual and it represents the knowledge processes for him

associated to the factors influencing each process. Three knowledge processes were identified and seven factors were allocated to those processes. On that basis, the model is being right now extended.

An alternative to the non-experiments could be a case study. A case study would provide valuable insights for RQ 2 and RQ 3. The possibility of conducting a case study will be discussed with the potential industry partners.

4.3 Prescriptive Study

The PS should provide an answer to the RQ 4. The proposed support will be based on the outcome of the DS I. Since the DS I is under development, the final requirements of the support are not final yet. However, a preliminary idea is proposed based on the main barrier found until the moment: the lack of awareness of the knowledge needs. If novice designers do not know during the process in which situations there is knowledge in the repository to support them, they will not look for it. The knowledge must be integrated in the design process in order to have the chance to be reused. Three hypothesis (H) are established:

H 1: Design situations (potential knowledge reuse situations) can be systematically characterized.
H 2: Characterizing the design situation according to pre-established parameters is easier for the novice designer than the formulation of a search question in early design phases of design.
H 3: The relevant types of knowledge to support a design situation can be systematically matched to the design situation.

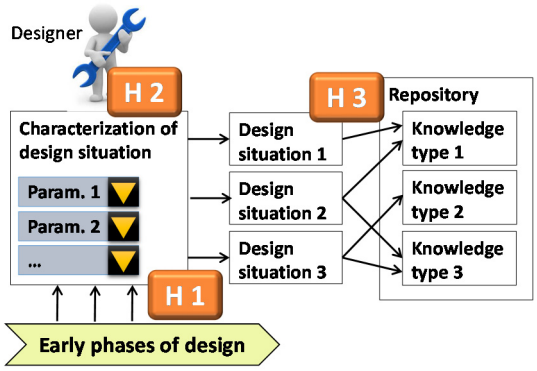

Figure 5: Overview of the hypothesis formulated to ideate the support.

The types of reuse situations and a way of characterizing them are addressed in RQ 2. The goal is to find a way of characterizing the design situations for novices during early phases of design that is suitable for designers to be made. Thus, they could characterize their situations during the design process and be connected to the type of knowledge that was previously generated and considered useful for the described situation.

The outcome of RQ 3 are the types of knowledge to be reused. The idea is that types of situations and types of knowledge can be systematically matched (see Figure 5).

Based on these hypothesis, we propose supporting novice designers in the final stage of the knowledge reuse cycle (defined as reusing stage by Markus 2001). One extra step have been added at the beginning based on the first results of RQ 1: realizing knowledge need. The proposed support is depicted in Figure 6.

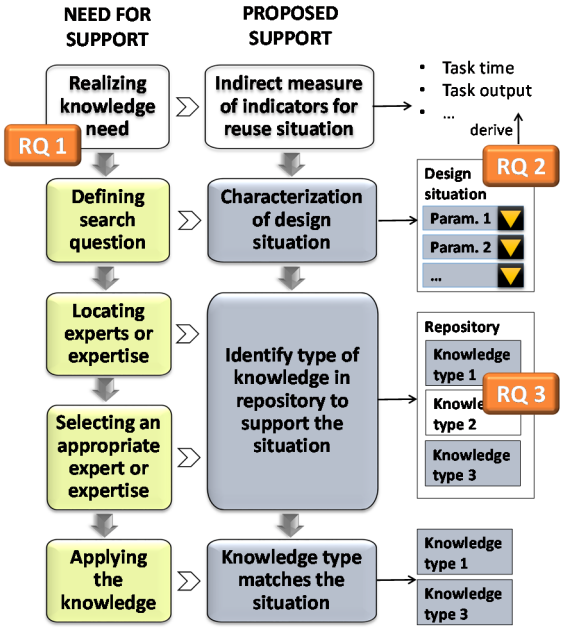

Figure 6: Proposed support of the steps during the "reusing" stage of the knowledge reuse cycle.

Realizing knowledge need is supported by indirect measure of indicators of a knowledge reuse situation. That means, monitoring certain aspects of the design process (e.g. time per task, keywords in the opened documents, etc.) and recognizing thus the knowledge need. The indicators will be investigated and a methods for measuring will be proposed.

Defining search question is supported by the characterization of the design situation (see H 2). The characterization is the outcome of the RQ 2.

Locating experts or expertise and selecting an appropriate expert or expertise are supported automatically through the mapping of the design situation characterized to the knowledge suitable for

it. All piece of knowledge in the repository is associated to a design situation. The types of knowledge to be associated to the design situations are the outcome of RQ 3.

The application of the knowledge is supported because the knowledge provided matches the situation. That means that aspects related to the situation like motivation of designer or need of knowledge contextualization are considered, so the adequate piece of knowledge for its correct interpretation under the situation is provided.

4.4 Descriptive Study II

The applicability of the proposed approach will be evaluated in non-experiments, in which novice designers are given a design task and the support. The suitability of the characterization of design situations by designers and the replicability of the characterization will be the main aspects to analyse. Suggestions for updates on the support will be considered and the support will be further developed. Several iterations will be conducted. The exact number depends on the available time.

The final evaluation will be done in comparative experiments. One group of novices will be given a design task to realize without the support, whereas another group of novices will receive the support. The results will be compared to analyse the effects of the support on the reuse of the knowledge contained in the repository.

5 EXPECTED OUTCOME

Two main outcomes are expected:

- Understanding about the influent factors for knowledge reuse by novice designers, their needs for knowledge and the situations during early-phases of the design process in which knowledge may be reused.
- An approach to support novice designers reusing knowledge from company's repositories during early-phases of design.

The approach will be continuously tested and refined according to the results of real application during design workshops with novice designers. Thus, the suitability for novice designers is assured.

The support to be developed does not attempt to address the complete knowledge reuse cycle under consideration of all its stakeholders. The intention is to understand the specific needs of novice designers and how they could be supported. The proposed support must be seen as the goal to pursue by a holistic approach for knowledge reuse. Further investigations should consider the integration in the support for novices in all stages of the reuse cycle (capture, package, distribution) and the requirements of the stakeholders involved (knowledge producers, intermediaries, other knowledge consumers).

6 STAGE OF THE RESEARCH

A *Research Clarification (RC)* based on literature review was conducted in order to find evidence of the existent problem and determine the research goals. The research questions have been defined as well as the areas of research and contribution.

The approach to address the *Descriptive Study I (DS I)* has been developed and initiated. The first findings from literature review provide an initial answer to RQ 2 and RQ 3. A model to understand the influent factors for the individual (novice designer) while reusing design knowledge was developed (Carro Saavedra et al. 2015). The model will support the analysis of the non-experiments in order to answer the RQ 1. At the actual stage we are looking for industry partners to collaborate for the non-experiments. The possibility of conducting a case study will be discussed with the potential partners. We plan to prepare and conduct the non-experiments in 2016. We hope to provide answers for research question RQ 2 and RQ 3 during 2016.

A preliminary approach for the *Prescriptive Study (PS)* was developed. It builds upon the outcomes of the DS I. The PS as well as the *Descriptive Study II* are planned for 2017. The research finishes in February 2018.

REFERENCES

Ahmed, S., Wallace, K., Blessing, L., 2000. Identifying differences between novice and experienced designers. *Proceedings of Engineering Design Conference*, Brunel University, Uxbridge, pp. 97-106.

Ahmed, S., Wallace, K. M., 2004. Identifying and supporting the knowledge needs of novice designers within the aerospace industry. *Journal of Engineering Design*, 15:5, 475-492.

Alavi, M., Leidner, D. E., 2001. Knowledge management and Knowledge Management Systems: Conceptual Foundations and Research Issues. *MIS Quarterly*, 25(1), 107-136.

Bhatta, S. R., Goel, A. K., 2002. Design patterns and creative design. In Chakrabarti, A., *Engineering Desing Synthesis. Understanding, Approaches and Tools* (pp. 271-284). London: Springer.

Baxter, D., Gao, J., Case, J., Harding, J., Young, B., Cochrane, S., Dani, S., 2007. An Engineering Design Knowledge Reuse Methodology Using Process Modelling. *Research in Engineering Design,* 18(1), 37-48.

Blessing, L. and Wallace, K. 2000. Supporting the Knowledge Life Cycle. *MIT Sloan Management Review*, pp. 75-83.

Blessing, L., Chakrabarti, A., 2009. *DRM, a Design Research Methodology*. Springer. London.

Carro Saavedra, C., Fernández Miguel, R. and Lindeman, U., 2015. A worker-centered model to understand the factors influencing knowledge application. *Proceedings of the 11th International Conference on Knowledge Management,* 04-06 November, Osaka.

Chirumalla, K., 2013. *Development of a Methodology for Lessons Learned Practice. From post-project learning to continuous process-based approach.* Doctoral Thesis. Lulea University of Technology.

Cook, T. D., Campbell, D. T., 1979. *Quasi-experimentation: design and analysis issues for field settings*. Houghton Mifflin Company, Boston.

Cross, M. S., Sivaloganathan, S., 2007. Specialist knowledge identification, classification, and usage in company-specific new product development processes. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*.

Dani, S., Harding, J. A., Case, K., Young, R. I. M., Cochrane, S., Gao, J., Baxter, D., 2006. A methodology for best practice knowledge management. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, 220(10), pp. 1717-1728.

Davenport, T. H., De Long, D. W., Beers, M. C, 1998. Successful Knowledge Management Projects. *Sloan Management Review*, 39(2), 43-57.

Davenport, T. H, Prusak, L., 1998. *Working Knowledge: How Organizations Manage what They Know*. Harvard Business School Press. Boston.

De Long, D. W., Fahey, L., 2000. Diagnosing cultural barriers to knowledge management. *Academy of Management Executive*, 14(4), 113-127.

Duffy, S. M., Duffy, A. H. B., MacCallum, K. J., 1995. A Design Reuse Model. *Proceedings of ICED 95*, Prague, 490-495.

Fruchter, R., Demian, P., 2002. Knowledge Management for Reuse. *International Council for Research and Innovation in Building and Construction*. 12-14 June, Aarhus School of Architecture.

Gainsburg, J., Rodríguez-Lluesma, C., Bailey, D. E., 2010. A "knowledge profile" of an engineering occupation: temporal patterns in the use of engineering knowledge. *Engineering Studies*, 2:3, 197-219.

Grant, R. M., 1996a. Prospering in Dynamically-competitive Environments: Organizational Capability as Knowledge Integration. *Organization Science*, 7(4), 375-387.

Grant, R. M., 1996b. Toward a knowledge-based theory of the firm. *Strategic Management Journal*, 17, 109-122.

Ichijo, K., Nonaka, I., 2007. *Knowledge Creation and Management: New Challenges for Managers*. Oxford University Press. New York.

Johansson, C., Frostevarg, J., Kaplan, A. F. H., Bertoni, M., Chirumalla, K., 2012. 3rd IEEE International *Conference on Congnitive Infocommunications*. December 2-5, Kosice, Slovakia.

Manohar Singh, R., Gupta, M., 2014. Knowledge management in teams: empirical integration and development of a scale. *Journal of Knowledge Management*, 18(4), 777-794.

Markus, M. L., 2001. Toward a Theory of Knowledge Reuse: Types of Knowledge Reuse Situations and Factors in Reuse Success. *Journal of Management Information Systems* (18:1). Pp. 57-93.

McMahon, C., Lowe, A., Culley, S., 2004. Knowledge management in engineering design: personalization and codification. *Journal of Engineering Design*, 15(4), 307-325.

Milton, N., 2010. *The Lessons Learned Handbook. Practical Knowledge-Based Approach to Learning from Experience.* Chandos Publishing, Oxford.

Nonaka, I., 1991. The Knowledge-Creating Company. *Harvard Business Review*, 69 (6), 96-104

Nonaka, I., 1994. A Dynamic Theory of Organizational Knowledge Creation. *Organization Science*, 5(1),14-37.

Polanyi, M., 1962. *Personal Knowledge: Towards a Post-Critical Philosophy*. The University of Chicago Press. Chicago.

Polanyi, M., 1966. *The Tacit Dimension*. Anchor Day Books. New York.

Ponn, J., 2007. *Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte.* Doctoral Thesis. Technische Universität München.

Probst, G., Gaub, S., Romhardt, K., 1998. Wissen Managen: *Wie Unternehmen ihre wertvollste Ressource optimal nutzen*, Gabler Verlag. Frankfurt.

Ranjbarfard, M., Aghdasi, M., López-Sáez, P., Emilio Navas, J., 2014. The barriers of knowledge generation, storage, distribution and application that impede learning in gas and petroleum companies. *Journal of Knowledge Management*, 18(3), 494-522.

Sim, S. K., Duffy, A. H. B, 2003. Towards an ontology of generic engineering design activities. *Research on Engineering Design*, 14, 200-223.

Wallace, K., Ahmed, S., Bracewell, R., 2005. Engineering knowledge management. In Clarkson, J., Eckert, C., *Design process improvement. A review of current practice* (pp. 326-343). London: Springer.

Von Krogh, G., 1998. Care in Knowledge Creation. *California Management Review*, v40, 133-154.

Zack, M. H., 1999a. Developing a Knowledge Strategy. *California Management Review*, 41(3), 125-145.

Zack, M. H., 1999b. Managing Codified Knowledge. *Sloan Management Review*, 40(4), 45-58.

Zack, M. H., 2003. Rethinking the Knowledge-Based Organization. *MIT Sloan Management Review*, 44(4), 67-71.

Zack, M. H., McKeen, J., Singh, S., 2009. Knowledge management and organizational performance: an exploratory analysis. *Journal of Knowledge Management*, 13(6), 392-409.