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A Methodology to Plan the Knowledge Reuse Cycle in Engineering Design Companies

Cristina Carro Saavedra

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Vorsitzender:	Prof. Dr.-Ing. Karsten Stahl
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FOREWORD OF THE EDITOR

Problem

Engineering companies possess large and widely spread knowledge resources. Efficient reuse of those resources saves development time and costs since it avoids “reinventing the wheel” by reworking issues which have been already addressed within the company. But managing knowledge and reusing it efficiently is a major challenge in the current globalised and dynamically changing industrial context.

The discipline of knowledge management emerged in the 1990s with the aim of providing methods to support companies in managing and reusing knowledge. As a result, most companies have already extensively implemented knowledge management methods. However, the implementation was done fast and without a systematic planning according to their needs, which leads to inefficient knowledge reuse in the present time. There is the need of investigating the reasons for the current failures in implementation and of developing applicable knowledge management methodologies.

Objectives

The objective of this thesis is improving the theoretical understanding and developing practical support to increase knowledge reuse in engineering design companies.

The improved understanding includes on the one side the analysis of the reasons for the lack of knowledge reuse in practice and on the other side, the investigation of the individual factors influencing knowledge reuse. Since knowledge is an abstract concept with a very subjective interpretation, the understanding of individuals’ behaviour dealing with knowledge seems necessary to develop suitable strategies for successful knowledge reuse in long-term.

The proposed support is a methodology to plan the four phases of the knowledge reuse cycle (capturing and documenting, packaging, distributing, reusing) in engineering design companies. This thesis’ goal is conceptualising, elaborating and evaluating this methodology.

Results

This thesis presents two main results: 1) improved theoretical understanding to increase knowledge reuse in engineering design companies; and 2) new solution approach to plan the knowledge reuse cycle in engineering design companies.

Three methods are applied in order to achieve result 1). First, an interview study with industrial practitioners contributes to understand the reasons for the lack of knowledge reuse in practice. Then, a systematic literature review is conducted to create a theoretical model (Worker-Centred Model) describing the processes experienced during knowledge reuse from the point of view of individuals (knowledge workers). Finally, two exploratory design experiments help to observe individuals’ behaviours and needs while reusing documented knowledge from knowledge bases. The conclusions extracted from the implementation of those three methods set the basis to define the requirements for supporting knowledge reuse.

Result 2) is the solution approach: the *k*-MORE methodology (*k*-MORE: **k**nowledge **M**anagement for **O**ptimised **RE**use). The eight steps of the *k*-MORE methodology support the following activities for the company: definition of company's goals for knowledge reuse, acquisition and visualisation of company's knowledge, analysis of company's knowledge map and individual perceptions of knowledge reuse, selection of methods to prepare the phases of the knowledge reuse cycle, and planning how to maintain the selected methods in daily work. Thus, companies can plan their knowledge reuse cycle from scratch, starting with basic issues such as the definition of "knowledge" and based on their individual company's situation and employees' perceptions. Additionally to the *k*-MORE methodology, an approach for knowledge package and reuse within a knowledge base is proposed.

Conclusions for Industrial Applications

The solution approach as presented in this thesis is directly applicable in industrial practice. The *k*-MORE methodology is described with the required level of detail (extensive appendix with procedures, templates and additional information) to be a practical guide for knowledge management practitioners to plan the methods to perform the knowledge reuse cycle from scratch. It is applicable without regard to the current implementation of knowledge management methods in the company, goals for knowledge reuse or understanding of what is "knowledge". Furthermore, several building blocks of the *k*-MORE methodology are developed to facilitate its industrial application. Especially useful for companies is the methods catalogue, which contains a summarised and structured collection of methods for knowledge reuse.

Conclusions for Scientific Researchers

This thesis contributes to research by proposing a solution approach that faces the problem of knowledge reuse from a more realistic perspective for industrial implementation than previous existing support. The most innovative aspect is the individualised analysis. It is the first approach which analysis a knowledge map with the goal of planning the four phases of the knowledge reuse cycle. It is also the first approach which fosters the differentiation of groups and individuals in the company in order to address them with individualised methods for knowledge reuse. Moreover, some of the models and methods developed in this thesis can be applied by researches, independently from the proposed solution approach. The theoretical model which is used as basis for the individualised analysis, the Worker-Centred-Model, can be used as a reference model to investigate individual knowledge reuse. The new characterisation of the collected methods for knowledge reuse allows their consideration under new points of view such as e.g. their ability to address factors influencing knowledge reuse for individuals. This characterisation can set the basis to structure future investigations.

Garching, November 2020

Prof. Dr.-Ing. Udo Lindemann
TUM Emeritus of Excellence
TUM Senior Excellence Faculty
Former Chair of Product Development
Technical University of Munich

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Garching, November 2020 Cristina Carro Saavedra

PRIOR PUBLICATIONS

The following publications are part of the work presented in this thesis (chronological order):

Carro Saavedra, C.; Schrieverhoff, P.; Lindemann, U. (2014). A knowledge-based approach to optimize simulations in the product development process. International Conference on Advanced Design Research and Education (ICADRE14), 16-18 June, Singapore.

Carro Saavedra, C.; Fernandez Miguel, R.; Lindemann, U. (2015). A worker-centered model to understand the factors influencing knowledge application. In K. Seta, T. Watanabe (Eds.) Proceedings of the 11th International Conference on Knowledge Management (ICKM), 4-6 November, Osaka, Japan.

d'Albert, H.; Carro Saavedra, C.; Lindemann, U. (2015). Elicitation of Requirements for a knowledge-based Framework in Product Development Process. In K. Seta, T. Watanabe (Eds.) Proceedings of the 11th International Conference on Knowledge Management (ICKM), 4-6 November, Osaka, Japan.

d'Albert, H.; Carro Saavedra, C.; Maurer, M. (2015). Business Knowledge Development using Knowledge Maps. International Conference on Business and Internet (ICBI 2015), 10-12 November, Nagoya, Japan.

Carro Saavedra, C.; Lindemann, U. (2015). Increasing the amount of knowledge reuse from engineering design repositories. In 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, 12-14 November, Lisbon, Portugal.

Fernandez Miguel, R.; Carro Saavedra, C.; Lindemann, U. (2016). Factors influencing knowledge application. A review from the knowledge management field. In D. Marjanović, M. Storga, N. Pavković, N. Bojcetic, Stanko Škec (Eds.) 14th International Design Conference. DESIGN 2016, 16-19 May. Glasgow: Design Society, pp. 985–996.

Carro Saavedra, C.; Marahrens, N.-J., Schweigert, S.; Kestel, P.; Kremer, S.; Wartzack, S.; Lindemann, U. (2016). Development of a Toolkit of Methods for Simulations in Product Development. In IEEE (Ed), 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). 4-7 December, Nusa Dua, Indonesia.

Carro Saavedra, C.; Serrano Villodres, T.; Lindemann, U. (2017). Review and classification of types of knowledge in engineering design. In Amaresh Chakrabarti, Debkumar Chakrabarti (Eds.) Proceedings of the 6th International Conference on Research into Design (ICoRD'17). Research into Design for Communities, vol. 2. 2 volumes: Springer, pp. 617–627.

Carro Saavedra, C.; Ocon Galilea, A.; Lindemann, U. (2017). Increasing knowledge seeking initiation based on theories of human behavior. Proceedings of the Design Management Academy Conference 2017, 7-9 June, Hong Kong, China.

Carro Saavedra, C.; Morales Quiles, J.; Lindemann, U. (2017). Characteristics of Design Situations Influencing the Knowledge to Reuse. R&D Management Conference 2017. 1-5 July, Leuven, Belgium.

Carro Saavedra, C.; Lindemann, U. (2017). k-MORE – A Methodology to Manage Documented Knowledge for Reuse. In Anja Maier, Stanko Škec, Harrison Kim, Michael Kokkolaras, Josef Oehmen, Georges Fadel et al. (Eds.) 21st International Conference on Engineering Design (ICED17), pp. 151–160.

LIST OF STUDENT PROJECTS

The following student projects were created in the context of this dissertation project. The author of this work in her role as supervisor defined the tasks and scope of these student projects and gave continuous input to the students. In frequent meetings, the methodology, objectives and results were discussed and coordinated. These projects in chronological order are:

Fernandez Miguel, R. (2015). Knowledge Management in New Product Development - Analysis of the Factors Influencing the Success in Real Praxis (Master Thesis). Technical University of Munich, München.

Salas de Arriba, G. (2015). Developing a Knowledge Basis to Support Junior Developers (Master Thesis). Technical University of Munich, München.

Querol Angresola, R. (2015). Knowledge Visualization - Comparative Analysis of Visualization Techniques (Master Thesis). Technical University of Munich, München.

Egea Sancho, V. (2015). User Centered Analysis of Knowledge Reuse in Engineering Design (Master Thesis). Technical University of Munich, München.

Gomez Durban, C. (2015). Development and Selection of Scenario-based Knowledge Strategies (Master Thesis). Technical University of Munich, München.

Morales Quiles, J. (2016). Characterising Situations of Knowledge Reuse during the Engineering Design Process (Master Thesis). Technical University of Munich, München.

Serrano Villodres, T. (2016). Review and Classification of Types of Knowledge in Engineering Design (Master Thesis). Technical University of Munich, München.

Alcalde Garcia, X. M. (2016). Development of an Approach to Determine the Knowledge to Be Reused in Design Situations Using Artificial Intelligence (Master Thesis). Technical University of Munich, München.

Montesa Rausell, P. (2016). Development of a Knowledge Base for the Development Project "Innovative Concepts for the MINI Interior" (Master Thesis). Technical University of Munich, München.

Ocon Galilea, A. (2016). Understanding How Psychological Aspects of Individuals Influence the Knowledge Reuse During Engineering Design (Master Thesis). Technical University of Munich, München.

Diebold, T. (2016). Wissensmanagement: Wissensdokumentation, -wiedernutzung und konzeptionelle Gestaltung der Wissensbasis bei ARRI (Master Thesis). Technical University of Munich, München.

Cakir, I. (2017). Further Development of a Methodology to Manage Documented Knowledge for Reuse (Master Thesis). Technical University of Munich, München.

Aira Palomares, J. L. (2017). Development of a Knowledge Base for Knowledge Reuse in Design Projects - Design of the MVG eTrike (Master Thesis). Technical University of Munich, München.

Garcia Mate, L. (2017). Plan for the Integration of Employees in the Implementation of Knowledge Reuse in Industrial Context (Master Thesis). Technical University of Munich, München

Plieger, L. (2017). Evaluation of the *k*-MORE proposals for Knowledge Reuse in Design Projects - Design of the MVG eTrike (Semester Thesis). Technical University of Munich, München.

Beul, M. (2018). Analyse der Wissensverwendung im Rahmen des Entwicklungsprozesses von SCHÜCO (Semester Thesis). Technical University of Munich, München.

Lucas, L. (2018). Wissenserfassung, -darstellung und -analyse im Rahmen des Produktentwicklungsprozesses von SCHÜCO (Master Thesis). Technical University of Munich, München.

TABLE OF CONTENTS

1. Introduction

"If only we knew what we know" (O'Dell and Grayson 1998)

This Chapter presents the introduction of this thesis. Section 1.1 depicts the initial situation and Section 1.2 the problem description. Based on those, the thesis objective and research questions are defined in Section 1.3. Section 1.4 describes the research methodology that was followed to answer the research questions and fulfil the objective of the thesis. The Chapter concludes presenting an overview of the thesis structure in Section 1.5.

1.1 Initial Situation

The importance of **knowledge** as an industrial **resource** has been increasing in the last decades. Three driving forces cause this effect in the modern worldwide industry: structural change, globalisation and information and communication technologies (ICT) (North and Kumta 2014, p. 3).

The structural change in industry is reflected in the substitution of labour and capital-intensive activities for information and knowledge-intensive activities. On the one hand, companies increasingly require information and knowledge to work, and on the other hand they increasingly sell information and knowledge as well. Thus, the situation has reached the point in which knowledge is considered the company's most valuable resource (Zack 1999a). Compared to other resources, knowledge is a resource with special characteristics (Dalkir 2005, p. 2). First of all, knowledge is abundant, but the ability to use it is scarce. Knowledge is not consumed when it is used and transferring it does not result in losing it. Last but not least, much of a company's valuable knowledge walks out the door at the end of the day.

Globalisation has changed the labour distribution which is now internationally spread. Multi-functional Integrated Product Teams including members working for different companies and with different nationalities are becoming the norm (McMahon et al. 2004, p. 308). This results in increased long-distance knowledge communication and faster learning processes that take place simultaneously around the world.

ICTs are the enabler in this global context by connecting people easily at low cost and by bringing worldwide information and knowledge transparency. Consequences of the extended implementation of ICTs are faster market changes, more product innovation, price reductions, shorter product lifecycles and highly customised products (North and Kumta 2014, p. 3).

The complexity of a worldwide industry with the abovementioned characteristics increases the risk of organisational forgetting and reinventing the wheel. This leads to inefficiencies in company's use of time and costs (Oshri 2006, p. 488). Especially engineering companies require strategies to **systematically reuse** their large and widely spread knowledge resources in order to reduce time and cost of product development, to increase product quality and to become more innovative (Vijaykumar and Chakrabarti 2008, p. 1).

As a result, **knowledge management** emerged as a recognisable discipline by the mid-to late 1990s with the aim to provide concepts and methods in order to manage knowledge in organisations (Probst et al. 2012, p. 11). A new discipline was required given the special characteristics of knowledge as a resource.

1.2 Problem Description

The existence of the discipline of knowledge management with extensive literature makes researchers believe that most questions regarding knowledge management have been answered. However, practitioners still see the **need** of developing **applicable knowledge management methodologies** (Schacht and Maedche 2016).

A characteristic of knowledge management initiatives in practice is aiming at many goals at the same time such as improving knowledge transparency, improving knowledge access, improving knowledge documentation, improving knowledge retention or improving knowledge sharing (Maier and Remus 2002, p. 104). This drives knowledge management initiatives into very broadly and vaguely defined projects and it can lead to low efficiency due to the **lack of focus** (Maier and Remus 2002, p. 104). Companies have to make sure that they tighten their efforts to high-priority objectives and concrete goals so they "do not invest in knowledge management just for knowledge management's sake" (Goncalves 2012, p. 8).

One way of increasing knowledge management focus is establishing the concrete goal of achieving systematic reuse of value-added company's knowledge resources. This is achieved by performing the knowledge management processes defined in the knowledge reuse cycle: *capturing and documenting* knowledge, *packaging* knowledge for reuse, *distributing* knowledge and *reusing* knowledge (Markus 2001). Literature offers numerous methods to perform individual phases of the knowledge reuse cycle like e.g. storytelling for knowledge capturing (Williams 2008, p. 253) or knowledge repositories for knowledge packaging (Milton 2010, p. 103). Approaches to support reuse of specific types of knowledge such as best practices (Dani et al. 2006), service knowledge (Vianello 2011) or PSS knowledge (Schenkl 2015) have also been proposed. However, **knowledge reuse** is **not** a **common** practice in engineering companies (Milton 2010; Lauer 2010; Chandrasegaran et al. 2013; Vijaykumar and Chakrabarti 2013; Schacht and Maedche 2016). An integrated approach to plan the knowledge reuse cycle for all kinds of company's initial situations seems necessary in order to increase knowledge reuse in practice.

Various authors from literature suggest reasons for the lack of knowledge reuse presence in industry. Vijaykumar and Chakrabarti (2008) say that the reason might be the lack of understanding of the knowledge needs of engineering designers. Lauer (2010) points to the lack of target-oriented knowledge supply. Schacht and Maedche (2016) see the problem in the lack of consideration of individuals' behaviour to design a knowledge management strategy. Schacht and Maedche (2016) also point out that most approaches to support knowledge reuse do not really involve the reusing stage. It seems that the **reasons** for the **lack of knowledge reuse** in industry might be various and they are still **unclear** within the research community.

Achieving knowledge reuse is more **challenging** in **engineering design** than in other fields. The reasons are the long lifecycles of many engineering projects and the high level of

expertise involved (Carey et al. 2012). Knowledge reuse systems and methods have to operate with data in different formats, operate with decentralised data storages, be integrated in the development process, support overall knowledge transparency and support traceability of information and evolution of history of design (Heisig et al. 2010, p. 527; Carey et al. 2012). The use of inadequate tools in this context or the lack of standards can be reasons for failure in reusing knowledge in engineering design practice (Chandrasegaran et al. 2013, p. 231). Vijaykumar and Chakrabarti (2013, p. 786) talk about a "technology push" that tends to implement knowledge reuse tools in engineering design companies without an adequate understanding of the knowledge processes in each company. This leads to low acceptance rates and failure of knowledge reuse initiatives. Furthermore, both personalisation and codification approaches for knowledge reuse are relevant in engineering design practice. Codification strategies emphasise in the collection and structuring of documented knowledge while personalisation strategies emphasise in human resources and oral knowledge communication within the organisation (McMahon et al. 2004, p. 307). Due to the creative nature of engineering design and the importance of sharing design rationale, engineers primarily retrieve information by talking to co-workers (Heisig et al. 2010, p. 527). Adopting a perspective which combines both knowledge codification and personalisation is not common, but it seems necessary to achieve knowledge reuse in real industrial environments (McMahon et al. 2004, p. 318)

1.3 **Objectives**

The objective of this thesis is **improving theoretical understanding** and **developing practical support** to increase **knowledge reuse** in engineering design companies. This objective is established based on the assumption that reusing knowledge during product design implies higher product quality and doing it systematically reduces time and costs during the design process.

In order to improve theoretical understanding of the phenomenon of knowledge reuse in industrial practice, two Research Questions (RQ) are formulated and investigated:

- RQ1: What are the reasons for the lack of knowledge reuse in industry?
- RQ2: What are the individual influencing factors for knowledge reuse?

RQ1 aims at understanding the reasons for the lack of knowledge reuse in industry, especially in engineering design companies. Current literature discusses several reasons that can be hardly all addressed at the same time. The goal of RQ1 is identifying which ones represent a priority and therefore should be considered as basis to design adequate support for knowledge reuse in practice.

RQ2 aims at understanding the individual factors influencing knowledge reuse. Knowledge is an abstract and subjective concept and every person possesses a different interpretation for it. This subjective perception influences designers' acceptance of methods and tools supporting knowledge reuse. However, there has been a lack of consideration of individuals' behaviour to develop knowledge reuse approaches and knowledge management strategies in general (Schacht and Maedche 2016). The answer of RQ2 should fill this research gap.

In order to develop **practical support**, the improved theoretical understanding provided by the answers of RQ1 and RQ2 is used. The proposed support is a methodology to plan the knowledge reuse cycle in engineering design companies from scratch and which is combining both personalisation and codification approaches for knowledge reuse: the *k*-MORE methodology. The goal of this thesis is conceptualising, elaborating and evaluating the *k*-MORE methodology.

1.4 Research Methodology

This research work is based on the **Design Research Methodology** (DRM) (Blessing and Chakrabarti 2009). DRM is an approach and a set of supporting methods and guidelines to be used as a framework for engineering and industrial design research. DRM consists of four stages: Research Clarification, Descriptive Study I, Prescriptive Study and Descriptive Study II. The stages and methods are not to be executed rigidly and linearly. Iterations take place to increase understanding and stages are executed in parallel to increase the efficiency of the process. There are different possible research configurations for the DRM depending on the state-of-the-art of a particular stage. If the state-of-the-art offers extensive information, a review-based study (based only on the review of literature) is sufficient for the stage. If the state-of-the-art is considered to be incomplete, the DRM stage requires a comprehensive study including literature review but also the incorporation of results produced by the researcher such as empirical studies, development of support or support evaluation.

Figure 1-1 presents an overview of the research methodology of this thesis including the type, basic means and main outcomes for each stage of the DRM.

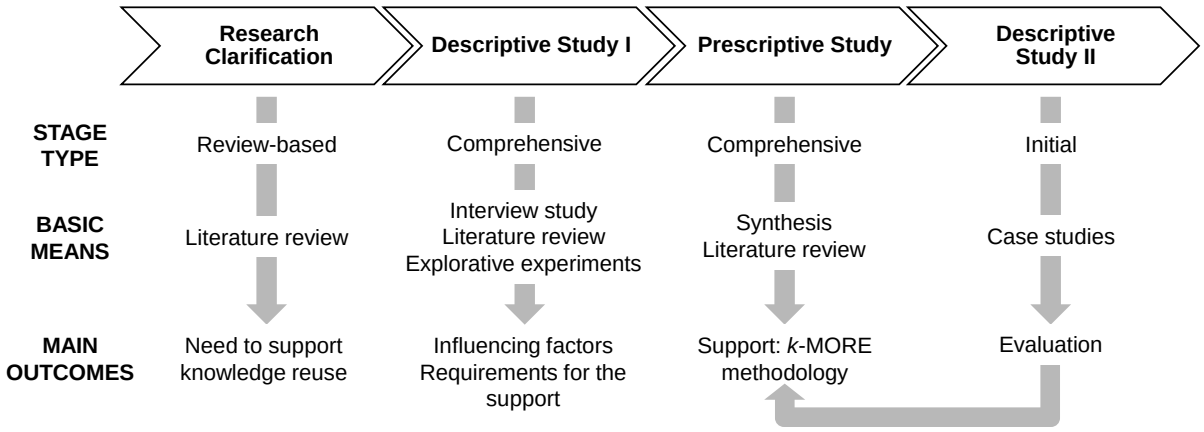


Figure 1-1: Research methodology of this thesis based on the DRM of Blessing and Chakrabarti (2009)

The first stage of the DRM is the **Research Clarification** (RC). RC aims at identifying and refining a research problem that is both academically and practically worthwhile and realistic. This thesis conducted a review-based RC reviewing literature on the topics of knowledge management and knowledge reuse, and how those are applied to the field of engineering design. As result of this stage the research gap was identified; the need to support knowledge reuse in practice for engineering design companies.

The second stage of the DRM is the **Descriptive Study I** (DS I). DS I aims at gaining understanding of the topic of interest and of the factors that determine its success. This thesis conducted a comprehensive DS I because the RC revealed a lack in understanding the reasons leading to low knowledge reuse in practice. Therefore, further research was required. The DS I of this work included an interview study involving engineers of engineering design companies, a systematic literature review and two explorative design experiments. As result of this stage the requirements for the support were determined and the main influencing factors for knowledge reuse were identified and represented in a model depicting the knowledge processes for individuals.

The third stage of the DRM is the **Prescriptive Study** (PS). PS aims at developing support to achieve a desired situation. In the case of this thesis the desired situation is increasing knowledge reuse in engineering design companies. The *k*-MORE methodology was developed to plan the knowledge reuse cycle in engineering design companies and thus, increase knowledge reuse. The development of the methodology followed the procedure of Blessing and Chakrabarti (2009, pp. 141–180). The conceptualisation of the methodology is based on a synthesis of the understanding gained from RC and DS I. Further literature review was conducted for the elaboration of some specific parts.

The fourth stage of the DRM is the **Descriptive Study II** (DS II). DS II aims at evaluating the application and impact of the support that has been developed in the PS stage. This thesis used five case studies to conduct an initial DS II. Parts of the *k*-MORE methodology were tested in three case studies that provided feedback to the PS stage. The other two case studies served in evaluating the final support.

1.5 Structure of the Thesis

The main content of this thesis is structured in seven chapters. Figure 1-2 presents an overview of the structure.

Chapter 1 presents the initial situation (Section 1.1), problem description (Section 1.2), objectives (Section 1.3), research methodology (Section 1.4) and structure of the thesis (Section 1.5).

The review-based RC is presented in **Chapter 2.** First, the state of the art is presented. Main terms, models and strategies for knowledge management are introduced in Section 2.1. The topic of knowledge reuse is first generally addressed (Section 2.2) and then its application to the field of engineering design is presented (Section 2.3). Approaches, benefits and challenges for knowledge reuse are discussed in both sections. Chapter 2 concludes in Section 2.4 with the identification of the research gap (Subsection 2.4.1) and the definition of key terms for the thesis (Subsection 2.4.2).

Chapter 3 presents the comprehensive DS I. After the presentation of the research plan in Section 3.1, various methods are applied to increase the understanding of the phenomenon of knowledge reuse. Section 3.2 shows the interviews conducted to identify current industrial practices for knowledge management and needs for knowledge reuse in practice. Section 3.3 presents a systematic literature review of individual influencing factors for knowledge reuse.

Two exploratory design experiments with students provide insights on the individual barriers for knowledge reuse out of industrial contexts (Section 3.4).

The PS is conducted in **Chapter 4.** The development of support starts in Section 4.1 with the task clarification which includes the definition of requirements for the support based on the results of the DS I. The conceptualisation of support as a methodology to plan the knowledge reuse cycle, the *k*-MORE methodology, is conducted in Section 4.2. Then, the elaboration (Section 4.3.) consists of a review of the literature to identify ideas and available means to perform some parts of the methodology. Section 4.4 presents the realisation of the *k*-MORE methodology including the detailed procedures and methods of each step.

Chapter 5 presents the DS II, the evaluation of the *k*-MORE methodology. After the presentation of the evaluation plan (Section 5.1) and the implementation means (Section 5.2), five case studies are presented. The case studies show the application of different parts of the methodology at different stages of development on engineering design companies. Three case studies (Sections 5.3, 5.4 and 5.5) were part of the support evaluation. Two case studies (Sections 5.6 and 5.7) were conducted for the application and success evaluation. Chapter 5 concludes in Section 5.8 reflecting the fulfilment of requirements of the proposed support.

Chapter 6 presents the discussion of the methodological procedure (Section 6.1) and the thesis results (Section 6.2). The discussion of results includes the research and industrial contributions as well as the limitations of the proposed support.

Chapter 7 concludes the main content of the thesis with the summary in Section 7.1 and the outlook deriving needs for further research in Section 7.2.

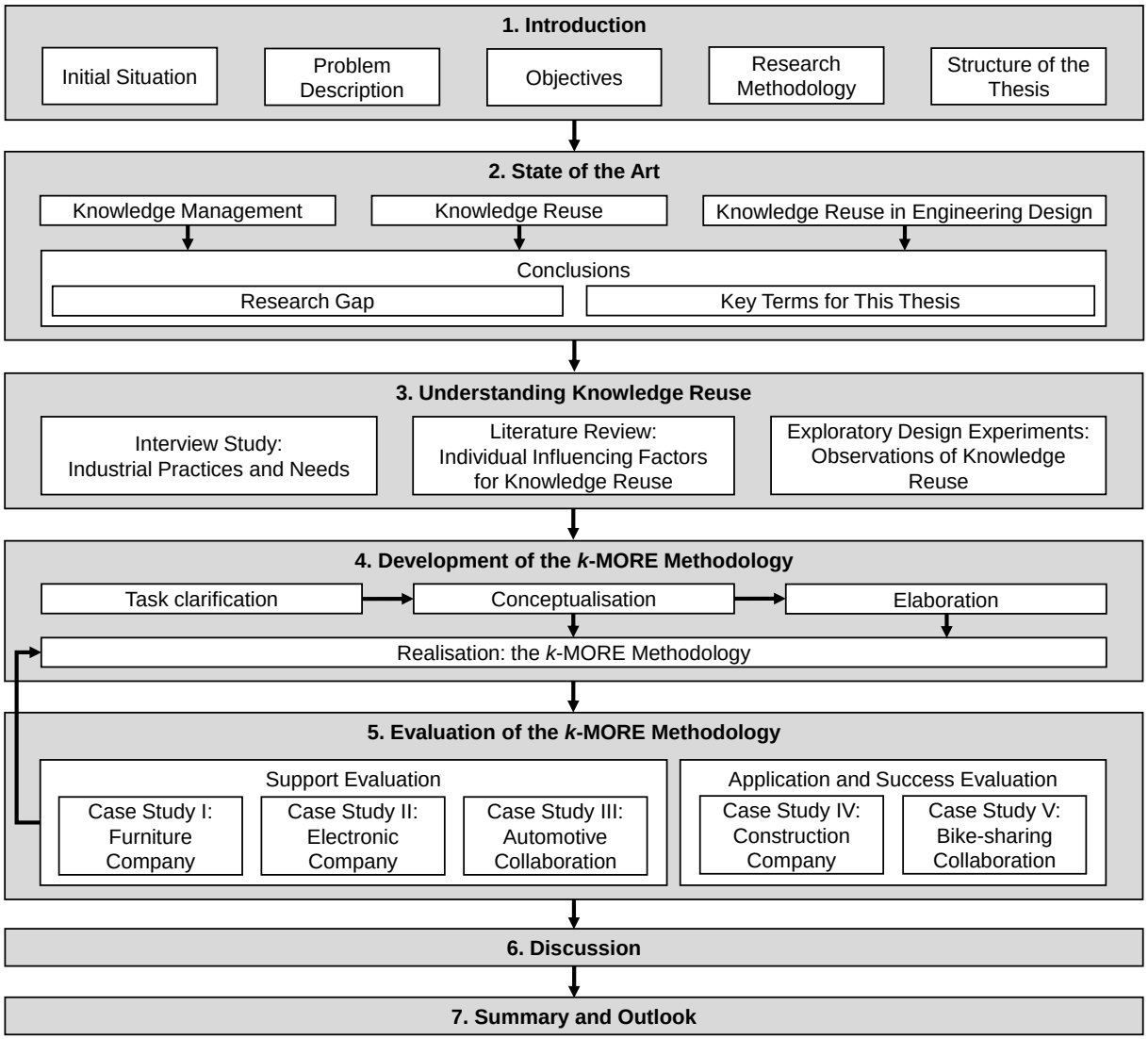


Figure 1-2: Structure of the thesis

2. State of the Art

This Chapter presents the Research Clarification. First, the state of the art is described. This is necessary to establish a theoretical background for the reader and to understand the current research gap. The discipline of knowledge management is presented in Section 2.1. Section 2.2 presents the fundamentals of knowledge reuse. Section 2.3 describes the particularities of knowledge reuse in the context of engineering design. The Chapter concludes in Section 2.4 with a discussion of the state of the art and the identified research gap as well as a definition of terms for this thesis.

2.1 Knowledge Management

Knowledge management is a discipline which provides an overview of concepts and methods to manage knowledge in organisations (Probst et al. 2012, p. 11). The **goal** of knowledge management is "to provide each and every decision-maker in all decision relevant areas with the right knowledge (according to his/her level of expertise) in the right form and quality, and at the right time and place" (Bodrow 2006, p. 46). Knowledge management is **necessary** due to the high complexity of knowledge in companies, which resides fragmented, is difficult to locate and share, is redundant, inconsistent and therefore is not applicable if it is not properly managed (Zack 1999b). "Knowledge management plays a critical role in efficiency, competitiveness and productivity of organisations" (Manohar Singh and Gupta 2014, p. 777).

According to Dalkir (2005, p. 3), a good **definition of knowledge management** should combine the perspective of capturing and storing knowledge with the perspective of valuing intellectual assets:

"Knowledge management is the deliberate and systematic coordination of an organisation's people, technology, processes, and organisational structure in order to add value through reuse and innovation. This coordination is achieved through creating, sharing, and applying knowledge as well as through feeding the valuable lessons learned and best practices into corporate memory in order to foster continued organisational learning"

(Dalkir 2005, p. 3)

According to the previous definition, organisational learning is seen as the result of knowledge management. Organisational learning occurs when an organisation achieves what it intended but also when a mismatch between intentions and outcomes is identified and corrected (Argyris 1992, p. 8). Individuals acting as agents of organisations are the ones performing the actions that lead to learning. By means of knowledge management organisations can "create conditions that may significantly influence what individuals frame as the problem, design as a solution and produce as action to solve a problem" (Argyris 1992, p. 8). Thus, knowledge management processes support organisations embedding knowledge in their practices to achieve their continuous improvement and therefore learning constantly (King 2009, p. 5).

Dalkir (2005) identified in literature over 100 definitions of knowledge management from which he considered very good at least 72 of them. The reason for this variety of definitions is

that knowledge management is a highly **multidisciplinary** field. Those are just some of the disciplines contributing to knowledge management: organisational science, cognitive science, linguistics and computational linguistics, information technologies, psychology, sociology, education and training, storytelling and communication studies, collaborative technologies and legal science (Dalkir 2005, p. 6; Lehner 2012, p. 117). Another reason for the multitude of definitions is that knowledge management can be seen from **different perspectives**, which lead to different goals and definitions. This aspect will be discussed in Subsection 2.1.4.

Knowledge management has been traditionally focused on managing knowledge that is recognised and articulated in some form. This can be knowledge about procedures, processes, documented best practices, lessons learned, intellectual property, forecasts, and solutions to recurring problems (Becerra-Fernandez and Sabherwal 2014, p. 5). However, during the last years the focus of knowledge management has been shifting and it increasingly includes the management of important knowledge which so far may had only been in the minds of organisations' experts (Becerra-Fernandez and Sabherwal 2014, p. 5).

The following Subsections describe relevant terms and concepts for knowledge management. Subsection 2.1.1 discusses the definitions and relations of the terms knowledge, information and data. Subsection 2.1.2 presents different types of knowledge. Well-established knowledge management models describing the processes involved in knowledge management are presented in Subsection 2.1.3. Finally, different strategies and perspectives on knowledge management are discussed in Subsection 2.1.4.

2.1.1 Knowledge, Information and Data

The terms knowledge, information and data appear constantly in knowledge management literature. The hierarchical relation between those terms is usually represented by the **"Knowledge Pyramid"** (Ackoff 1989), which is presented in Figure 2-1. Data, which is placed on the bottom of the pyramid, can be used to create information, and information can be used to create knowledge. Thus, the higher levels of the pyramid include the categories below them.

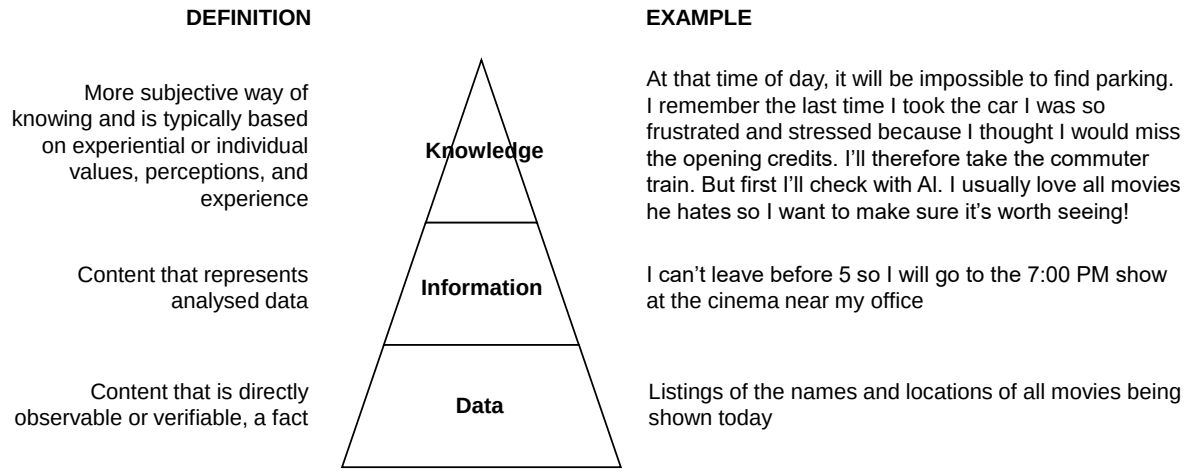


Figure 2-1: Knowledge Pyramid with definitions and examples from Dalkir (2005, p. 7)

Dalkir (2005, p. 7) defines **data** as "content that is directly observable or verifiable, a fact". Taking as an illustrative example the situation in which someone is deciding to go to the cinema, he suggests that "listings of the names and locations of all movies being shown today" are examples of data. **Information** is for Dalkir (2005, p. 7) "content that represents analysed data". Following the previous example, information would be for him "I can't leave before 5 so I will go to the 7:00 PM show at the cinema near my office." **Knowledge** is a "more subjective way of knowing and is typically based on experiential or individual values, perceptions, and experience" (Dalkir 2005, p. 7). This could be the corresponding knowledge to the example: "at that time of day, it will be impossible to find parking. I remember the last time I took the car I was so frustrated and stressed because I thought I would miss the opening credits. I'll therefore take the commuter train. But first I'll check with Al. I usually love all movies he hates so I want to make sure it's worth seeing!" (Dalkir 2005, p. 7).

Definitions of data, information and knowledge provided by the most recognised authors in the field of knowledge management are presented in Appendix 9.2. Their definitions of the terms are similar, especially in the cases of data and information. In the case of knowledge, different views on the possibility of codifying knowledge can be observed. When Davenport and Prusak (2000, p. 5) say "knowledge often becomes embedded not only in documents or repositories", they are assuming that knowledge can be in fact codified. However, Alavi and Leidner (2001, p. 109) say that "knowledge is information possessed in the mind of individuals", meaning that all that is written is not knowledge but information. Many authors share the view of knowledge as information combined with experience, interpretation and reflection (Nonaka 1994; Zack 1999b; Long and Fahley 2000; Alavi and Leidner 2001).

There are also numerous authors who do not try to strictly differentiate the terms. They do not address the definitions and they treat the terms indistinctly. This probably happens because the boundaries between data, information and knowledge in practice are not easy to define and therefore, their distinction in practice is rarely done (Wildner 2011, p. 237). Furthermore, managers are usually not overly concerned about the distinctions between the terms (Earl 2001, p. 218).

On the other hand, some authors even add more terms to the Knowledge Pyramid, in what is commonly called the "**Knowledge Ladder"** (North and Kumta 2014, p. 32). The Knowledge Ladder (see Figure 2-2) offers an organisational vision on the "levels of knowing". **Symbols** are the minimal unit of people's communication; these can be letters, signs or numbers. These symbols can be interpreted because of the rules established by the syntax, and thus they become data. The next steps of the ladder are **data**, **information** and **knowledge**, what corresponds to the popular Knowledge Pyramid. From knowledge, the ladder continuous with three steps more. Knowledge becomes **actions** through its application to problem solving. If the actions prove to be the right choice, this ability becomes a **competence**. Company's core competences which are unique and remarkably good in the market lead to the company's **competitiveness**, which is the final step in the Knowledge Ladder (North and Kumta 2014, pp. 32–35).

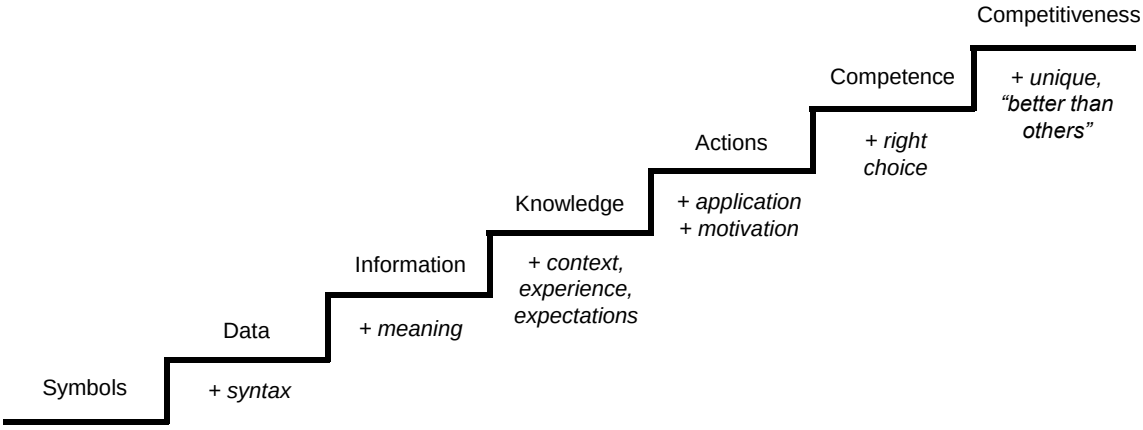


Figure 2-2: The Knowledge Ladder (adapted from North and Kumta (2014, p. 32))

2.1.2 Types of Knowledge

Polanyi (1966) was the first author who distinguished between two types of human knowledge: tacit and explicit. **Tacit** knowledge is „subconsciously understood and applied, difficult to articulate, developed from direct experience and action" (Zack 1999b, p. 46). The concept of tacit knowledge emerges from the observation that "we know more than we can tell" (Polanyi 1966, p. 4). In contrast, **explicit** knowledge is "more precisely and formally articulated" (Zack 1999b, p. 46). Whereas tacit knowledge is exchanged through "highly interactive conversation, storytelling and shared experience" (Zack 1999b, p. 46), explicit knowledge can be written down and communicated in "symbolic form and/or natural language" (Alavi and Leidner 2001, p. 110). Some authors introduced an intermediate status between explicit and tacit knowledge: the **implicit** knowledge (Li and Gao 2003; Frappaolo 2008). Implicit knowledge is the one that can be articulated but its articulation is challenging (Li and Gao 2003, p. 8). Thus, when the authors only distinguish between explicit and tacit, what they mean as "tacit" includes "implicit" (Li and Gao 2003, p. 8).

The distinction between tacit and explicit knowledge is probably the most present and is discussed in knowledge management literature. However, knowledge can be classified in various ways depending on the point of view. Zack (1999b) distinguishes between general and specific knowledge. **General** knowledge is „broad, often public available, and independent of particular events" (Zack 1999b, p. 46). It is recognised, spread and shared among different communities, and therefore it is usually codifiable. **Specific** knowledge is context-specific and it requires of precise descriptions of the context for its understanding (Zack 1999b, p. 46).

Depending on the kind of content of the knowledge, Zack (1999b) proposes the distinction between declarative knowledge, procedural knowledge and causal knowledge. **Declarative** knowledge is "about *describing* something" (Zack 1999b, p. 46). It can also be referred to as "know-about" (Alavi and Leidner 2001, p. 112). **Procedural** knowledge is „about *how*

something occurs or is performed" (Zack 1999b, p. 46). It is also the so called "know-how" (Alavi and Leidner 2001, p. 112). Finally, **causal** knowledge is "about *why* something occurs" (Zack 1999b, p. 46) or "know-why" (Alavi and Leidner 2001, p. 112). Alavi and Leidner (2001, p. 112) add two more types to the three defined by Zack (1999b); the **conditional** knowledge (know-when) and the **relational** knowledge (know-with).

Long and Fahley (2000) differentiate between human, social and structured knowledge. **Human** knowledge represents „what individuals know or know how to do […]. It is a manifested skill" (Long and Fahley 2000, p. 114). An example of human knowledge is knowing how to ride a bike. **Social** knowledge emerges in groups of individuals, in which "the collective knowledge is more than the sum of the individual knowledge" (Long and Fahley 2000, p. 114). Social knowledge is necessary to achieve a goal which is the result of working together in an effective collaboration. **Structured** knowledge is "knowledge embedded in an organisation's systems, processes, tools, and routines" (Long and Fahley 2000, p. 114). It is an organisational resource which can exist "independently of human knowers" (Long and Fahley 2000, p. 114).

Zack (1999a) suggests a classification on a company-strategic-level, in which he classifies knowledge as core, advanced and innovative. **Core** knowledge is the minimum knowledge required for a company to operate its business. It provides little advantage to competitors because it is "commonly held by members of an industry" (Zack 1999a). **Advanced** knowledge allows a company to stand out from its competitors through differentiation (Zack 1999a). **Innovative** knowledge is the knowledge that enables a company to be the leader of the industry. Being the leader, the company can differentiate from competitors and, in some cases, change the rules of the game (Markides 1998).

Summarising, knowledge can be classified according to various dimensions which can be complementary, i.e. the same piece of knowledge can be classified at the same time in more than one way (e.g. knowledge can be simultaneously explicit, general and declarative).

2.1.3 Knowledge Management Models

Knowledge management models represent the **processes** included in knowledge management, their **relations** and the relation with the **type of knowledge** to manage. Subsequently the most popular models from knowledge management literature are presented.

SECI Model

Nonaka and Takeuchi (1995) proposed a model depicting the processes of knowledge conversion in an organisation. The model is based on the assumption that "human knowledge is created and expanded through social interaction between tacit and explicit knowledge". The model presents four modes of knowledge conversion in an organisation:

1. **Socialisation**: from tacit knowledge to tacit knowledge
2. **Externalisation**: from tacit knowledge to explicit knowledge
3. **Combination**: from explicit knowledge to explicit knowledge

4. **Internalisation**: from explicit knowledge to tacit knowledge

This model is commonly known as the SECI model, which stands for the initials of the four processes described. Nonaka and Takeuchi (1995, p. 71) postulate that organisational knowledge creation is a continuous and dynamic interaction between tacit and explicit knowledge, which can be depicted in form of a spiral going through the four processes of the SECI model. First, socialisation takes place to share experiences and mental models. Second, externalisation is achieved in order to articulate hidden tacit knowledge. Third, combination takes place through "networking" and in the end, "learning by doing" triggers internalisation. The SECI model with the knowledge spiral is depicted in Figure 2-3.

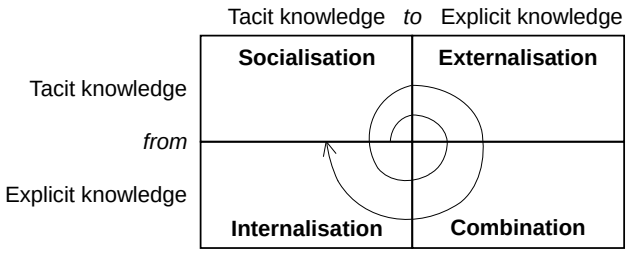


Figure 2-3: SECI model with knowledge spiral (Nonaka and Takeuchi 1995, p. 71)

Building Blocks of Knowledge Management

Probst et al. (2012) defined the "building blocks" of knowledge management. Their motivation to create this model was that they considered previous literature about knowledge management and organisational learning too abstract and they wanted a more specific way to structure learning problems in organisations.

The "building blocks" of knowledge management are six central knowledge processes and two additional processes necessary for practice-oriented knowledge management. Each process is associated to a question that companies should answer by applying the suitable methods. Figure 2-4 depicts the processes indicating with the arrows the logical implementation order. The implementation of one process could be individually considered, but it will in all cases imply consequences for the other processes.

The central processes and the questions described by Probst et al. (2012) are the following:

- Knowledge **identification** – how can the transparency of the internal and external available knowledge be achieved?
- Knowledge **acquisition** – how can external knowledge be acquired?
- Knowledge **development** – how can new knowledge be developed?
- Knowledge **distribution** – how can knowledge be delivered in the right place?
- Knowledge **usage** – how can the usage be assured?
- Knowledge **protection** – how can knowledge lost be avoided?

The two additional processes proposed by Probst et al. (2012) to extend the model in a dynamic practical environment are:

- Knowledge **goals** – how can a direction for the learning efforts be selected?
- Knowledge **evaluation** – how can the learning process be measured?

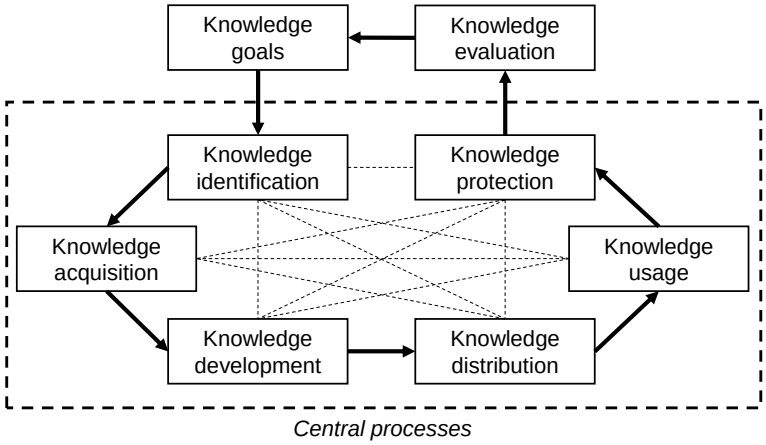


Figure 2-4: Processes of knowledge management (Probst et al. 2012)

Munich Knowledge Management Model

Reinmann-Rothmeier (2001) presented a model with four knowledge processes and two additional processes (see Figure 2-5). **Goals** definition is triggered by the problem/situation and it leads to the processes of knowledge **representation**, knowledge **generation** and knowledge **communication**, which take place in parallel. These three processes lead to knowledge **use**. The **evaluation** of the knowledge use closes the cycle and provides feedback to the first process of goals definition. The knowledge processes are under consideration of the personal (competences management) and the technical dimensions (information management).

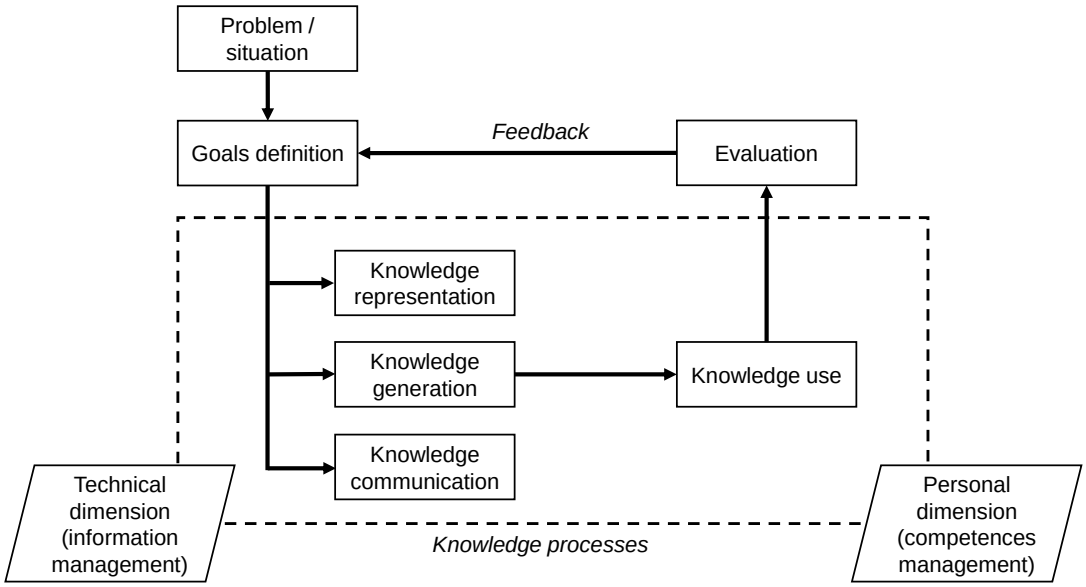


Figure 2-5: Munich Knowledge Management Model (adapted from Reinmann-Rothmeier (2001, p. 27))

Other Models

Many other researches have provided their view on the processes of knowledge management. However, no consensus was achieved in the interpretations and terms applied to the knowledge management processes, which leads to the lack of an established model. Schacht and Maedche (2016) collected the knowledge management processes described by Gold et al. (2001), Alavi and Leidner (2001), Markus (2001) and Szulanski (1996), which are presented in Figure 2-6. It can be observed that even though they consider the same number of processes (four), those are not always referring to the same activities or terms. One example of the inconsistent use of terms is the case of "application" and "reuse". What Gold et al. (2001) and Alavi and Leidner (2001) define as "application" is defined as "reuse" by Markus (2001). For Markus (2001) "application" is the last step in the phase reuse, which consists itself of four activities: 1) defining search question, 2) locating experts or expertise; 3) selecting an appropriate expert or expertise; and 4) applying the knowledge. Those are only some examples of the lack of consensus on the knowledge processes which can be observed in knowledge management literature.

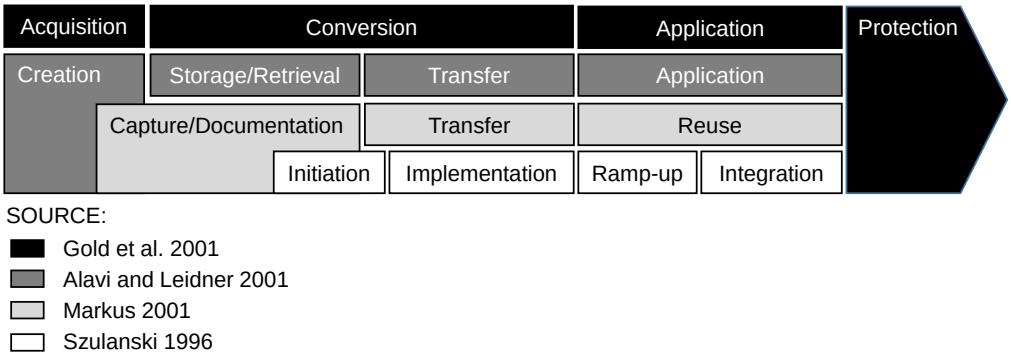


Figure 2-6: Knowledge management processes defined by several authors (Schacht and Maedche 2016, p. 21)

2.1.4 Knowledge Management Strategies

Knowledge management can be seen from different perspectives and each perspective suggests a different strategy for managing knowledge and a different use of methods and systems to support knowledge management (Alavi and Leidner 2001, p. 110).

One of the most popular differentiation is between the **codification** and **personalisation** strategies. Codification strategies emphasise in the collection and structuring documented knowledge while personalisation strategies emphasise in human resources and oral knowledge communication within the organisation (McMahon et al. 2004, p. 307). von Krogh (1998, p. 134) talks about the **cognitivist** perspective and **constructionist** perspective, which can be considered as equivalent to codification and personalisation respectively. The goal of cognitivists is to develop formal models of cognitive systems as a machine for logical reasoning and information processing. Knowledge is for them universal, explicit and easy to transmit to others. The constructionist perspective considers that knowledge is constructed and created instead of represented. For constructionists, knowledge is not universal, it is highly personal, not easily expressed, and not easy to share with others. Lehner (2012, p. 38) distinguishes between the **human-oriented** approach, the **technological** approach and the **integrative** approach. Lehner's human-oriented approach corresponds to the personalisation approach and his technological approach corresponds to the codification approach. He discusses that the technological approach is often restricted to the use of Information Technology (IT) solutions such as Knowledge Management Systems (KMS) in supporting the various knowledge management processes. This strategy can be associated with the discipline of information management and the development of information systems as KMS are not technologically distinct from information system. However, KMS involve databases such as lessons learned repositories, directories and networks that require human activity to be operated (King 2009, p. 5). For example, a sales database requires people designing and structuring it but in its operational phase, it works automatically. On the contrary, a lessons learned database always requires people assessing and selecting the lessons learned relevance and importance in different situations (King 2009, p. 5). Lehner (2012) points out that the

tendency in knowledge management is evolving towards combining both the human-oriented and the technological approach in a unique knowledge management concept, which constitutes the integrative approach.

Alavi and Leidner (2001, p. 110) argue that the different strategies derive from different considerations of what is knowledge and they present five different perspectives. If knowledge is seen as a **state of mind**, the knowledge management strategy focuses on enabling individuals to expand their personal knowledge and to apply it to the organisation's needs. If knowledge is seen as an **object**, the strategy is to store it and manipulate it. Knowledge can be also seen as a **process**. In this case, the focus of the knowledge management strategy would be on how to apply expertise. The fourth view of knowledge is as an **access to information**. The strategy in this case would be organising knowledge to facilitate access to and retrieval of content. Finally, knowledge can be also seen as a **capability**, or the capacity to use information.

North and Kumta (2014, p. 39) proposed different "maturity levels" for knowledge management in organisations depending on what is managed from the Knowledge Ladder, as it is shown in Figure 2-7. They propose four levels: 1) **IT solutions**, 2) **specific individual solutions**, 3) **professional knowledge organisation**, and 4) **knowledge-based management** of company.

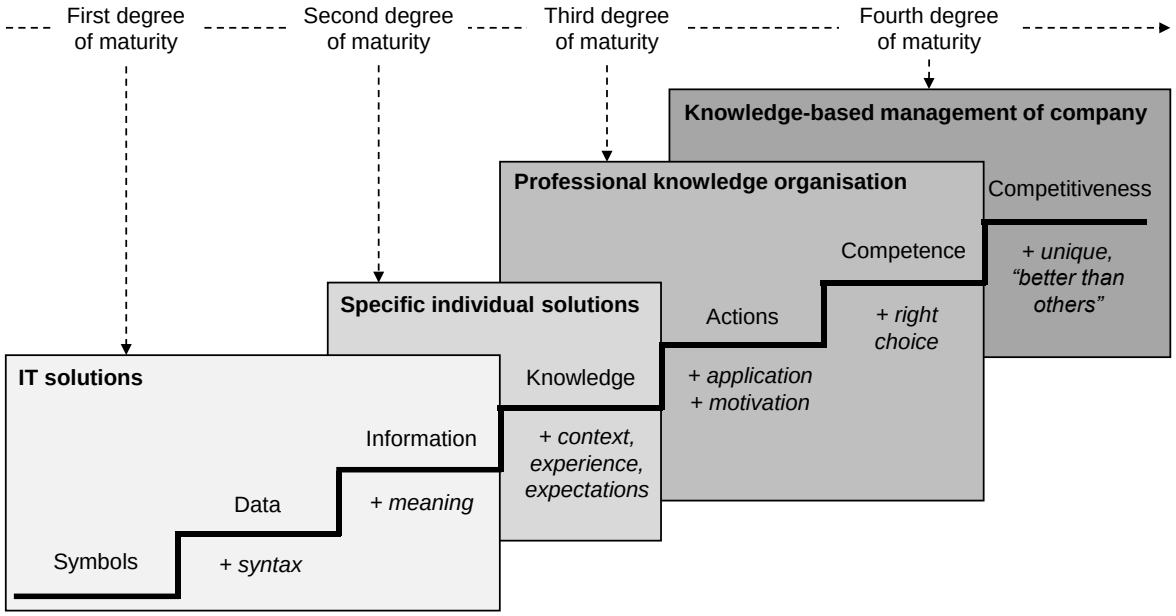


Figure 2-7: Degrees of maturity of knowledge-based management of a company (adapted from North and Kumta (2014, p. 39))

North and Kumta (2014, p. 38) also deduced three fields of action from the Knowledge Ladder. The **strategic knowledge management** focuses on identifying the required competencies for the company to be competitive and on developing motivational and organisational structures and processes to establish those competencies. The **operative**

knowledge management involves interconnecting information, know-how and actions in order to transfer tacit individual knowledge to explicit collective knowledge and vice versa. The last field, **information and data management (digitalisation)** pursues the supply, storage and distribution of information, which are prerequisites for creating and transferring knowledge, but cannot be used optimally without adequate motivational and organisational conditions.

Reinmann-Rothmeier and Mandl (1998) presented the three pillars in which a knowledge management strategy can focus in practice, as it is depicted in Figure 2-8. **Technology** involves the technical aspects of information and communication. **Organisation** involves structural and process-related aspects and **people** involves the psychological, mental and cultural aspects.

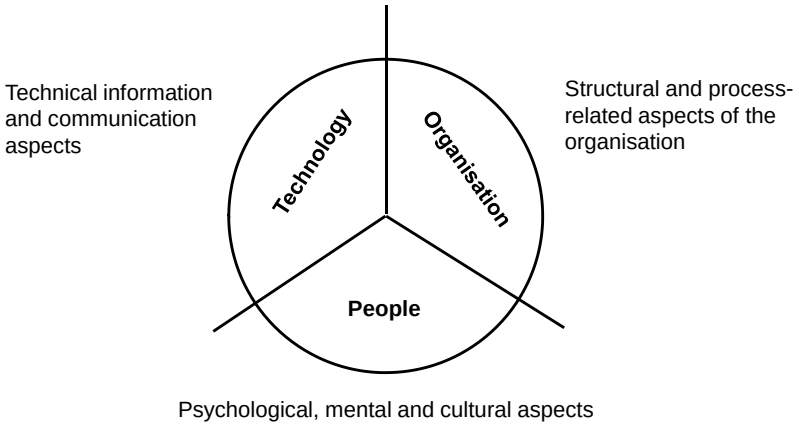


Figure 2-8: Pillars of knowledge management in practice (adapted from Reinmann-Rothmeier and Mandl (1998, p. 13))

Another way of differentiating knowledge management strategies is depending on the origin of the knowledge to be managed. Lehner (2012, p. 44) distinguishes between **internal learning**, which establishes the focus of knowledge management on the generation of knowledge inside the organisation, and **external learning**, which has the objective of obtaining knowledge from sources external to the company. External learning can be seen as Open Innovation (OI).

2.2 Knowledge Reuse

The term knowledge reuse can be interpreted in two different ways. The first interpretation is equivalent to the process of **"knowledge usage"** which is included in the building blocks of knowledge management defined by Probst et al. (2012). This process refers to the specific moment in which an individual performs reuse. Markus (2001) describes this moment as a four-step process which starts by defining a search question and finishes by applying the knowledge. Fruchter and Demian (2002) differentiate between internal and external knowledge reuse. Internal reuse relays on personal memories and own experiences acting as

repository of knowledge. On the contrary, external reuse occurs when the knowledge is obtained from an external source.

The second interpretation of the term considers that knowledge reuse refers to the **complete knowledge cycle**, i.e. to all the knowledge management processes required to end up reusing knowledge. This paradox can be observed in Markus (2001), since she describes a knowledge reuse cycle of four phases, in which one of the phases is called reusing (see Figure 2-9 in Subsection 2.2.1).

The following Subsections describe relevant concepts for knowledge reuse. Subsection 2.2.1 presents the knowledge reuse cycle and its phases. Approaches to implement knowledge reuse are presented in Subsection 2.2.2. The Section concludes in Subsection 2.2.3 with a discussion of the benefits and challenges of reusing knowledge for companies.

2.2.1 The Knowledge Reuse Cycle

Markus (2001) created the foundations of a theory for knowledge reusability, which includes the knowledge reuse cycle. The knowledge reuse cycle proposed by Markus is presented in Figure 2-9 and it consists of four phases: *capturing and documenting* knowledge, *packaging* knowledge for reuse, *distributing* knowledge and *reusing* knowledge.

Capturing and documenting knowledge can take place in at least four different ways: 1) documentation as a passive by-product of the work; 2) using facilitators such as brainstorming techniques which can be supported by electronic means 3) creating (pre)structured records 4) deliberate filtering, indexing, packaging, and sanitising of knowledge for its later reuse.

Packaging knowledge consists of culling, cleaning, structuring, formatting or indexing documents within a classification scheme. Adding significant context and deleting trivial information in order to avoid information overload are also activities involved in knowledge packaging.

Distributing knowledge can be passive (e.g. inform about a filled repository, publish a newsletter) or active (e.g. “After Action Review” meeting, knowledge push via electronic alerts). Facilitation activities to promote the understanding of the importance of reuse or to develop communities for knowledge transfer are also activities included in knowledge distribution.

Reusing knowledge consists of a four-step process, which is presented together with the knowledge reuse cycle in Figure 2-9. The process starts first by defining a search question, then by locating experts or expertise, it continues by selecting an appropriate expert or expertise, and it finishes by applying the knowledge.

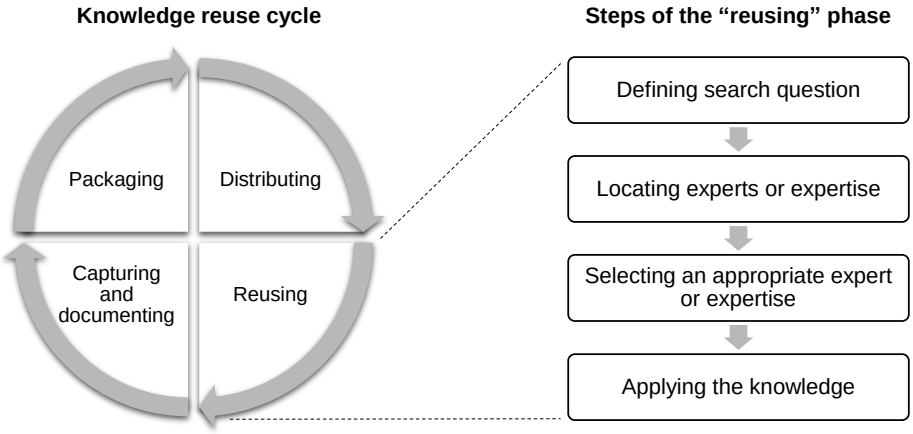


Figure 2-9: Knowledge reuse cycle (adapted from Markus (2001))

Markus (2001) defined three roles which actively participate in the knowledge reuse cycle. The **knowledge producer** is the originator and documenter of knowledge to begin with. The **knowledge intermediary** prepares knowledge for reuse through its elicitation, indexing, summary and package, and it is also on charge of facilitation and dissemination activities included in the distributing phase of the knowledge reuse cycle. The **knowledge consumer** is the knowledge reuser. The three roles can be performed by the same or different individual(s) or group(s), or by some combination of them.

Different combinations of the roles result in different types of knowledge reuse situations (Markus 2001). **Shared Work Producers** are those teams which work together and who are the producers of the knowledge they are going to reuse. **Shared Work Practitioners** are those people who are conducting similar works in different settings and who are the producers of each other's knowledge. **Expertise-Seeking Novices** are those people who occasionally need expert knowledge and therefore search for experts who can help them. **Secondary Knowledge Miners** are those people who develop new knowledge by analysing records produced by others.

Each one of the above-described reuse situations presents different challenges in order to conduct successfully the reusing phase of the knowledge reuse cycle. Markus (2001) analysed those challenges and proposed lists of recommendations for promoting successful reuse in each of the situations.

2.2.2 Approaches to Implement Knowledge Reuse

Literature offers some frameworks and methodologies for the definition of knowledge management strategies that should lead to the practical implementation of knowledge reuse in organisations.

Zack (1999a) proposed a theoretical **framework** for **describing** and **evaluating** an organisation's **knowledge strategy**. The framework aims at giving a strategic focus to

knowledge management claiming that knowledge management initiatives should be directed toward closing the strategic knowledge gap. He proposes to derive the knowledge gap (difference between "what firm knows" and "what firm must know") directly from the strategic gap (difference between "what firm can do" and "what firm must do") by means of a knowledge-based SWOT (strengths, weaknesses, opportunities, and threats) analysis. Based on this analysis the organisation must decide towards an explorative vs. exploitative orientation of internally vs. externally acquired knowledge sources.

Figure 2-10 shows the steps for **selecting a knowledge management strategy** proposed by Earl (2001) and Kamara et al. (2002). Earl (2001) formulated a six-steps framework starting in step 2 with the procedure proposed by Zack (1999a) to establish the Business Performance Gap. Step 3 aims to analyse how better acquisition, distribution, use or protection of knowledge could contribute to close the performance gap and thus create a knowledge business vision in step 1. Step 4 examines possible knowledge management initiatives. The feasibility in the implementation of the proposed initiatives is analysed in step 5. Finally, the allocation of resources and plan for execution of the knowledge management program is conducted in step 6. Kamara et al. (2002) defined four steps for implementing knowledge management in a company: 1) define knowledge management problem; 2) identify "to-be" solution; 3) identify critical migration paths; and 4) select appropriate knowledge management processes.

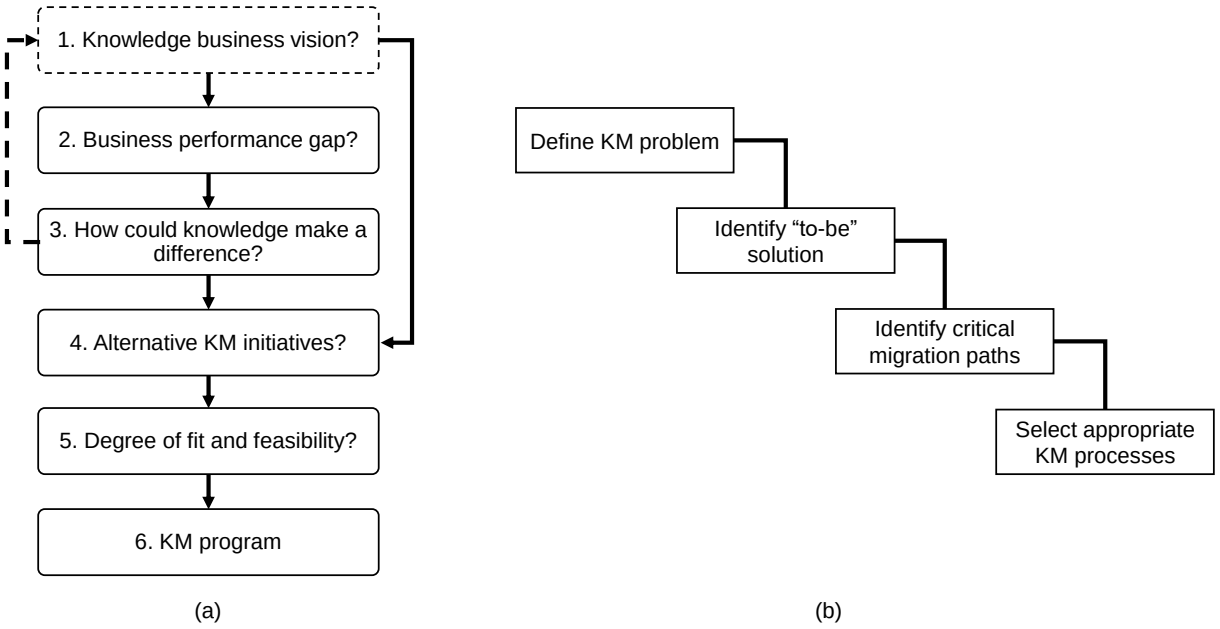


Figure 2-10: a) Formulating a knowledge management strategy (Earl 2001); b) Framework for selecting a knowledge management strategy (Kamara et al. 2002)

Rubenstein-Montano et al. (2001) created **SMARTVision**, a methodology addressing the entire knowledge management process which is "sufficiently detailed to explain how to actually "do" knowledge management" (Rubenstein-Montano et al. 2001, p. 307). The

methodology proposes five steps in a cycle and specific procedures (and subprocedures) for each phase.

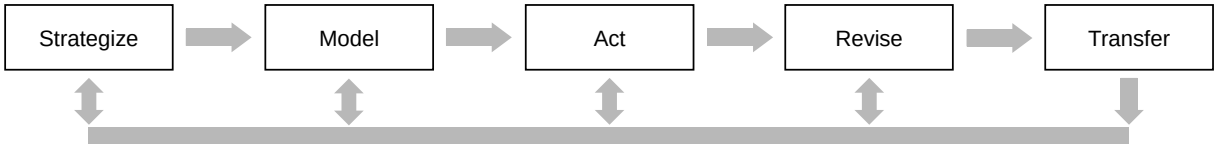


Figure 2-11: The SMARTVision knowledge management methodology (Rubenstein-Montano et al. 2001)

Knowledge audits are a well-established and applicable method of knowledge management which constitute the first step to develop a knowledge management strategy (Liebowitz et al. 2000, p. 3; Choy et al. 2004, p. 681; Burnett et al. 2004). Paramasivan (2003, p. 499) describes knowledge audit as a "fact-finding, analysis, interpretation, and reporting activity, which includes a study of the company's information and knowledge policies, its knowledge structure and knowledge flow". A typical knowledge audit includes the identification of the organisation's knowledge needs, knowledge assets or resources, existing knowledge gaps and current knowledge flows (Paramasivan 2003, p. 499). Basically, the knowledge audit corresponds to the initial activities of Kamara's framework (define knowledge management problem, identify "to-be" situation and identify critical migration paths) or of SMARTVision (strategize and model). Several knowledge analysing methods can be applied in a knowledge audit. Table 2-1 presents a selection of methods that are most commonly used.

Table 2-1: Analysing methods that could be used in a knowledge audit (adapted from Wiig (1995, pp. 117–119))

Analysing methods	**Use in a Knowledge Audit**
Questionnaire-based knowledge surveys	Used to obtain broad overviews of an operation's knowledge status
Middle management target group sessions	Used to identify knowledge-related conditions that warrant management attention
Task environment analysis	Used to understand, often in great detail, which knowledge is present and its role
Verbal protocol analysis	Used to identify knowledge elements, fragments, and atoms
Knowledge mapping	Used to develop concept maps as hierarchies or nets
Critical knowledge functions analysis	Used to locate knowledge-sensitive areas
Knowledge scripting and profiling	Used to identify details of knowledge intensive work and which role knowledge plays to deliver quality products
Knowledge flow analysis	Used to gain overview of knowledge exchanges, losses, or inputs of the task business processes or the whole enterprise

In order to facilitate the implementation of audits in practice, Sharma and Chowdhury (2007) developed a diagnostic tool to perform a knowledge audit in four steps: 1) knowledge needs analysis, 2) knowledge needs inventory analysis, 3) knowledge flow analysis, and 4) knowledge mapping. Sharma and Chowdhury (2007) propose templates and surveys to be used as diagnostic instrument. Perez Soltero et al. (2007) developed a methodology for knowledge auditing with emphasis on identifying and assessing only knowledge of the company's core processes. They claimed that previous methodologies attempt to audit everything, regardless of its significance for the organisation. The methodology of Perez Soltero et al. (2007) has ten steps: 1) acquire organisational strategic information and identify organisational processes, 2) identify organisation's core processes and establish measurement criteria, 3) prioritise and select organisation's core processes, 4) identify the key people, 5) meeting with key people, 6) obtaining knowledge inventory, 7) analysing knowledge flow, 8) knowledge mapping, 9) knowledge auditing reporting, and 10) continuous knowledge re-auditing. Perez Soltero et al. (2007) described the objective of each step, how to implement it and the support tools required.

The frameworks and methodologies described until now aim at implementing knowledge reuse from scratch, prioritising above all the analysis of the company and its situation. Other methodologies have been published aiming at reusing specific types of knowledge or reusing it in a predefined way. A representative selection of those is presented in the following paragraphs.

Dehghani and Ramsin (2015) conducted a review of methodologies for **developing of KMS**. A KMS is a "class of information systems applied to managing organisational knowledge. That is, they are IT-based systems developed to support and enhance the organisational processes of knowledge creation, storage/retrieval, transfer, and application" (Alavi and Leidner 2001, p. 114). Not all knowledge management initiatives include the implementation of IT but many of them rely on IT as an important enabler (Alavi and Leidner 2001, p. 114).

Dehghani and Ramsin (2015) selected seven methodologies for developing KMSs based on their prominence in the field, degree of innovation, concreteness and comprehensiveness and availability of adequate documentation. Among those, the methodology of Amine and Ahmed-Nacer (2011) will be described as a representative example. Amine and Ahmed-Nacer (2011) proposed an ontology-based agile methodology which is composed of a starting phase called initialisation and four other iterative phases: domain mapping, profiles and policies identification, implementation and personalisation, validation. The methodology is depicted in Figure 2-12.

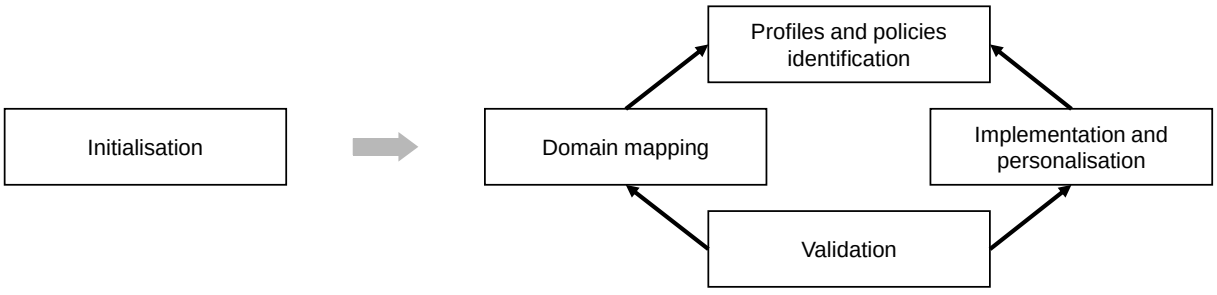


Figure 2-12: KMS implementation methodology (Amine and Ahmed-Nacer 2011, p. 162)

Some methodologies have been proposed to support the reuse of the particular type of knowledge defined as **lessons learned**. Lessons learned is a "change in personal or organisational behaviour as a result of learning from experience" (Milton 2010, p. 16). Milton (2010, p. 15) distinguishes between lessons and lessons learned. A lesson represents knowledge gained from experience that can help or impact the work of others. However, a lesson is not "learned" until something changes as a result, i.e. until the learning is implemented in practice. Following this reasoning, companies can differentiate between lessons identified and lessons learned. Chirumalla (2013) developed a methodology for lessons learned reuse consisting on a video-based seven-step representation of lessons learned: 1) lessons learned statement, 2) working context, 3) task description, 4) "what went wrong" or "what went well", 5) lessons learned, 6) lessons learned measures, and 7) applicability and delimitations. Video-based lessons learned have the advantage of capturing the context of dynamic problem situations and of reducing time-consuming manual processes while capturing lessons (Chirumalla 2013, p. 170). Schacht and Maedche (2016) developed a knowledge reuse methodology defining the processes, activities and roles to conduct effective lessons learned sessions. The core of the methodology is a double-cycled process that supports lessons learned sessions at the beginning of a project (lessons learned as preparation) and after a project is completed (lessons learned as recap). Schacht and Maedche (2016) combined a standard project management framework with the double-cycled lessons learned process in order to create the knowledge-centric project management process that is presented in Figure 2-13.

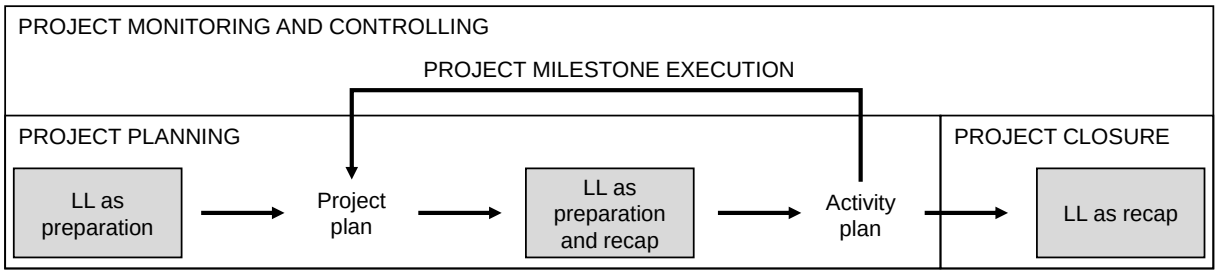


Figure 2-13: Knowledge-centric project management process (Schacht and Maedche 2016, p. 18)

Furthermore, there are numerous methods for the individual implementation of each of the phases of the knowledge reuse cycle. Some methods are applicable to all types of knowledge and some of them work only for specific types. Common methods for knowledge capturing and documenting are storytelling, video collection or interviews (Williams 2008, p. 253; Chua et al. 2006, p. 257). For knowledge packaging methods like repositories, libraries or indexing are applied (Milton 2010, p. 103; Chua et al. 2006, p. 257). Common methods for knowledge distribution are communities of practice (CoP), newsletters or blogs (Milton 2010, p. 95). Finally, reusing can be supported by expert systems or workflow systems (Binney 2001, p. 38; Alavi and Leidner 2001, p. 125).

2.2.3 Benefits and Challenges of Knowledge Reuse

Reusing knowledge is **beneficial** for organisations because it prevents them from "reinventing the wheel" in terms of products, components, processes and templates (Oshri 2006, p. 488). In other words, knowledge reuse avoids organisational forgetting, which can take place in several forms. Lehner (2012, p. 82) presented a table with the forms of organisational forgetting, which can be allocated to the three pillars of knowledge management in practice, described by Reinmann-Rothmeier and Mandl (1998) already presented in Figure 2-8. The table is presented in Table 2-2.

Avoiding organisational forgetting and reinventing the wheel saves company's time that can be used to perform core activities. The results for product development companies are shorter times to market, reducing R&D costs and reducing risks (Oshri 2006, p. 488).

Table 2-2: Forms of organisational forgetting (adapted from Lehner (2012))

			Concerned pillar of knowledge management		
			People	Organisation	Technology
Type of forgetting	Knowledge is deleted through		Quitting, death spiral, amnesia, retirement	Dissolution of teams, reengineering, outsourcing	Data loss through: virus, hardware failure, system crash, backup failure, hackers
	Access is not possible	Temporary	Temporary overload, relocation, illness, holiday, inadequate training, call of duty	Inertia to maintain old routines, collective sabotage	Reversible data loss, temporary overload, interface problems
		Permanently	Permanent overload, lack of awareness of the own knowledge's importance, internal quitting	Company's sale to third party, team migration	Systems incompatibility, permanent overload, wrong codification

Reusing knowledge can also have some **disadvantages**. Within a strong reusing culture, explorative activities necessary for the company's development might not be performed anymore and this can hinder innovation. Finding a right balance between reusing and developing is critical. Furthermore, the boundaries for knowledge reuse influence the impact on innovation; continuous knowledge reuse within the same environment or department might hinder innovation whereas knowledge reuse across company's departments might have a

positive influence in innovation. Information distortion is another risk of reusing knowledge. Relying on previous knowledge without questioning and reflecting on it may lead to repetitive failures in cases of false or outdated information. Companies should work on creating a critical culture and knowledge validation process to cope with those challenges and assure the quality of their knowledge (Oshri 2006, p. 488).

The implementation of knowledge management and achieving efficient knowledge reuse in practice seems to be the major **challenge** of the discipline. Literature offers some overall frameworks for the implementation of knowledge management initiatives and numerous methods to support different phases of the knowledge reuse cycle. Schacht and Maedche (2016, p. 8) discuss that the existence of this extensive literature makes researchers believe that most questions regarding knowledge management have been answered but practitioners still see the need for developing applicable knowledge management methodologies. Fact is that, companies still struggle to manage what they know. A survey conducted by COVEO in 2014 revealed that 67% of the knowledge workers had trouble finding the information they need (COVEO 2014). A survey conducted by Milton (2010, p. 8) revealed that more than 50% of the companies that attempted to collect lessons learned think that they do not use them efficiently.

Knowledge reuse is usually associated to information systems and codified knowledge. However, knowledge reuse is also the outcome of informal people-based activities, which are complementary to the information system approach (Oshri 2006, p. 487; Goncalves 2012, p. 7). This two-dimensional view implies technical IT and procedural challenges as well as challenges related to motivational and social factors such as acceptance for knowledge sharing, which are human-related factors (Oshri 2006, p. 487). Issues regarding intellectual property can be a barrier for knowledge reuse across companies and creating a trusting environment to share knowledge can be challenging for both internal and external knowledge reuse (Oshri 2006, p. 488).

Knowledge management initiatives aim strongly at many goals at the same time such as improving knowledge transparency, improving knowledge access, improving knowledge documentation, improving knowledge retention or improving knowledge sharing (Maier and Remus 2002, p. 104). This makes of knowledge management initiatives very broadly and vaguely defined projects and it can lead to low efficiency due to the lack of focus (Maier and Remus 2002, p. 104). Companies have to make sure that they tighten their knowledge management efforts to high-priority business objectives (Goncalves 2012, p. 8). How to achieve the right balance between necessary knowledge management activities to achieve knowledge reuse and feasible intervention focus is a challenge for the practical application of knowledge management.

2.3 **Knowledge Reuse in Engineering Design**

engineering design is a discipline that aims at designing and developing products as the result of conducting a “set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product” (Ulrich and Eppinger 2003, p. 2). The focus of engineering design is on developing products that are engineered, discrete and

physical like e.g. consumer electronics, machine tools and medical devices (Ulrich and Eppinger 2003, p. 2).

There are two ways of understanding knowledge reuse in engineering design. The first one is usually named "**Design Reuse"** and it means the utilisation of "past proved designs in new situations so that chances of product success are increased" (Cross and Sivaloganathan 2007, p. 1286). The ultimate goal of Design Reuse is to assist designers in the development of products that maximise user satisfaction with minimal resources and cost as well as minimal design effort (Sivaloganathan and Shahin 1999, p. 641). This type of reuse is associated to computer-supported solutions such Computer Aided Design (CAD) and expert systems.

The second way of understanding knowledge reuse in engineering design is seeing reuse as the **use** of **design knowledge**, i.e. the "use of concepts such as ideas, knowledge, decisions, past designs, etc., and objects such as artefacts (realisation of designs), components, assemblies of components, sub-assemblies of components, etc., in new situations" (Duffy et al. 1995, p. 491). This definition embraces more types of reuse than the view of Design Reuse presented in the previous paragraph, which basically considers only the so called "objects" in the definition of Duffy et al. (1995).

The following Subsections describe relevant concepts to understand how both types of knowledge reuse applied in engineering design. Subsection 2.3.1 presents the most popular models of the design process and its activities. The types of knowledge involved in the discipline of engineering design are discussed in Subsection 2.3.2. Current approaches to implement knowledge reuse in engineering design are presented in Subsection 2.3.3. Finally, the benefits and challenges of the implementation of knowledge reuse in engineering design are discussed in Subsection 2.3.4.

2.3.1 The Design Process

A process can be understood as a sequence of activities using information, knowledge and resources to transform an input into an output Lindemann (2009, p. 16). Numerous generic processes have been proposed in literature to describe the product design or product development process (Gericke and Blessing 2012). Subsequently some of the most popular ones are presented.

A very popular design process model is the one created by **Pahl and Beitz** (Pahl et al. 2007). This model presents five working steps with their corresponding input and output. The working steps are included in four sequential phases. The model is presented on the left side of Figure 2-14.

The **VDI** (Verein Deutscher Ingenieure) proposed a model in the guideline VDI 2221 (VDI 1993, p. 9). The model presents seven steps included in four partially overlapping phases. This model is depicted on the right side of Figure 2-14.

Ulrich and Eppinger (2003, p. 12) propose a six-step product development process with the following phases: 0) planning, 1) concept development, 2) system-level design, 3) detail design, 4) testing and refinement, and 5) production ramp-up. They also describe that the

correspondent activities are performed in each phase by different company's departments such as design, marketing, manufacturing, finance or sales.

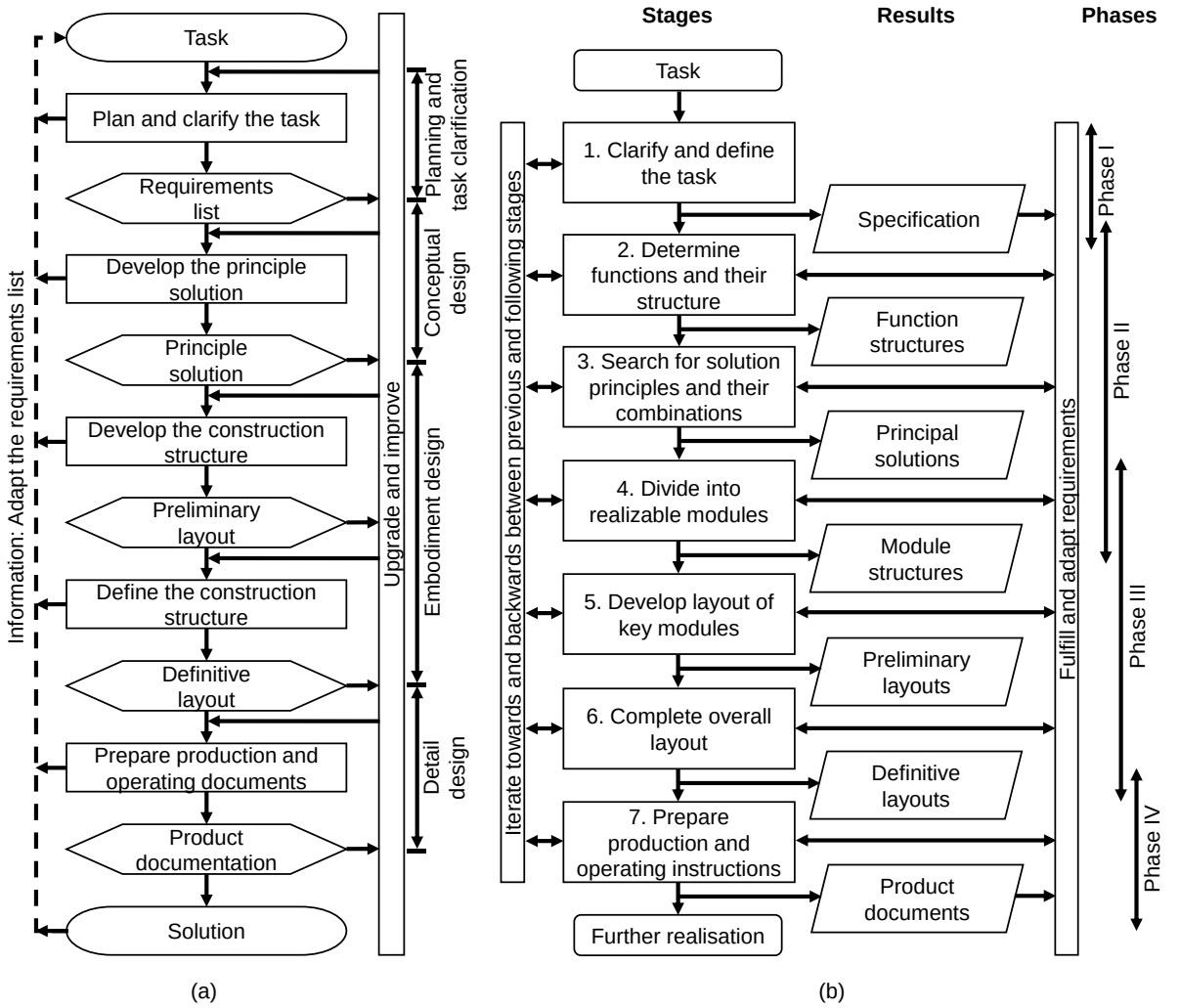


Figure 2-14: a) Pahl and Beitz design process model (Pahl et al. 2007, p. 130); b) VDI 2221 process model (Jänsch and Birkhofer 2006, p. 49)

The **V model** is well-established in the domain of software engineering and it has been adapted to depict a methodology for the development of mechatronic products (VDI 2004, p. 29). The V-model proposes a development in cycles in which starting from the definition of requirements, the system is generally designed as a mechatronic entity and then each discipline develops separately the details. Then, the system integration and validation take place and the cycle can start again.

Lindemann (2009, p. 47) proposes the **Munich Procedural Model** (MPM) to support the planning of development processes and general problem solving processes. Instead of the traditional model steps, the MPM has seven elements: goal planning, goal analysis, task structuring, generate solution ideas, properties assessment, decision making and ensuring goal

achievement. The elements of the MPM are represented in a network which allows moving forward and backwards through them and therefore it depicts process iterations better than sequential models.

The design and development department is of central importance in any company due to its position in the overall development process. It has to constantly exchange information and knowledge with a large number of departments such as production, assembly, sales or marketing (Pahl et al. 2007, pp. 6–7). The view of the design process as a knowledge flow in which design and development have a central role, highlights the importance of managing and reusing knowledge during the different process phases and activities.

2.3.2 Types of Knowledge in Engineering Design

van Aken (2005, p. 8) defines design knowledge as "knowledge that can be used to produce designs". This definition leaves quite open the interpretation for the (re)user of what is to be considered as knowledge or not. The types of knowledge relevant during engineering design can be classified in the same way as it can be done for other disciplines (see Subsection 2.1.2). Thus, types of knowledge depending on the knowledge nature (tacit, implicit or explicit) or depending on the knowledge concretisation level (general or specific) can be applied to engineering design. Depending on the context of knowledge reuse such as between companies (inter-firm knowledge reuse) or within an organisation (intra-firm knowledge reuse) knowledge can be respectively characterised as internal or external (Oshri 2006, p. 448). Some specific categories can also be identified for the discipline of engineering design. Carro Saavedra et al. (2017b, p. 7) summed up the numerous types named in literature into four main groups with their correspondent subgroups:

- Knowledge about the **product**: constraints and specifications, conceptual knowledge, structural knowledge, functional knowledge, behavioural knowledge, technical knowledge, calculations.
- Knowledge about the **process**: design process, manufacturing process.
- Knowledge about **contacts**: supplier(s), customer(s), competitor(s), other stakeholders.
- Knowledge about product and company's **environment**: legislation, country/market, environmental entity, product lifecycle.

The previous categories are the result of the extensive review on types of knowledge in engineering design that was conducted by Serrano Villodres (2016).

The previous Subsection presented various design process models depicting design activities. A design activity can be seen as a knowledge process with a knowledge input and a knowledge output using the Knowledge Level of Newell (1982) as level of abstraction (Sim and Duffy 2003, p. 4). Sim and Duffy define a design activity as "a rational action taken by a design agent to achieve a knowledge change of the design and/or its associated process (i.e. sequence of actions) in order to achieve some design goal" (Sim and Duffy 2003, p. 4).

Sim and Duffy (2003) identified three generic design activities during the design process: design definition activities, design evaluation activities, and design management activities. For each one of the 27 activities included in the three generic categories they described the

knowledge input, knowledge output and knowledge change. Table 2-3 shows an example for the activity “structuring” which belongs to the category of design definition activities.

Table 2-3: Knowledge flow for the design activity “structuring” (Sim and Duffy 2003, p. 15)

Goal of design activity	**Input knowledge**	**Output knowledge**	**Knowledge change**
Optimal product architecture that minimise the complexity of coordination required to develop the total product/system	Knowledge of interfaces/ interactions between parts, systems	Knowledge product architecture in terms of chunks and their interactions	Knowledge grouping system to system interactions based on system similarity or functional dependency
	Knowledge of specifications components/parts, systems of the product	Reasons for fundamental and incidental interactions	

2.3.3 Approaches to Implement Knowledge Reuse in Engineering Design

In order to review the existing approaches, an exploratory literature review was conducted on Google Scholar, Scopus and Web of Science. The most popular approaches had been published more than ten years before the search. In order to assure the presentation of the latest state of the art, a systematic literature review on the publications of the last five years before review date (2010 to 2015) in three relevant engineering design journals was also conducted. The selected journals were the Journal of Engineering Design, Research in Engineering Design and Design Studies. The results of this review are documented in Appendix 9.3. Furthermore, approaches developed in the Chair of Product Development of the Technical University of Munich are also included.

The approaches found in literature can be divided in two groups; those supporting the previously described Design Reuse and those supporting the reuse of general design knowledge about e.g. the design process, product functions or product in service. Furthermore, some approaches present theoretical models for understanding, and some offer applicable methods or computer-based tools. Subsequently those approaches are presented. The approaches described in detail are those supporting the reuse of general design knowledge or addressing in greater extent the phases of the knowledge reuse cycle.

Models

Duffy et al. (1995) proposed the **Design Reuse Model**, which consists of three processes and six knowledge-related components. The aim of the model is to describe the totality of design reuse and thus indicate the reasons for failure of existing support to recognise the totality of design reuse. The model describes the reuse of codified knowledge for computationally support design.

Hicks et al. (2002) developed a **framework** to outline the **requirements** for acquisition, capture and electronic storage of knowledge, information and data. The framework distinguishes various levels and extents for each term and it defines different requirements for them. Based on that, the authors discuss that for higher levels of knowledge elements and processes, such as general principles or generic knowledge, are required within-person processes rather than computational processes. They conclude that an organisation must combine electronic-information knowledge repositories and processes with within-person sources of information and knowledge.

Ahmed-Kristensen and Vianello (2015) developed the **RSK** (Reusing Service Knowledge) model. The model depicts a path to support the availability of knowledge about *issues*, *changes* and *improvements* from service and to apply those to new contexts. The model is proposed to be used on the step "Identification of migration paths" of the Kamara et al.'s framework to select a knowledge management strategy. The detailed development of the RSK and its application is presented in Vianello (2011).

Methods and Tools

Blessing and Wallace (1998) presented **PROSUS**, a PROcess-based SUpport System, which aims to support the knowledge life-cycle based on a model of the design process. The proposed method addresses the knowledge-life cycle with the focus on capturing codified design data as it is generated. It supports computer systems using a design matrix as interface between the user and the system. The design matrix offers a structure to capture and retrieve *issues* and *activities* during the design process.

Fruchter and Demian (2002) presented **CoMem** (Corporate Memory), which is a prototype corporate memory system that supports knowledge reuse by three processes: find, explore evolution history and explore project context. The human-computer interaction experience of the tool is based on the approach *"overview first, zoom and filter, and then details-on-demand"*. Some years later, Demian and Fruchter (2009) proposed the use of visual storytelling for the process of exploring the evolution history and thus tell the story of how an item evolved from an abstract idea to a fully designed physical artefact. They concluded that storytelling is a helpful metaphor to apply in a tool for exploring design evolution.

Ahmed and Wallace (2004) developed **C-QuARK**, which is a question-based method to help novice designers to gain experience rapidly. The method supports novice designers by making them reflect on the questions that experienced designers would ask themselves and therefore, guiding them towards what they need to know. Thus, the method contributes to the reuse of general design knowledge, regardless of whether it is codified, embedded in computer systems or in form of expertise and competences from other designers.

Dani et al. (2006) proposed a **methodology** for the identification and sharing of **best practice** knowledge. The methodology shows how to identify what information should go to the Knowledge Base (KB), how knowledge should be classified and how to structure the KB. It also includes a person-to-person linkage to support the reuse of tacit knowledge.

Lauer (2010) developed a **method** for the parametric description of documents and processes in order to support the **reuse of documents** in dynamic product development processes. The

method was implemented in an IT-tool prototype which allows the description of documents and their half-automatic link to the process.

Kohn (2014) created a **KB** for collecting, structuring and retrieving knowledge about **product models**. A framework for locating existing knowledge from different sources assists in filling the KB. An ontology forms the meta-model of the KB by defining the concepts, their relations and their relevance to work with product models.

Schenkl (2015) proposed a **methodology** for the knowledge-oriented **development of Product Service Systems (PSS)**. The methodology combines a traditional model for PSS development with a knowledge assessment in order to select measures for the development of the company's PSS knowledge. The knowledge modelling is done with knowledge maps, which represent employees, tasks and their related knowledge.

Regarding the support of the so called Design Reuse, numerous approaches propose methods for computer-based support by applying Knowledge-Based-Engineering (KBE) to CAD (Schaal 1991; Baxter et al. 2007, 2008; Sung et al. 2011; Yu et al. 2012; van Eck 2015). KBE systems generally involve a combination of object-oriented programming, rule-based systems, knowledge representation and computer-aided geometric design. KBE is mostly applied in design domains in which products are variations of an established design pattern (McMahon et al. 2004, p. 318).

Other publications propose solutions for the computer-based reuse of codified knowledge, information and/or data based on ontologies and models to improve knowledge representation and facilitate its transfer or retrieval (Štorga et al. 2010; Park 2011; Howard et al. 2011; van Eck 2011; Li et al. 2014; Modoni et al. 2015).

2.3.4 Benefits and Challenges of Knowledge Reuse in Engineering Design

Engineering design has dramatically changed over the past decades as the complexity of the products developed has increased. Multi-functional Integrated Product Teams including members working for different companies and with different nationalities are becoming the norm (McMahon et al. 2004, p. 308). Within this context of wide geographic distribution, big timescales and high complexity of designs, the systematic knowledge reuse of internal and external knowledge is **beneficial** so product development time and cost can be reduced, product quality can be increased and companies can be more innovative (Vijaykumar and Chakrabarti 2008, p. 1).

As it happens in other disciplines, the practical application of knowledge reuse in the field of engineering design is the major **challenge** (Lauer 2010; Vijaykumar and Chakrabarti 2013; Schacht and Maedche 2016). Various tools have been proposed in literature to support the reuse of design knowledge but their practical application is low (Vijaykumar and Chakrabarti 2013, p. 786). Some of the possible reasons for that are discussed below.

Knowledge capturing and codification are more challenging in engineering design than in other fields due to the long lifecycles of many engineering projects and the high level of expertise involved. Capturing, codifying and transferring the large amount of possible

knowledge assets in an engineering project can be a significantly large task (Carey et al. 2012). Knowledge reuse systems and methods have to operate with data in different formats, operate with decentralised data storages, be integrated in the development process, support overall knowledge transparency and support traceability of information and evolution of history of design (Heisig et al. 2010, p. 527; Carey et al. 2012). The use of inadequate tools in this context or the lack of standards can be reasons for failure in reusing knowledge in engineering design practice (Chandrasegaran et al. 2013, p. 231). Vijaykumar and Chakrabarti (2013, p. 786) talk about a "technology push" that tends to implement knowledge reuse tools in engineering design companies without an adequate understanding of the knowledge processes in each **company**. This leads to low acceptance rates and failure of knowledge reuse initiatives.

Designers' acceptance of methods and tools is essential for their successful implementation. However, designers have usually a lack of understanding of their own needs and it is common that they realise about those needs once the solutions have already been implemented (Carey et al. 2012, p. 1407). Moreover, the acceptance might vary **individually**. A method or tool that is well accepted and considered helpful for one designer, can be rejected and not helpful for other. One example of individual designers' consideration in knowledge reuse methods is C-QuARK, the method developed by Ahmed and Wallace (2004), which considers the differences between novice and expert designers and it is especially designed to support the needs of novices. Many other aspects of the designers' background and personality might have an influence and this fact has been disregarded so far for the implementation of knowledge reuse in practice.

Engineering companies have the tendency to take either the personalisation or the codification approach for the implementation of knowledge reuse. But both views are not mutually exclusive and combining both perspectives seems especially relevant for engineering design. For example, computer-driven knowledge retrieval by keyword search seems to be not as relevant in engineering environments as it is in information retrieval in general (Heisig et al. 2010, p. 526). Due to the creative nature of engineering design and the importance of sharing design rationale, engineers primarily retrieve information by talking to co-workers (Heisig et al. 2010, p. 527). Adopting an **integrative perspective** seems necessary to achieve knowledge reuse in real industrial environments (McMahon et al. 2004, p. 318).

Summarising, there are three key challenges to overcome for the implementation of knowledge reuse in engineering design companies:

- Understanding of company's processes and needs in order to select the adequate knowledge reuse methods and tools for each company.
- Understanding of individuals' behaviours and needs in order to select the adequate knowledge reuse methods and tools for each individual.
- Combining both codification and personalisation approaches for knowledge reuse.

2.4 Conclusions

The following Subsections present the conclusions derived from the state of the art. Subsection 2.4.1 presents the research gap and establishes three main needs for further

research. Subsection 2.4.2 discusses different interpretations of key concepts and defines the meaning of different terms for this thesis.

2.4.1 The Research Gap

Despite numerous existing frameworks and methods to explain and support knowledge management and knowledge reuse, reality is that efficient knowledge reuse still does not take place in industrial practice (Milton 2010; Lauer 2010; Chandrasegaran et al. 2013; Vijaykumar and Chakrabarti 2013; Schacht and Maedche 2016).

Taking a look at the state of the art it can be observed that most proposals to select a knowledge management strategy provide a set of guiding principles but they do not give enough details to conduct the steps in practice. They are theoretical frameworks instead of applicable methodologies. The only methodology explaining in detail the steps for the practical application of each phase of the general framework is SMARTVision (Rubenstein-Montano et al. 2001). Even though SMARTVision is much more complete than other proposals, the procedures, subprocedures and outputs are just enumerated and therefore how to conduct those in practice is still undefined. Furthermore, it is not said how it deals with different types of knowledge, which methods are available to perform the knowledge management processes or which criteria could be used to select them.

The process of knowledge auditing constitutes the first steps in all proposals for selecting the appropriate knowledge management strategy. Scientific literature offers more detailed methodologies for knowledge auditing than for selecting knowledge management strategies in general and their practical application is actually much more extended. However, specific methodologies that describe in detail how to execute an audit are usually owned by consulting enterprises and therefore, not publicly available (Perez Soltero et al. 2007, p. 11). Audits reveal potentials for improvement in knowledge processes but they also require high amounts of resources. It is questionable if the audit results report enough benefit for the invested effort.

Methods addressing partially the knowledge reuse cycle like e.g. storytelling for knowledge capturing (Williams 2008, p. 253) or knowledge repositories for knowledge packaging (Milton 2010, p. 103) as well as methods addressing only one type of knowledge like e.g. best practices in the methodology of Dani et al. (2006), service knowledge for Vianello (2011) or PSS knowledge in the work of Schenkl (2015) require a good company's understanding of their initial situations. In order to apply those methods, the company must know its needs and deficiencies regarding knowledge reuse. However, this is often not the case in reality. The typical initial situation is that companies perceive that they are not reusing efficiently their knowledge but they cannot specify what knowledge they refer to or why its reuse is inefficient.

Thus, the first identified gap is the **need to develop practical support** to reuse knowledge in engineering design companies. Such support should be detailed enough to be applicable by practitioners (shortcoming of current frameworks and methodologies) and it should also set a feasible implementation focus in the company so the effort-benefit trade-off remains positive (shortcoming of current knowledge audit). In order to be accepted in real practice, the support should help practitioners from scratch without an a priori definition of what knowledge is to

be reused. It is necessary to address different types of knowledge and different understandings of what knowledge is, different types of people and different types of technology. Last but not least, both codification and personalisation approaches for knowledge reuse have to be considered at the same time since both coexist in real industrial environments. This gap is addressed with the development of support in form of a methodology to plan the knowledge reuse cycle. The methodology is developed in the Prescriptive Study that is presented in Chapter 4.

Various authors from literature suggest specific reasons for the lack of knowledge reuse industry. Vijaykumar and Chakrabarti (2008) say that the reason might 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) see the problem in the lack of consideration of individuals' behaviour to design a knowledge management strategy. Schacht and Maedche (2016) also point out that most approaches to support knowledge reuse do not address supporting of the reusing stage. It is just assumed that if knowledge is documented, stored and distributed, it will be reused automatically. However, this is not what actually happens.

It seems that the reasons for the lack of knowledge reuse in industry might be various and they are still unclear within the research community. There is a need for extensive investigation previous to support development. Therefore, the second identified research gap is the **need of understanding the reasons for the lack of knowledge reuse** in industry. The investigation of this aspect is part of the DS I that is presented in Chapter 3.

Even though people are one of the three pillars for a knowledge management strategy in practice (Reinmann-Rothmeier and Mandl 1998), there has been a lack of consideration of individuals' behaviour to develop knowledge reuse approaches and to increase the acceptance of knowledge management strategies in general (Schacht and Maedche 2016). Knowledge is a subjective abstract concept for which every person possesses a different interpretation. This explains the lack of consensus in the term definition (see Subsection 2.1.1). But reality is that reusing knowledge depends ultimately on individuals (Davenport and Prusak 2000) and for this reason, individuals should constitute the focus of understanding what leads to successful knowledge reuse. Thus, the third identified research gap is the **need of understanding individual factors influencing knowledge reuse**. The investigation of this aspect is required previous to support development and it is included in the DS I presented in Chapter 3.

2.4.2 Discussion and Definition of Key Terms for This Thesis

Numerous terms referring to key concepts to understand knowledge management and knowledge reuse were introduced along this Chapter. The literature review showed a lack of consensus in the terminology used. This leads to confusion in understanding the meaning and relations between the terms. This Subsection presents eight blocks discussing different interpretations of key concepts and defining the meaning of the terms for this thesis.

Knowledge Management and Organisational Learning

- Discussion: the terms *knowledge management* and *organisational learning* are sometimes considered analogue. In this case, both terms are referring to activities pursuing the goal of coordinating the "organisation's people, technology, processes, and organisational structure in order to add value through reuse and innovation" (Dalkir 2005, p. 9). Those activities are the ones depicted in the popular knowledge management models presented in Subsection 2.1.3. In other cases, *organisational learning* is not seen as analogue to *knowledge management* but as the result of applying *knowledge management*. In this case, the abovementioned goal definition is assigned to refer just to the term of *knowledge management*.
- Understanding of the terms for this thesis: it corresponds to the second case, in which *organisational learning* occurs thanks to the application of *knowledge management*. Thus, *knowledge management* is considered an action or set of actions and *organisational learning* is its result.

Knowledge Management and Knowledge Reuse

- Discussion: *knowledge reuse* is sometimes considered the specific moment in which an individual performs reuse. In other occasions, the term *knowledge reuse* refers to the set of *knowledge management* activities that lead to the moment in which an individual performs reuse. In this second case, the sequence of *knowledge management* activities can receive the name of knowledge reuse cycle. The activities of the knowledge reuse cycle were presented in Subsection 2.2.1.
- Understanding of the terms for this thesis: the term *knowledge reuse* refers to the specific moment in which an individual performs reuse. The set of *knowledge management* activities leading to this moment receive the name of knowledge reuse cycle. Thus, the knowledge reuse cycle is considered an action or set of actions and *knowledge reuse* is its result.

Knowledge Reuse and Organisational Learning

- Discussion: in this thesis the term *organisational learning* is understood as the result of applying knowledge management in the company. *Knowledge reuse* is also seen as a result of performing knowledge management but only some activities of it, the ones considered in the knowledge reuse cycle. Following this understanding, *knowledge reuse* constitutes one part of the *organisational learning*. *Organisational learning* is achieved not only when knowledge is reused but also when new knowledge is created or developed. Knowledge management activities that have the goal of creating new knowledge instead of reusing it are included in the main knowledge management models as knowledge development (Probst et al. 2012) or knowledge generation (Reinmann-Rothmeier 2001).
- Understanding of the terms for this thesis: *knowledge reuse* is one part of the *organisational learning*. The knowledge management activities required to achieve *knowledge reuse* are the ones described in the knowledge reuse cycle. Knowledge management activities such as knowledge development or knowledge generation do not contribute to *knowledge reuse* but they do contribute to *organisational learning*.

Knowledge Reuse, Knowledge Use and Knowledge Usage

- Discussion: these three terms are used indistinctly in literature. Literally, *use* or *usage* would refer to the "first time" that a certain knowledge is used after it has been acquired. Once this knowledge has been used once, the upcoming times it would be *reused* and not used anymore. The distinction of the terms seems irrelevant in practice because a piece of knowledge is not going to be treated or retrieved differently if it is prepared to be *used* or *reused*. Thus, the distinction of the terms does not have practical implications for the (re)user.
- Understanding of the terms for this thesis: no differentiation is applied to the use of these terms and the term *reuse* is selected for upcoming chapters of the thesis.

Knowledge Reuse and Knowledge Application

- Discussion: *knowledge reuse* and *knowledge application* are sometimes considered analogue and some other times *knowledge application* is seen as the final step of *knowledge reuse*. In this second case, *knowledge reuse* is defined as the specific moment in which an individual performs reuse and this specific moment is considered a process with several steps, *knowledge application* being the last one of them.
- Understanding of the terms for this thesis: *knowledge application* is the final step in the process of *knowledge reuse* by an individual in a specific moment.

Knowledge, Information and Data

- Discussion: literature presents conceptual differences between the terms *knowledge*, *information* and *data* (see Subsection 2.1.1). However, the terms usually are treated indistinctly when it comes to the practical application of knowledge management. This can be explained by the fact that since the goal of knowledge management is providing decision-makers with the right knowledge, this input "*knowledge*" can actually be *data* or *information*. Depending on the background and level of expertise of the decision-maker he or she will be able to generate from the provided input a knowledge output as it is described in the Knowledge Pyramid (see Subsection 2.1.1). Thus, even though *data*, *information* and *knowledge* are different in their nature, all of them support the generation of *knowledge* and therefore, all of them should be managed to achieve knowledge reuse. This effect is depicted in Figure 2-15.

  Furthermore, differentiating between a data management, information management or knowledge management problem a priory in a company is very difficult. A knowledge management initiative usually starts with the company's impression that their knowledge resources are not efficiently exploited. Those resources are in many cases not even known and they are a mix of data, information and knowledge. It is only after an in-depth analysis that potentials for improvement can be identified and the application of methods from the correspondent discipline (data management, information management, or knowledge management) can be suggested. A company's situation can require first the application of data management and information management methods such as data bases or product information management systems to structure *data* and *information* that can be used later to generate *knowledge*.

- Understanding of the terms for this thesis: the word knowledge will be used from now on to embrace all the terms as they are considered knowledge resources (left part of Figure 2-15). Knowledge management is the discipline that takes an overall consideration of the company's knowledge resources and based on that information management and data management can be required.

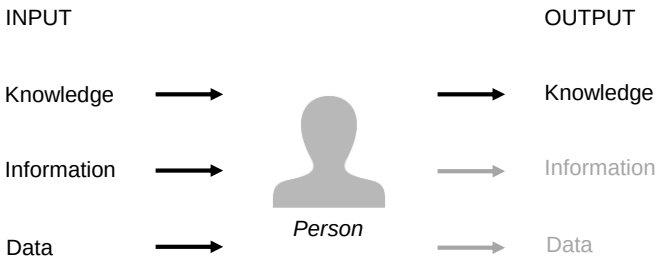


Figure 2-15: Expected knowledge management outcome of a person processing input knowledge resources

Designers, Developers, Workers and Employees

- Discussion: the participants in the product design or product development process can receive different names such as *designers*, *developers* or more generally *workers* or *employees*. Using one word or the other is a personal choice of each author. For example, Pahl et al. (2007, p. 1) selected the word designer "synonymously to mean design and development engineers". *Designers* and *developers* or development engineers perform the product design and development, and they belong to the design and development departments. The words *workers* and *employees* describe persons working in the company. Those do not necessary belong to the design and development departments but to any other department in the company.
- Understanding of the terms for this thesis: this thesis will use the word *designer* to refer to persons performing the product design or product development process. The word *employee* will be used to refer to any person performing a job inside a company.

Organisation, Firm and Company

- Discussion: literature refers to knowledge management in *organisations*, in *firms* or in *companies*. Merriam-Webster (2018) provides the following definitions for those terms. An *organisation* is "an administrative and functional structure (such as a business or a political party)". *Firm* is defined as "a business unit or enterprise". A *company* is "an association of persons for carrying on a commercial or industrial enterprise". According to these definitions, *organisation* and *firm* are basically synonymous, whereas a *company* has a commercial or industrial goal.
- Understanding of the terms for this thesis: since this thesis focuses on the implementation of knowledge reuse in industrial enterprises of product development, the term *company* will be used in the rest of the thesis. The terms industrial context and industry will also be used as synonymous of *company*.

3. Understanding Knowledge Reuse

This Chapter presents the Descriptive Study I, in which various methods are applied in order to increase the understanding of the phenomenon to study. The research plan for DS I is introduced in Section 3.1. Section 3.2 shows the interviews conducted to identify the current industrial practices for knowledge management and needs for knowledge reuse. Section 3.3 presents a literature-based model depicting the factors influencing knowledge reuse for individuals in the context of a company. Finally, Section 3.4 shows two explorative experiments with students that provide insights on the individual barriers for knowledge reuse out of industrial contexts.

3.1 Research Plan

The RC conducted in Chapter 2 revealed needs for further understanding on the phenomenon of knowledge reuse in industrial practice. Two RQs emerge from those needs:

- RQ1: What are the reasons for the lack of knowledge reuse in industry?
- RQ2: What are the individual influencing factors for knowledge reuse?

The approach to answer those questions combines an interview study to industrial practitioners and a systematic literature review. The results of the interview study are a major contribution to answer RQ1 and they contribute significantly to answer RQ2. The results of the literature review are a major contribution to answer RQ2 and they contribute significantly to answer RQ1.

Two Hypotheses (H) on individual influences for documented knowledge reuse emerged from initial ideas for the development of support. Those hypotheses were tested in exploratory design experiments (EDE). The aim of the exploratory design experiments was to improve the understanding of individuals' needs and behaviours based on the observation of designers outside the industrial environment. In this way, factors related to the company such as structures or culture do not play a role and designers' are freely to reuse knowledge from a Knowledge Base (KB) without company's "noise". The following hypotheses were formulated and investigated in the experiments:

- H1: The awareness of knowledge availability does not assure knowledge reuse.
- H2: Designer's familiarity with the knowledge contained in a KB has a direct influence on the preferred knowledge search method.

Table 3-1 shows the overview of the research plan for DS I including the level of contribution or each method to each RQ or H. The following Sections explain in detail the application and results obtained for each method.

Table 3-1: Research Plan for DS I

++ major contribution to answer RQ / H + contribution to answer RQ / H	**Interview Study**	**Systematic Literature Review**	**Exploratory Design Experiments (EDEs)**
RQ1: What are the reasons for the lack of knowledge reuse in industry?	++	+	
RQ2: What are the individual influencing factors for knowledge reuse?	+	++	
H1: The awareness of knowledge availability does not assure knowledge reuse			++
H2: Designer's familiarity with the knowledge contained in a KB has a direct influence on the preferred knowledge search method			++

3.2 Industrial Knowledge Management Practices and Needs for Knowledge Reuse

In order to understand the reasons for the lack of knowledge reuse in industry, an interview study was conducted. The goal of the study was to gain understanding of the current industrial practices on knowledge management, the practical challenges and to understand if there is a need to increase knowledge reuse. The study took place in December of 2014 as part of the student project of Fernandez Miguel (2015). Subsection 3.2.1 presents the preparation of the study. The results are exposed and analysed in Subsection 3.2.2. Finally, the conclusions and the implications for the support are discussed in Subsection 3.3.3.

3.2.1 Preparation of the Study

The **checklist** suggested by Blessing and Chakrabarti (2009, pp. 243–244) for determining the characteristics of empirical studies served as base for the preparation. Table 3-2 shows the dimensions of the checklist considered as suitable for this study, since "not all categories may apply to each type of study" (Blessing and Chakrabarti 2009).

The **aim** of the study was to understand the reasons for the lack of knowledge reuse in industry. Therefore, a questionnaire with **38 open questions** was prepared, covering the **ten blocks** related to the interviewee's background, company's knowledge management practices and personal opinions:

A) General information
B) Job position and experience
C) Understanding of knowledge management

D) Company's knowledge management
E) Tasks' knowledge requirements
F) Knowledge acquisition/transfer in interviewee's company
G) Knowledge networks or repositories in interviewee's company
H) Conflicts in interviewee's company
I) Knowledge documentation in interviewee's company
J) Efficiency perception and further information

Table 3-2: Checklist for determining the characteristics of the interview study

Dimensions	**Option selected for the study**
Aim, Research Question (RQ), Hypothesis (H)	RQ: What are the reasons for the lack of knowledge reuse in industry?
Nature of the study	Observational, non-comparative
Theoretical basis	Knowledge management processes and methods
Unit(s) of analysis	German automotive industry
Data-collection method	Face-to-face semi-structured interviews
Role of researcher	Interviewer
Time constraint	1'5 hour (per interview)
Setting	The interviews were conducted either in a private room or in public establishments (coffee house), away from the workplace
Number of cases	Seven interviews
Case size	The seven participants belonged to five different companies
Participants	Junior engineers up to four years of experience
Coding and analysing method(s)	All answers were documented in written form during the interview. Qualitative analysis methods were applied

The complete interview questionnaire as well as the purpose of the questions can be found in Appendix 9.4.1. The study was observational and non-comparative. The knowledge management processes and methods described in Chapter 2 established the theoretical basis. Seven junior engineers with until four years of experience were interviewed away from their workplace in face-to-face interviews of 1,5 hours of duration. The participants were employed in five different German automotive companies. All answers were documented in written form during the interview.

The automobile sector was selected for the study due to its significance in the region of Bavaria, the variety of products developed and the wide range of engineering tasks performed. Regarding the participants profile, junior engineers were interviewed for two

reasons: 1) since they lack experience, they are more objective than experience engineers to evaluate the degree of application of knowledge management methods in their company. Experience engineers tend to assume as "established methods" logical actions that they developed during the course of they work, even though those actions are neither standard nor spread in the company; and 2) since they lack experience, they have higher needs for knowledge management.

3.2.2 Analysis of Results

Seven interviews were conducted. The **minutes** of the interviews are presented in Appendix 9.4.2. In order to preserve the participants' confidentially, they receive the names of P1, P2, P3, P4, P5, P6 and P7. The companies receive letters from A to G. The following paragraphs present first the participants background and then a discussion of the interviews' results for each of the addressed question blocks.

General information

The seven participants are employees of five different companies ranging from 1.000 to 100.000 employees. Three participants work for a big automobile group and the companies of the other four participants are service providers. Six participants work in design departments, one works in testing and validation.

Job position and experience

Three participants work as trainees or students. They have been working in their companies up to one year. One of them had previously worked in other companies during almost three years. Two of the participants are design engineers with up to one year experience in their current company, from which one of them has 6 months experience in a different company. One participant has been working as problem manager for 5 months and other participant has been working as development engineer for a year.

Understanding of knowledge management

All participants have a similar understanding of knowledge and knowledge management. Typical examples of knowledge are for them "ability to use CATIA", "ability to synthesise ideas", "know-how", "language" or "knowledge about the company structure". Knowledge management is for them the management of "knowledge resources", "experiences" and "lessons-learned", which is associated mostly with the following activities: "transfer", "document" and "coordinate". As the reasons to implement knowledge management, the participants named "avoid knowledge loss from employees leaving the company", "avoid reinventing the wheel", "work faster" and "efficiency". All participants but one (P2) consider knowledge management important for them for reasons such as "know what is going on in the company", "know who knows what", "transfer my knowledge to others" and "help others use what I made". The one participant who answered that knowledge management is not important for him, distinguishes between knowledge management at "company level" and at "individual level". This participant recognises the importance of knowledge management "at

the level of the company and its resources" but he argues that individual knowledge management "forces you to be organised but it also requires time for it".

Company's knowledge management

Generally, the participants consider their companies concerned with knowledge management, although to different extents. Two companies (A and C) seem more concerned than the others. These companies are well-organised, "everything" is documented and they have "data bases" or "repositories (intranet)". Most of the other companies are concerned but their engagement to knowledge management implementation seems scarce based on comments like "it does not exist a specific department for knowledge management" or "the company makes efforts in this direction". P4 talked about his experience in two previous companies, which were not concerned with knowledge management since "there was not even consistency naming the files" and "no coordinated developments". P5 pointed the lack of concern for the need of aligning knowledge management between service client company and service provider.

The application of non IT-based methods like mentoring, training or communities of practices is common in the companies included in the study. P4 said "communities of practice are used often and they are useful". Also the use of IT-based methods like internal chats, databases, wikis, social networks or document managers is broadly extended. P3 pointed that "there is a chat but it is not used. I think it is necessary […]".

All participants answered that there are no incentives for knowledge sharing and reuse in their companies.

Tasks' knowledge requirements

The routine tasks of the participants are mostly development and simulations of virtual designs or models. The periodic tasks are preparing presentations or reports, attending meetings and searching information. Sporadic tasks involve working with physical prototypes, meeting people from other departments, attending courses or fairs.

The necessary knowledge for those tasks is analogue to the knowledge mentioned in point C) Understanding of knowledge management. All participants state strongly that they do not always possess the knowledge they need. They used to miss informatics knowledge, since they are not able to solve problems with the software when it crashes. Parts requirements and characteristics are also commonly mentioned. Three of the participants would not only like to have the requirements but also the reasons for those. They miss know-why and they claim that "this could avoid mistakes".

Knowledge acquisition/transfer in interviewee's company

Various ways of finding the missing knowledge are mentioned by the participants. The most popular ones are searching in digital repositories (intranet) for old projects, in internet, and asking colleagues. Also checking internal manuals was often mentioned. The participants face various problems in their search. The most commonly mentioned problem is the bad organisation of the intranet or its IT-limitations. Another problem is the limited access to the documents and therefore the need of getting credentials (which take even days to be

approved) or not being allowed to search personally in the intranet. In some companies "there is no access to documents from previous designs. This leads to reinventing the wheel". P2 mentioned the lack of an index for non-digital material and for P7 the problem is that people don't answer the phone.

Asking for someone's help is mostly done by direct contact per email, phone or meeting. P1 and P7 also use a chat, and P3 mentioned WhatsApp. Company C has an "intra-firm transportation system (an intern drives a car and it is useful to make contacts)". The problems experienced while asking for help are various. Most participants reported too much time is wasted waiting for answers, which can lead to the expiration of licences for data sharing. P6 and P7 experience difficulties finding available meeting rooms. P5 commented that "accessing employees from high positions is difficult and it takes time".

The methods used to learn a task for the first time are similar in all companies. Mentoring, manuals, checking in internet and trainings are broadly extended. P5 comments that they can use presentations from past trainings (or workshops) to learn on their own. However, the presentations do not contain all necessary knowledge and he thinks that "there should be more documentation and it should be in English because there are many international employees". Regarding the efficiency of using manuals, P3 comments that "they are efficient for the company but not for your knowledge. You learn the process but don't understand it".

Knowledge networks or repositories in interviewee's company

Storing knowledge in repositories is generally considered as necessary but there are different opinions regarding what should be documented. P2 thinks that basic knowledge does not need to be documented, whereas P5 and P6 think that it is precisely the basic knowledge (basic routines and systems) which should be documented and stored in company's repositories. P7 points out that it is "better not documenting too complex tasks". All participants stated that there isn't any kind of rating or credibility indicator in their companies to check the quality of the knowledge or information available in their repositories. Regarding their personal contribution to improve the quality of the documents stored, two cases can be distinguished; some participants contribute actively by creating new versions to update and correct mistakes, and some participants do not contribute actively, they are just users who are not allowed to modify documents on their own or they simple do not have access to previous documents. They may give feedback in meetings if they find mistakes.

Conflicts in interviewee's company

Four participants reported different conflicts between knowledge sharing/reuse of protocols and the team's work: writing reports causes rejection due to repetition, senior employees are not open to changes, there is lack of time to fill reports and the bureaucracy slows down the work. The main barrier to access knowledge, mentioned by five participants, are licenses, which come along with various problems: it is unclear who can get a license for what, licenses arrive too late causing delays and version changes. P1 points out the importance of "documenting the responsible persons", since many times it is needed to call someone to find out how to get a license. P5 reported an additional barrier: the client company does not want to give know-why, which could avoid mistakes. The main reason for not using knowledge

when it is available is that handbooks and manuals offer too vague or general knowledge, so they are not helpful. P6 states "in the end I had to check in internet". Two participants report that getting other knowledge would not improve their efficiency, whereas four participants agree that getting knowledge would improve their efficiency. Some of the knowledge mentioned were "soft skills", "know-why" and "knowledge about the development status in other departments". P7 misses in his company more cross-department connection and as a result "departments make twice the same thing".

Knowledge documentation in interviewee's company

All participants document the knowledge and information generated during their tasks performance, but they do it in different ways. Two participants reported the knowledge to be documented in the meetings' protocols. P3 documents all design changes in an Excel file including "personal data, date, index, type of change and version control". Some other participants mentioned project reports, summary presentations for managers or saving emails. Most companies have standard templates for presentations and reports, although in the case of P2 those templates are not for everything and P3 refers to them as "suggested templates". Standard coding for files, standard colours and version managers for CATIA are also extended practices. Best practices are usually documented, just P6 states that this is not explicitly done in his company. There are basically two ways of documenting best practices: 1) in presentations, meeting protocols and reports; 2) informal or freely with small annotations/recommendations. P5 also talked about the use of the documented best practices and he said that "the client company either does not use them or they do it wrong".

Efficiency perception and further information

Based on the issues addressed on the previous blocks, all participants consider that their work and their teamwork could be more efficient. Three participants explicitly mentioned the following ways to improve efficiency: "more efficient and flexible data protection system", "faster licenses management and less bureaucracy", and "faster access to information and intelligent search". As final remarks P4 highlighted the differences in knowledge management between the three companies in which he had worked and P7 stated that "people are not concerned with documenting knowledge and it should be given more importance to that".

3.2.3 Conclusions and Implications for the Support

This interview study provided an understanding of current knowledge management practices in industry. The study revealed that companies are generally concerned with knowledge management and they already apply a large number of IT-based and non IT-based methods supporting knowledge management. However, knowledge reuse is in the end not used as much as expected. Employees report lacking knowledge to perform their tasks but they have problems to find and reuse company's knowledge.

The lack of strategic planning in the implementation of knowledge management methods seems to be the major reason for low knowledge reuse. Knowledge management methods are implemented but without consideration of target users, processes involved, control and

maintaining issues. This leads to situations such as chats being available but not being used, limitations for knowledge accessibility due to credentials or experts lacking the time to transfer their knowledge to others. The application of knowledge management is extensive but not goal-oriented. Consequently, the support to be developed should enable the **strategic planning** of knowledge management methods in order to achieve knowledge reuse in the areas of the company in which it is required by using the appropriate methods.

The interview study exposed the large amount of knowledge that is possessed by engineering companies. Amongst others, parts requirements, parts characteristics, know-why, soft skills and knowledge from other departments were named. A common problem searching in this vast amount of resources is the lack of overview of the company's existing knowledge. Bad organisation of intranets, lack of index for non-digital material or lack of documentation of responsible persons were reported as problems regarding knowledge search of employees. Therefore, the support to be developed should facilitate the **knowledge acquisition** and **visualisation**. A knowledge overview is not only necessary for the active knowledge search and reuse but is also required in order to proceed with the strategic planning of knowledge management methods.

Furthermore, this study confirms the different perceptions and expectations of individuals when it comes to knowledge management, especially concerning which knowledge should be documented and how it should be transferred. The need of **individual consideration** to achieve successful knowledge reuse was already discussed in the research gap (Subsection 2.4.1) and it is one of the main assumptions for the DS I and the whole thesis.

3.3 Individual Influencing Factors for Knowledge Reuse

In order to understand which factors are influencing the knowledge reuse of individuals, a systematic literature review was conducted. A model was created first to represent the process of knowledge reuse from individuals' perspective. Subsection 3.3.1 introduces the Worker-Centred-Model (WCM) including the reasons for its creation as well as its theoretical foundation. Subsection 3.3.2 presents the systematic literature review of influencing factors and the factors' allocation to the processes of the WCM. Finally, the conclusions and the implications for the support are discussed in Subsection 3.3.3.

3.3.1 The Worker-Centred-Model (WCM)

Numerous authors from literature have analysed the factors influencing knowledge management and they have associated them to the organisational processes (company level) of knowledge management (Long and Fahley 2000; Rego et al. 2009; Lotti Oliva 2014; Ranjbarfard et al. 2014). However, as it was discussed in the research gap (Subsection 2.4.1), there is a lack of consideration of how individuals experience knowledge management and specifically knowledge reuse. The need for differentiation between knowledge management at company's level and at individual level was also reported in the interviews of Section 3.2 and it seems key to understand the lack of knowledge reuse in industry. Organisational processes are necessary for knowledge reuse but they are not enough for actually applying knowledge in the company. The decision of applying knowledge depends ultimately on individuals

(Davenport and Prusak 2000) and therefore, individuals should constitute the focus on understanding of what leads to successful knowledge reuse.

The **Worker-Centred-Model (WCM)** was developed to describe the processes experienced during knowledge reuse from the point of view of individuals or knowledge workers, defined as a workers whose main capital is their knowledge (Goncalves 2012). Influencing factors can be allocated to the processes described in the model. The WCM was published in Carro Saavedra et al. (2015).

Theoretical Foundation

The WCM is based on three theoretical pillars:

- **Knowledge-based view** of the firm[1] (Grant 1996): it provides a framework for understanding the company, its elements and their relations. The knowledge-based view considers the company divided in the following elements: knowledge stocks (individuals or artefacts), knowledge flows and knowledge enablers (individuals).
- **SECI model** (Nonaka and Takeuchi 1995): it describes the processes of knowledge creation in an organisation. Knowledge is created by a continuous and dynamic interaction between tacit and explicit knowledge through the processes of socialisation, externalisation, combination and internalisation. The SECI model was presented in Subsection 2.1.3.
- **Theory of Planned Behaviour** (Ajzen 1991): it describes the factors regulating the performance of a behaviour, being the behaviour in the case of the WCM „knowledge application" as the final step in the process of knowledge reuse. The three factors influencing individual's behaviour are the following:
    - Attitude toward behaviour: "degree to which a person has a favourable or unfavourable evaluation of the behaviour".
    - Subjective norm: "perceived social pressure to perform or not to perform the behaviour".
    - Perceived behavioural control: "perceived ease or difficulty of performing the behaviour. It is assumed to reflect past experience as well as anticipated impediments and obstacles".

  These three factors influence individual's intention to perform the behaviour that in consequence leads to the actual performance of the behaviour.

View of the Company

The WCM view of the company is presented in Figure 3-1. Inspired by the knowledge-based view of the firm, the view of the company for the WCM defines the knowledge unit as the focus of analysis. **Knowledge units** have flexible boundaries and they can include

[1] The word firm is used in this Section in order to preserve the original wording of Grant (1996). Firm refers to company according to terms' understanding of this thesis (see Section 2.4.2).

individuals, **artefacts**, or both. For example, one individual's physical body (individual) can be a knowledge unit. A group of individuals' physical bodies (individuals) and their computers (artefacts) can also be a knowledge unit. This view allows the understanding of the processes experienced during knowledge reuse in the context of the company in which there are **knowledge flows** between the units. The boundaries of the knowledge units are determined depending on the purposes of the study using the WCM.

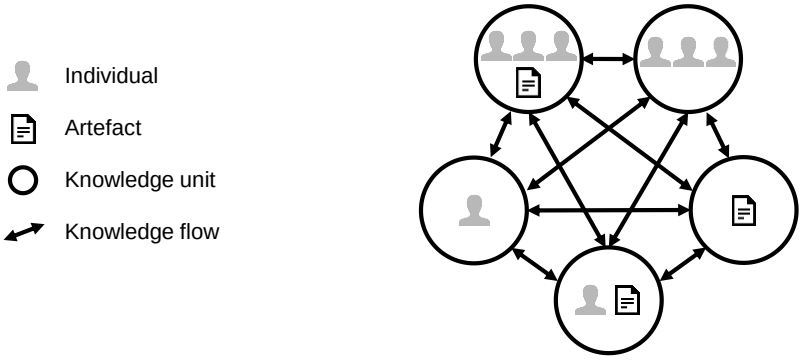


Figure 3-1: WCM view of the company (Carro Saavedra et al. 2015)

Knowledge Processes

The WCM considers that in order to reuse knowledge, a knowledge unit experiences the processes of knowledge transfer, knowledge integration, knowledge creation, and knowledge application.

Knowledge transfer is "the process by which knowledge available within one unit of the organisation (individual, team or a division of organisation) is made available to other unit(s) of the organisation" (Manohar Singh and Gupta 2014, p. 780). Knowledge transfer implies a flow of knowledge between a sender and a recipient, which are both knowledge units. Transfer is different from sharing because it implies a clear direction of the knowledge flow. Knowledge transfer requires a deliberated action of knowledge flow from A to B whereas knowledge sharing can be conceptualized as the general concept of spreading knowledge.

Knowledge integration/creation is the process of integrating external knowledge that has been transferred to a knowledge unit, with previously existing internal knowledge in order to create "new knowledge" (Grant 1996). The definition of what is internal or external knowledge depends on the definition of the boundaries of the knowledge unit to be considered. As example, if the unit contains an individual person, the boundaries can be established at the individual's physical body or they can include the documentation the individual has direct access to, such as e.g. files saved in his/her computer. The definition of boundaries depends on the particular purposes of each study. According to the SECI model, knowledge integration leads to knowledge creation, which occurs in people's heads (Davenport and Prusak 2000). "New" knowledge is created as outcome of the integration

process. The WCM considers that knowledge integration and creation are so much intrinsically related that they can be defined as one process occurring in the individual's mind.

Knowledge application is the process that turns knowledge into effective action and it is the source of company's competitive advantage (Alavi and Leidner 2001, p. 129). This action is possible due to the contribution of knowledge in decision-making. Thus, knowledge gives the "capacity to act" (Nonaka and von Krogh 2009), i.e. to perform behaviour. The performance of the behaviour is explained by the Theory of Planned Behaviour.

The three processes described are mutually dependent processes; one cannot exist without the others. Figure 3-2 depicts in a knowledge unit the process from knowledge transfer to integration/creation and application, and then to integration and transfer again. As an example, the knowledge unit of Figure 3-2 comprises one individual (knowledge stock and enabler at the same time). The individual as knowledge enabler integrates knowledge that is transferred from external stocks (arrow 1) with the internal stocks of knowledge. The integration occurs according to the processes of the SECI model of knowledge creation. The newly created knowledge (arrow 2) serves as an input for the Theory of Planned Behaviour, which can lead to the output of knowledge application. Knowledge application initiates a learning-by-doing effect because the outcomes of the application are integrated into the knowledge stocks of the unit (arrow 3). Knowledge is transferred to other units when it crosses the boundaries of the knowledge unit itself (arrow 4).

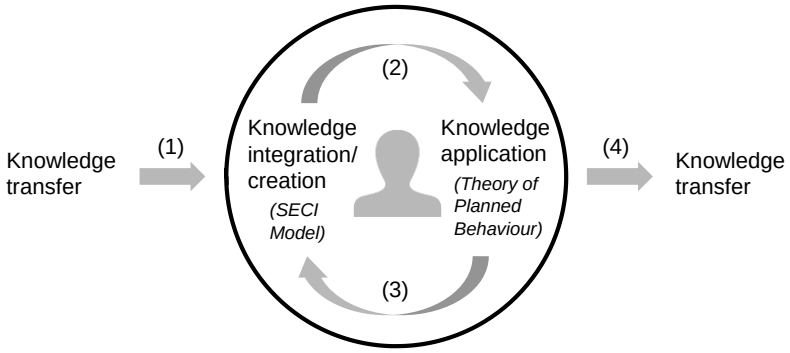


Figure 3-2: Knowledge processes for a knowledge unit (Carro Saavedra et al. 2015)

Since knowledge application is defined as an action, the WCM can be used not only to describe the classical application of knowledge to solve design issues, but also to describe other actions performed by knowledge units during knowledge reuse, such as seeking for knowledge, documenting knowledge or modifying documents. For example, in the case of documenting knowledge, knowledge learned from praxis is integrated within the prior KB (arrow 3) creating new knowledge (arrow 2), which the individual applies creating a document (arrow 3). This document can then remain inside the knowledge unit boundaries, or can be transferred (arrow 4) to another knowledge unit (artefact for example); these two possibilities depend on the definition of the boundaries.

The Model

The WCM is presented in Figure 3-3. The model proposes that knowledge transfer affects knowledge integration/creation, which affects knowledge application. Thus, knowledge integration/creation has a moderating role on the impact of knowledge transfer on knowledge application. Numerous factors influence the knowledge processes and the WCM proposes a one-to-one factor type-process influence. The following types of influencing factors affect each one of the three knowledge processes:

- Knowledge transfer is mainly influenced by factors related to the company's **infrastructure**. Gressgård (2014) stated that technical infrastructure directly impacts knowledge transfer. IT systems have a strong impact on knowledge sharing among team members (Choi et al. 2010). The organisational infrastructure is also influencing because organisational roles help sharing and integrating knowledge and a team-based structures help coordinating individuals with specialist knowledge (Grant 1996).
- Knowledge integration/creation is mainly influenced by factors related to the **knowledge** itself. They represent characteristics of the transferred knowledge (e.g. knowledge breadth and depth (Majchrzak et al. 2013)) or characteristics of the relation between sender and receiver's knowledge that determine to which degree the receiver possesses a common KB to integrate the knowledge transferred (Alavi and Leidner 2001).
- Knowledge application is influenced by **psycho-social** factors which explain individual's behaviour. Those factors, described in the Theory of Planned Behaviour (Ajzen 1991), are directly influenced by the outcomes of the process of integration/creation.

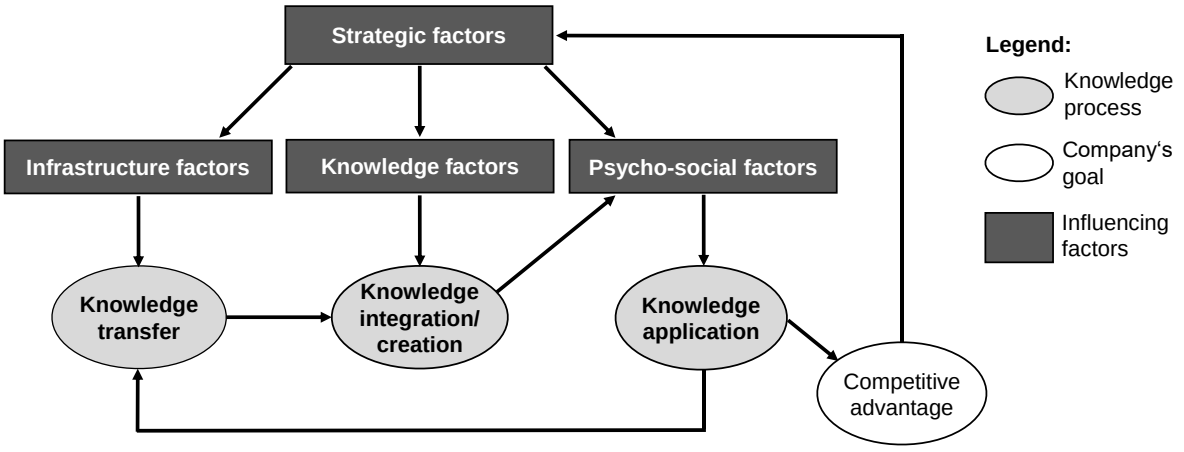


Figure 3-3: Generic WCM (Carro Saavedra et al. 2015)

The infrastructure, knowledge, and psycho-social factors influence directly one process and indirectly the other two. Company's strategy, characterised by strategic factors influences directly the other types of factors (Zack 1999a), and indirectly the three knowledge processes. Strategy is defined as "a set of actions that the managers take to increase their company's performance goals" (Hill et al. 2015, p. 33). At the same time, company's strategic factors are influenced by the type of competitive advantage desired by reusing knowledge.

3.3.2 Systematic Literature Review and Factors Allocation to the WCM

In their guidelines for literature review, Webster and Watson (2002) point out that "the major contributions are likely to be in the leading journals". Therefore, journals were the selected source for this review. A review of the last five years before review date (2010 to 2015) in three relevant journals of the engineering design field (Journal of Engineering Design, Design Studies, and Research in Engineering Design) did not reveal any study regarding factors influencing knowledge management or knowledge reuse. Therefore, the scope of the search was extended to the field of knowledge management, which offers numerous literature discussing influencing factors. The assumption for this literature review is that factors considered in the superordinate field of knowledge management, are also representative for the field of engineering design. This assumption is consistent with the interviews presented in Section 3.2, in which engineers named influencing factors like structure of knowledge repositories or language, which are factors commonly discussed in knowledge management literature.

The WCM was used to classify the types of influencing factors found in literature. The systematic literature review was conducted in November 2015 and it was published in Fernandez Miguel et al. (2016).

Methodology for Review and Analysis

The methodology to review and analyse the results consisted of seven steps. A table in Appendix 9.5.1 shows the steps, the specific conditions applied on each of them and the results obtained.

Step 1 was the **selection of the leading journals**. The search was done in Web of Science searching in all text fields with the term "knowledge management AND (barrier OR factor)". The word knowledge management was selected for the search because the term knowledge reuse provided few results. The three journals with the greatest number of results between 2005 and 2015 were selected: Journal of Knowledge Management, Knowledge Management Research & Practice, and Information & Management.

Step 2 was the **selection of relevant papers**. All papers between the years 2005 and 2015 that contained in the title the words "factor" or "barrier" were selected. A total amount of 43 papers were selected. The DOI of the selected papers are listed in Appendix 9.5.2.

Step 3 was the **collection of all factors** appearing in the papers that were accessible and reviewed. In total, 364 factors were collected.

Step 4 was **filtering out of scope factors**. Factors were discarded according to the following criteria: they were too abstractly defined (e.g. absorptive capacity); their impact crossed company's boundaries (e.g. clash of personalities between organisations); they were a process or strategy rather than a factor (e.g. knowledge transference); they were variables that predict individuals' behaviour (e.g. lack of positive attitude). In total, 110 factor were discarded.

Step 5 was **filtering of duplicated factors**. Numerous factors were exact duplicates and many others referred to the same concept using different terms. Different terms were considered duplicates in the following cases: the term was described as a barrier or enabler in

one paper and as an influencing factor in other (e.g. arduous relationship and relationship); the terms were synonyms or antonyms (e.g. untrustworthiness and trust); one factor was more restrictively defined than the other (e.g. interpersonal trust and trust). In total, 112 factors were discarded as duplicates in this step, resulting a final list of 142 items.

Step 6 was the **classification into the four WCM categories**. The classifications of the 142 factors into the categories was done according to the personal interpretations of the review authors that was supported by the statements contained in the reviewed sources. 26 factors were allocated to infrastructure factors. The category of knowledge factors included 16 factors. 77 factors were allocated to the category of psycho-social factors and 23 factors were included in the category of strategic factors.

Finally, **step 7** consisted of **grouping into similar factors**. In order to obtain a manageable number of factors to be included in the WCM, the factors of each category (also defined as barriers, i.e. negatively like e.g. untrustworthiness) were grouped. In the end, 21 final factors were defined. Those 21 influencing factors were defined in a neutral way, i.e. they are defined as influencing factors and not as barriers. The grouping was done according to the personal interpretations of the review authors that was supported by the statements contained in the reviewed sources. Figure 3-4 shows the WCM including the influencing factors resultant from the systematic literature review and analysis. More information about the reasoning followed and examples are described in Fernandez Miguel et al. (2016).

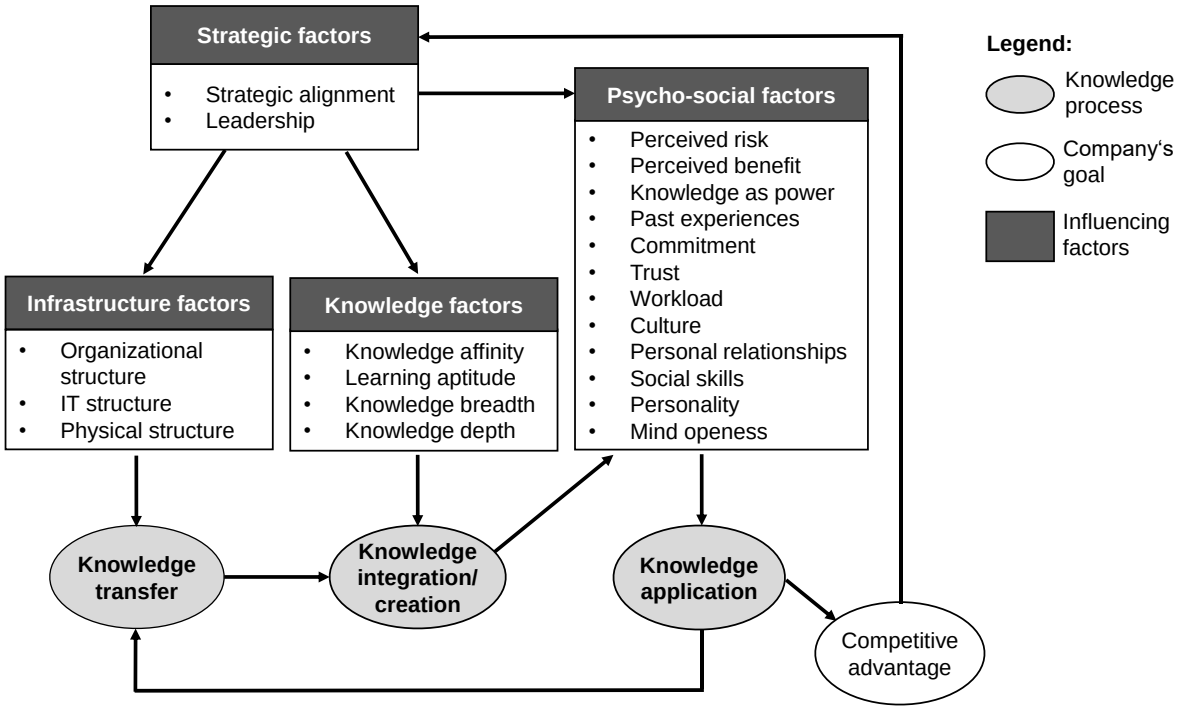


Figure 3-4: Worker-Centred Model (WCM) depicting the final influencing factors (Fernandez Miguel et al. 2016)

The following blocks present the definitions of the 21 influencing factors resulting from the literature review and analysis. The factors are presented in the four categories of the WCM. The definitions were created for this thesis based on the understanding gathered from the descriptions contained in the original sources. The similar factors from original sources which were grouped to each one of the final influencing factors are presented in Appendix 9.5.3.

Infrastructure Factors

Infrastructure factors are defined as those that ease or hamper the transfer of knowledge from one knowledge unit to another by means of crossing the boundaries of both units. Three factors are included in the category of infrastructure factors:

- **Organisational structure**: it is the distribution of the company's human resources (hierarchies, departments, teams, etc.) and the company's processes that to carry out the employees' work.
- **IT structure**: it is the implementation of IT systems such as intranets, email, chat-clients, and/or videoconferencing systems that your company provides for knowledge management and coordination.
- **Physical structure**: it is the arrangement of people (and other resources such as meeting rooms, meeting places, etc.) within buildings. This also includes the positioning of departments in the same or different buildings or in different cities or countries.

Knowledge Factors

Knowledge factors affect the efficiency of knowledge integration/creation. Those factors represent the characteristics of the transferred knowledge or the characteristics of the relation between sender and receiver's knowledge. Four factors are included in the category of knowledge factors:

- **Knowledge affinity**: it describes how easy it is for one or various individuals to understand the knowledge received based on what they already know.
- **Learning aptitude**: it is the ability to learn new things and understand how they can be used.
- **Knowledge breadth**: it indicates to which degree knowledge can be generalised and applied to different situations.
- **Knowledge depth**: it indicates to which degree knowledge is detailed and specific to restricted situations.

Psycho-social Factors

Psycho-social factors represent individual/environmental characteristics and perceptions that influence individuals' behaviour towards knowledge application. Twelve factors are included in the category of psycho-social factors:

- **Perceived risk**: it describes the personal perception of negative effects that can occur due to an act of knowledge reuse.
- **Perceived benefit**: it describes the personal perception of positive effects that can occur due to an act of knowledge reuse.

- **Knowledge as power**: it is the perception that knowledge can be used to maintain a competitive position in the company (uniqueness, reputation, etc.) or to lose it (criticism, exposure, etc.).
- **Past experiences**: they can be positive or negative. These experiences allow the establishment of analogies for new situations from memories.
- **Commitment**: it indicates the degree to which employees are ready to work for the success of the company.
- **Trust**: it is the belief in the reliability, truth or ability of a person or thing.
- **Workload**: it describes the relationship between the time it takes to complete a task and the length of the time-window to perform it.
- **Culture**: it describes the behavioural characteristics of a particular social group (company, country, etc.).
- **Personal relationships:** they describe the interaction between two or more people.
- **Social skills**: they are the ability to communicate, persuade, and interact with others without causing inappropriate conflicts or disagreements.
- **Personality**: it represents the different mental attitudes of a person.
- **Mind openness**: it means being open to others' views, ideas and knowledge.

Strategic Factors

Strategic factors are the actions managers take to influence the infrastructure, knowledge and psycho-social factors. Two factors are included in the category of strategic factors:

- **Strategic alignment**: it is the degree to which the different resources (IT, buildings, daily meetings, available knowledge, etc.) are coordinated to meet common goals.
- **Leadership**: it is the ability of company's leaders to create an environment in which employees seek and share the knowledge they need.

3.3.3 Conclusions and Implications for the Support

The systematic analysis of the literature review resulted in 21 factors influencing individuals' knowledge reuse. This result provides an answer to RQ2. Four types of factors have been identified: strategic, infrastructure, knowledge-related, and psycho-social factors. The psycho-social factors are considerably more in number than the factors from other categories. This confirms the importance of considering individuals' characteristics and perceptions for the practice of knowledge reuse. Also in the category of knowledge-related factors there are factors, such as knowledge aptitude, which refer to individuals' characteristics. As it was discussed in Subsection 2.4.1, current knowledge reuse approaches do not consider this fact enough. Therefore, the support to be developed should **enable the analysis of individual characteristics and perceptions.**

The WCM provides a new approach to describe individual influences for knowledge reuse. The model is an attempt to understand a phenomenon that has been rarely studied (knowledge reuse) from a point of view that has been considered less despite its significance (individuals point of view) until now. The effort in synthesis and the allocation of the factors to one unique model, facilitates the intuitive understanding of the large amount of hardly comparable

literature results. Thus, the WCM is a feasible tool for further research on knowledge reuse and to support its practical application.

The WCM can be used by researchers as a reference model for the development of new approaches to support knowledge reuse. In practice, the factors of the WCM can be used as a checklist to evaluate the current status of factors influencing knowledge reuse for individuals. Different impressions may come up since the whole idea of the model is that individuals perceive differently the processes involved in knowledge reuse. Based on this analysis, methods to individually address the influencing factors can be selected and applied. Then, the checklist can be used again to evaluate the impact of the new implemented methods. Two industry experts confirmed the practical applicability of the WCM since "the model gives the impression that it is reduced to the required and therefore easy to understand. We believe that the acceptance of a model for knowledge management is directly linked to its clarity." Therefore, the **WCM** will be considered as a **tool** to be **used in the support** to be developed in this thesis.

Since the WCM depicts the knowledge processes in a cycle and the processes influence each other, it seems logical to assume that the more one process occurs, the more the other processes will occur (if the respectively factors influence positively to a certain extent). The cycle feeds itself. For example, if knowledge is transferred regularly in a team through weekly meetings, it is more likely that the participants integrate/create knowledge that they later on apply and continue transferring. Basically, making a habit of the knowledge processes keeps the cycle going on and it increases automatically knowledge reuse in the company. Thus, habit is a major influencing factor and it is common to all individuals. This implies that the support to be developed should **foster the implementation of habits and routines** for knowledge reuse.

3.4 Exploratory Design Experiments (EDE)

Two exploratory design experiments (EDE) were conducted in order to improve understanding of individuals' needs and behaviours through observation of documented knowledge reuse, i.e. reuse from KBs, outside the industrial environment. Exploratory design experiments correspond to the method "investigating user behaviour" proposed by Blessing and Chakrabarti (2009, p. 278) amongst the methods for analysing objectives and establishing requirements for support. Exploratory design experiments belong to non-experimental research, which is normally not sufficient for permitting strong tests of causal hypothesis but are useful for suggesting new ideas (Blessing and Chakrabarti 2009, pp. 267–268). The results of the exploratory design experiments provide insights to develop support for knowledge reuse that considers individuals' characteristics. Subsection 3.4.1 presents EDE I which was part of the student project of Salas de Arribas (2015). EDE II took place within the work of Montesa Rausell (2016) and it is presented in Subsection 3.4.2. Finally, the conclusions and implications for the support are discussed in Subsection 3.4.3.

3.4.1 EDE I: Observing "barrier-free" Knowledge Reuse

This Subsection presents the motivation, goal, experimental set-up and results of the EDE I.

Motivation and goal

The **checklist** suggested by Blessing and Chakrabarti (2009, pp. 243–244) for determining the characteristics of empirical studies served as base for the preparation. Table 3-3 presents the dimensions of the checklist considered suitable for this exploratory design experiment.

Table 3-3: Checklist for determining the characteristics of EDE I

Dimensions	**Option selected for the study**
Aim, Research Question (RQ), Hypothesis (H)	H: The awareness of knowledge availability does not assure knowledge reuse
Nature of the study	Observational, non-comparative
Unit(s) of analysis	Amount of knowledge requested and reused
Data-collection method	Participant observation in controlled environment, questionnaire
Role of researcher	Preparation of experimental set-up, interface to KB and experiment supervision
Time constraint	2,5 hours
Observed process	Reuse of knowledge from KB during individual product design (from initial idea to design specification)
Setting	Design workshop with predefined procedure
Task	Realistic product design
Number of cases	One design problem
Case size	Three participants
Participants	Engineering design students in last year of Master
Object	Design a solution to carry out reparations under bridges in Munich
Coding and analysing method(s)	Researcher documents knowledge requests and knowledge provided. Participants document their solutions and answered a questionnaire.

The hypothesis of EDE I is that the awareness of knowledge availability does not assure knowledge reuse. The background idea behind this hypothesis is the following. Literature often states that knowledge is not reused because of several barriers derived from the complexity of industrial environments. In this context, employees are often not aware of the existence of knowledge in the company. This seems to imply that if they were aware, knowledge would be reused. Searching for knowledge is also difficult within complex company's structures and numerous processes. However, there are probably other individual influences causing that even when there is awareness of knowledge availability, knowledge is not reused. The **aim** of this exploratory design experiment is observing the amount of

knowledge requested and reused during product design in a "barrier free" environment in which the existence and availability of useful knowledge for the task contained in a KB is assured.

Experimental Set-up

EDE I consisted of a design workshop in which three engineering design students in their last year of Master (considered as novice designers) were given a **design task** to solve in 2,5 hours. The overview of the procedure is presented in Figure 3-5. The study was observational and non-comparative. Participants had to follow a predefined procedure consisting of three phases: 1) idea conception, 2) conceptual design, and 3) detailed design. Each participant had to document sketches of their solutions and provide them to the researcher as output for each phase. There was no time constraint per phase; each participant decided when to conclude it. The task consisted of designing a solution to carry out reparations under bridges. The following considerations had to be taken into account:

- The bridges are located in Munich
- The reparation work is performed during 4 h per day
- The repair material can weigh up to 400 kg
- The height of the bridges is between 6 m and 15 m above ground level
- The width of the bridges is between 3 m and 7 m

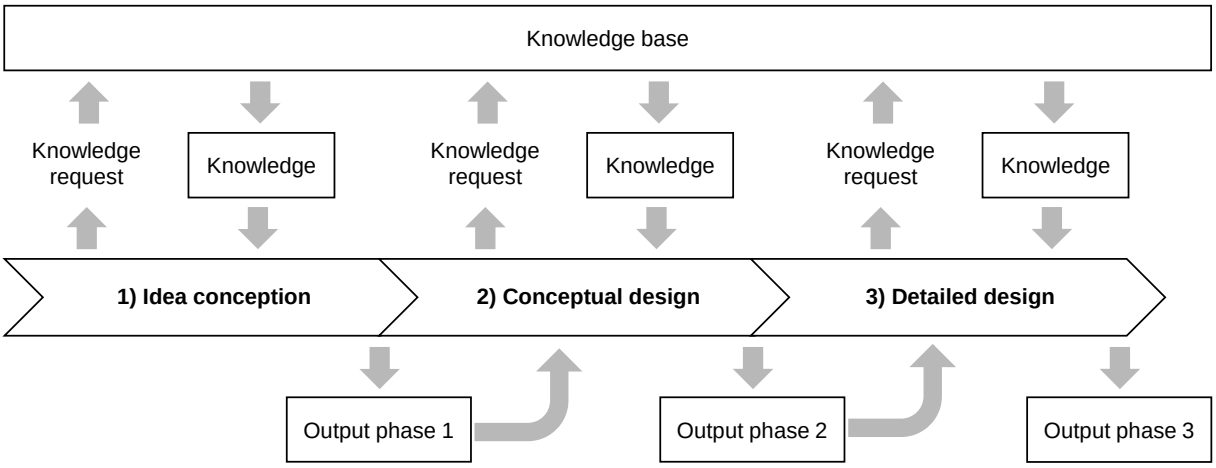


Figure 3-5: Procedure during EDE I

During the design task, the participants could **access a KB** containing relevant knowledge for the task and they also had internet access. The KB was prepared in advance by the researchers and it contained knowledge in form of knowledge pages according to the framework for structuring and representing specific design knowledge proposed by Cross and Sivaloganathan (2007). The framework includes the following categories of knowledge: country or market-specific requirements; preferred parts & installation requirements; knowledge contacts; experience, best practice, tips & tricks; parameters & typical values; interactions, trade-offs & design rules; stakeholder behaviour; legislation; manufacturing

processes & materials; and stakeholder requirements. The complete KB documentation is contained in Salas de Arribas (2015). The participants did not have direct access to the KB but the researcher acted as interface. In order to access the KB, the participants formulated a written knowledge request to the researcher, who acted as an intelligent search engine providing them with the knowledge corresponding to their request.

The role of the researcher was the preparation of the experimental set-up, interface to KB and experiment supervision. The amount of knowledge requested by participants and provided by the researcher from the KB was measured.

After the experiment, the participants had to rate from "completely disagree" to "completely agree" the following statements regarding their experience during the design process:

1. You asked questions to the KB
2. It was easy to formulate knowledge requests
3. You used to receive knowledge for your requests
4. When you received knowledge, it was what you expected
5. When you received knowledge, it was easy to understand it
6. When you received knowledge, it was useful for your work

In case they disagreed, they were asked to comment on reasons for that.

Results

Table 3-4 presents the **amount** of **knowledge** requests (Req), accepted knowledge requests (A. Req) and knowledge pages provided (K Prov) per participant and design phase. Requests (Req) and accepted requests (A Req) are differentiated because in some cases the participants formulated requests for which there was no correspondent knowledge in the KB. Accepted requests (A Req) are those requests for which knowledge was provided.

Table 3-4: Knowledge requests (Req), accepted knowledge requests (A. Req) and knowledge provided (K Prov) during EDE I

	Idea conception			Conceptual Design			Detailed Design		
	Req	A. Req	K Prov	Req	A. Req	K Prov	Req	A. Req	K Prov
P1	2	0	0	1	1	2	6	0	0
P2	0	0	0	0	0	0	0	0	0
P3	7	3	6	0	0	0	0	0	0

Participant 1 (P1) made requests in the three design phases and most of requests were formulated for the detailed design. Participant 2 (P2) did not make any knowledge request during his design. Participant 3 (P3) made all requests in the idea conception phase and then finished the design without formulating new requests.

After the experiment, the three participants answered the questionnaire. Table 3-5,

Table 3-6 and Table 3-7 show their answers.

Table 3-5: Answers of Participant 1 (P1)

		Completely disagree	Disagree	Neutral	Agree	Completely agree
1	You asked questions to the KB					x
2	It was easy to formulate knowledge requests					x
3	You used to receive knowledge for your requests		x			
4	When you received knowledge, it was what you expected			x		
5	When you received knowledge, it was easy to understand it					x
6	When you received knowledge, it was useful for your work			x		

Table 3-6: Answers of Participant 2 (P2)

		Completely disagree	Disagree	Neutral	Agree	Completely agree
1	You asked questions to the KB	x				
2	It was easy to formulate knowledge requests		x			
3	You used to receive knowledge for your requests	No answer				
4	When you received knowledge, it was what you expected	No answer				
5	When you received knowledge, it was easy to understand it	No answer				
6	When you received knowledge, it was useful for your work	No answer				

Table 3-7: Answers of Participant 3 (P3)

		Completely disagree	Disagree	Neutral	Agree	Completely agree
1	You asked questions to the KB					x
2	It was easy to formulate knowledge requests					x
3	You used to receive knowledge for your requests				x	
4	When you received knowledge, it was what you expected			x		
5	When you received knowledge, it was easy to understand it				x	
6	When you received knowledge, it was useful for your work				x	

The two participants who requested knowledge (P1 and P3) found easy to formulate requests. They did not always find the required knowledge in the KB but when knowledge was provided, it was easy to understand and it contributed to a certain extent to their work. P3 commented that sometimes he did not receive what he expected but that the knowledge provided was still useful for other aspects of the design. The participant who did not make any request (P2) commented that he found difficult to formulate requests because he did not know what to ask. Since he did not formulate requests, he could not answer questions 3 to 6 of the questionnaire.

The complete set-up and results of EDE I including all designs, knowledge requests, questionnaire about the experiment and participants' answers are contained in Salas de Arribas (2015).

3.4.2 EDE II: Exploring Knowledge Reuse for Project Insiders and Outsiders

This Subsection presents the motivation, goal, experimental set-up and results of the EDE II.

Motivation and goal

The **checklist** suggested by Blessing and Chakrabarti (2009) for determining the characteristics of empirical studies served as base for the preparation. Table 3-8 presents the dimensions of the checklist considered suitable for this study.

Table 3-8: Checklist for determining the characteristics of the experiment

Dimensions	**Option selected for the study**
Aim, Research Question (RQ), Hypothesis (H)	H: Designer's familiarity with the knowledge contained in a KB has a direct influence on the preferred knowledge search method
Nature of the study	Interventional, comparative
Unit(s) of analysis	Preferred search method
Data-collection method	Questionnaire to participants
Role of researcher	Preparation of the KB, experimental set-up, interface to KB for one method and experiment supervision
Time constraint	None
Observed process	Knowledge search in KB using two search methods
Setting	Presentation of two cases for knowledge search
Task	Simulated knowledge search in KB
Number of cases	Two cases
Case size	Eight participants
Participants	Engineering design students in last year of Master. Four project insiders and four project outsiders.
Object	Find knowledge to support two cases of innovations required in the automobile sector
Coding and analysing method(s)	Participants rate and comment their preferences towards the search methods

The hypothesis of EDE II is that designer's familiarity with the knowledge contained in a KB has a direct influence on the preferred knowledge search method. The background idea behind this hypothesis is the following. Designers who have worked in previous projects, in which the knowledge was generated (project insiders), may feel more confident searching freely in a KB because they know its content. On the other hand, designers who have not participated in the knowledge creation (project outsiders) may need more target-oriented ways of supporting their search for knowledge in a KB because they may be overwhelmed by information in a free search. The **aim** of this exploratory design experiment is observing the behaviours of project insiders and outsiders using a KB with two search approaches and determine if there are different preferences depending on the group.

Experimental Set-up

The KB to be used in EDE II was prepared during a collaboration project between the Chair of Product Development of the Technical University of Munich and the BMW Group. This

project was used as Case Study for the support evaluation of this thesis and it is presented in Section 5.5. The configuration of the KB is explained in that Section. The KB presents an overview of the project's knowledge in two visualisations: one visualisation showing knowledge categories in hierarchical trees; and one visualisation showing the project documents used and generated in the project timeline (see Figure 5-3).

EDE II consisted of conducting individual sessions with eight participants to search knowledge on a KB for two design cases using **two search methods**. From the eight participants, four participants were project insiders (they participated in the collaboration project from which the KB was created) and four participants were project outsiders (they were not involved in the collaboration project from which the KB was created). The design cases were not related to the design tasks addressed in the project from which the KB was created. Hence, the design cases were new for both project insiders and project outsiders. The difference between both groups of participants was that project insiders were familiarised with the knowledge which was contained in the KB because they had worked in the project from which the knowledge was collected.

During the experiment, two design cases were presented to each participant. Each case proposed a design task and described the context of the design situation. Each participant had to search knowledge for Case I applying a filter-based search method (this method receives the name of Characterisation of Design Situation or CDS) and search knowledge for Case II applying free search on the KB (this method receives the name of Free Search in Visualisations or FSV). The two design cases proposed in the exploratory design experiment are contained in Appendix 9.6.1. Even though the correctness of the knowledge provided was irrelevant for the experiment, two different cases had to be planned in order to avoid that the second knowledge search was influenced by the knowledge gained after the first knowledge search. Figure 3-6 shows the experimental procedure. At the end, the participants were asked to select a preferred method and comment their reasons.

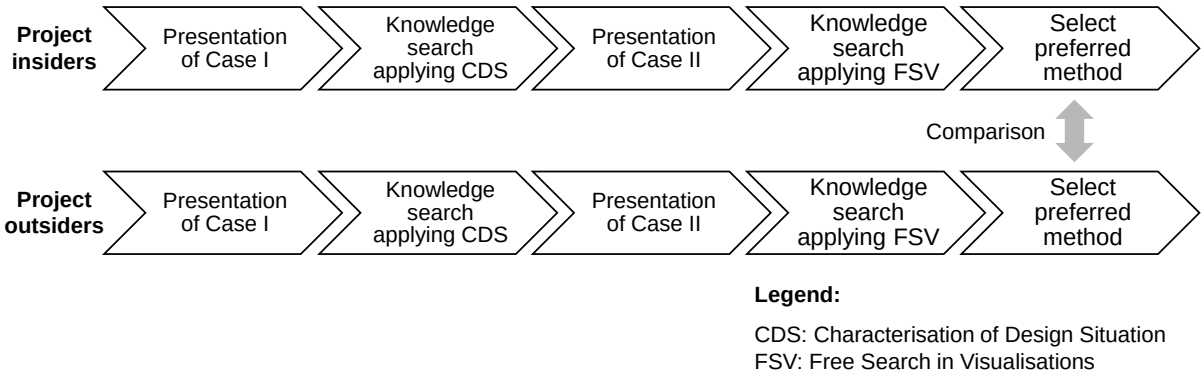


Figure 3-6: Procedure during EDE II

The search method applied for Case I received the name of **Characterisation of Design Situation (CDS)**. The participants had to characterise their design situation in Case I in order to receive knowledge from the KB. The design situation is understood as the context and

individual characteristics of a designer in his/her design place during design. Table 3-9 presents the characteristics and answers used in the experiment.

The CDS method is based on the hypothesis that for the same design situation (characterised by the same characteristics), the same documented knowledge (characterised by its metadata) may be useful for reuse (Carro Saavedra and Lindemann 2015). The metadata for the documents contained in the KB used for this experiment are presented in Table 5-2 in Section 5.5. Rules were established for different status of the characteristics of the design situation in order to associate the situation with the documents' metadata in the KB. The rules are include in Appendix 9.6.2. Those rules do not attempt in any case to be true. They were just created for EDE II as a guide for the researcher to provide knowledge from the KB rapidly to the participants and thus allow a fluent application of the CDS method during the experiment.

Table 3-9: Characterisation of Design Situation

Characteristic of the design situation	**Status**
Familiarity with the product	Familiar
	Non familiar
Type of group work	Independent
	Collaborative
Design phase	Research
	First iteration
	Second iteration
Type of activity	Beginning
	Middle-End
Product complexity	General
	Specific
Design purpose	Innovate
	Improve
Restriction on time	Time available
	No time available

The search method applied for Case II received the name of **Free Search in Visualisations (FSV)**. It consisted in searching knowledge by navigating through the KB visualisations. The KB is presented in Figure 5-3 in Section 5.5 and it was implemented in Soley Studio.

The role of the researcher was the preparation of the experimental set-up, the interface to KB for the CDS method and the experiment supervision. After the experiment, the participants had to determine their preferred method indicating if this was "strongly preferred", "slightly preferred" or if they had "no preference". The validity of the knowledge provided by each

search method was not considered. Participants were only asked to define their preferences based on the level of satisfaction with the method application, not with the method result.

Results

Table 3-10 presents the preferred method for each participant. Each one of the participants showed a preference for one of the methods. Two project insiders (P1 and P2) slightly prefer the CDS method and two project insiders (P3 and P4) slightly prefer the FSV method. Two project outsiders (P5 and P8) slightly prefer the FSV method. The other two project outsiders (P6 and P7) strongly prefer the CDS method.

Table 3-10: Participants preference towards the search method

			Strongly preferred	Slightly preferred	No preference	Slightly preferred	Strongly preferred	
Project insiders	P1	**FSV**				x		**CDS**
	P2					x		
	P3			x				
	P4			x				
Project outsiders	P5			x				
	P6						x	
	P7						x	
	P8			x				

The following lines present the comments of the participants.

Project insiders:

- P1: CDS assures a more structured procedure so it is less likely to forget something.
- P2: CDS is easier to understand.
- P3: Using CDS you do not have the direct control of your search.
- P4: Applying FSV you can be more specific.

Project outsider:

- P5: FSV offers a clearer structure.
- P6: no comments.
- P7: no comments.
- P8: no comments.

3.4.3 Conclusions and Implications for the Support

The results of the exploratory design experiments emphasise on the importance of individual characteristics of designers over other aspects such as knowledge availability or knowledge background during knowledge request and reuse.

EDE I showed different individual behaviours for knowledge request and reuse under the same design conditions. Participant 1 (P1) formulated concrete questions when he needed specific knowledge. This occurred mostly in the phase of detailed design. Participant 3 (P3) decided to gather lots of knowledge at the beginning and then use it gradually during the rest of design. Participant 2 (P2) decided not to use the KB even though he was aware of its availability.

The fact that one participant (P2) did not use at all the KB **matches** the **hypothesis** of EDE I that the awareness of knowledge availability does not assure knowledge reuse. Knowledge was not reused by P2 despite the absence of the complexity of an industrial environment which allowed a "barrier free" knowledge reuse. The set-up of EDE I does not allow to derive any causal relation for this fact but it describes that there are **individual barriers** for knowledge reuse playing a key role in designers' behaviour that should be consider to design support for knowledge reuse. The two participants who did request knowledge did not use the available knowledge to their maximum potential. The quality of their designs could have been improved if they had requested and use more of the available knowledge. EDE I evidences the need of **supporting the formulation of search questions** so all knowledge available in a KB is provided and it can be reused at the adequate phase of the design process.

The results of EDE II do not show differences in the preferred method depending on the fact of being project insider or outsider. More than being familiar with the knowledge or not, the main factor determining designers' preferences for knowledge search methods seems to be their personality. This reveals a very interesting field to work with in further studies in order to increase designers' acceptance of methods for knowledge reuse. Regarding the support for knowledge reuse to be developed, it should provide **individualised search and reuse solutions** independent of the participation of designers in previous projects.

4. Development of the *k*-MORE Methodology

This Chapter presents the Prescriptive Study, in which the proposed support is developed according to the procedure of Blessing and Chakrabarti (2009, pp. 141–180). The development starts in Section 4.1 with the task clarification that includes the definition of requirements for the support based on the results of the DS I. The conceptualisation of support as a methodology to plan the knowledge reuse cycle, the k-MORE methodology, is done in Section 4.2. Section 4.3 shows existing means and ideas to perform the steps of the methodology. Finally, Section 4.4 presents the realisation of the k-MORE methodology including the detailed procedures and methods of each step.

4.1 Task Clarification

The aim of the support has been increasing the knowledge reuse in engineering design companies. The results of the DS I set the basis to define the main **requirements** for the support. Table 4-1 presents the findings obtained from each method applied in DS I and the implications for the support that can be defined based on these findings. The first finding was that the currently, already extended, application of knowledge management methods in engineering design companies is not sufficient to achieve a satisfactory level of knowledge reuse. Companies implement knowledge management methods without consideration of strategic aspects such as target users, processes involved, control and maintain issues. The support to be developed should enable the **strategic planning** of knowledge management methods in order to achieve knowledge reuse. A goal-oriented planning is required in order to implement the appropriate methods for each area of the company.

The lack of knowledge overview, both for knowledge contained in documents as well as for competences of the employees, is the most typical situation for engineering design companies. The overview is not only necessary for the employees' knowledge search and reuse but it is also required in order to proceed with the strategic planning of knowledge management methods to achieve knowledge reuse. Therefore, the support to be developed should facilitate the **knowledge acquisition** and **visualisation**.

Habit is a major factor influencing knowledge reuse and it is common for all individuals. The knowledge processes described in the WCM operate in a cycle that feeds itself. Making a habit of company's processes and actions contributing to knowledge reuse increases automatically knowledge reuse. This implies that the support to be developed should foster the implementation of **habits and routines** contributing to knowledge reuse.

Most factors influencing the knowledge processes that lead to knowledge reuse are subjective. Thus, they can be perceived differently by different individuals. The support should enable the **analysis of individual** characteristics and perceptions in order to define habits and routines as well as to select knowledge management methods that are accepted by each individual.

The existence of a Knowledge Base (KB) containing design knowledge and the awareness of its availability does not assure knowledge reuse during product design. The formulation of a search question can be such a challenge for some designers that the search process is not

initiated and therefore, knowledge cannot be reused. Hence, the support should facilitate the **formulation of a search question**.

Designer's personality plays an important role in the way a search in a KB is faced. This finding aligns with the high influence of individual characteristics and perceptions derived from the literature review. Thus, the support should provide **various search** and **reuse solutions** in order to fit the search and reuse approaches of different individuals.

Table 4-1: Requirements for the support (adapted from Carro Saavedra and Lindemann (2017))

Method applied in DS I	**Hypothesis (H) or Research Question (RQ)**	**Finding**	**Implication for the support**
Interview Study	RQ: What are the reasons for the lack of knowledge reuse in industry?	Companies implement knowledge management methods without consideration of strategic aspects such as target users, processes involved, control and maintaining issues	The support should enable the strategic planning of knowledge management methods to achieve knowledge reuse
		Companies lack an overview of their knowledge	The support should facilitate the knowledge acquisition and visualisation
Literature Review	RQ: What are the individual influencing factors for knowledge reuse?	Habit is the major influencing factor common to all individuals	The support should foster the implementation of habits and routines contributing to knowledge reuse
		Individual characteristics and perceptions have a high influence and they are not considered enough in current approaches	The support should enable the analysis of individual characteristics and perceptions
EDE I	H: The awareness of knowledge availability does not assure knowledge reuse	H confirmed. The formulation of a search question is a critical step to ensure knowledge reuse that can be challenging for designers	The support should facilitate the formulation of a search question
EDE II	H: Designer's familiarity with the knowledge contained in a KB has a direct influence on the preferred knowledge search method	H refused. The approach to search in a KB does not depend on the participation or not in previous projects but on individual characteristics of the person	The support should provide individualised search and reuse solutions independently of the participation of designers in previous projects

4.2 Conceptualisation

Efficient knowledge reuse can take place in a company only if all phases of the knowledge reuse cycle have been previously conducted in a way that they contribute to the phase of reusing. For this reason, the approach of this thesis in order to increase knowledge reuse in engineering design companies is to **support the planning of the knowledge reuse cycle**. This means selecting the adequate knowledge management methods for each phase of the cycle. The knowledge reuse cycle was described by Markus (2001) and it is presented in Subsection 2.2.1 of this thesis. The cycle consists of four phases: *capturing and documenting* knowledge, *packaging* knowledge for reuse, *distributing* knowledge and *reusing* knowledge. The knowledge reuse cycle was selected for this thesis for two reasons. First, because it is a practice-oriented model. It provides a description of the activities required in a company to achieve knowledge reuse in practice. The second reason to use the knowledge reuse cycle is that it pursues the specific goal of knowledge reuse. Other models describing knowledge management activities or how to achieve organisational learning are more general and conceptual. They are rather oriented in establishing cultures and philosophies in the company than in achieving a concrete result. A discussion of the differences and relations between knowledge management, organisational learning and knowledge reuse is presented in Subsection 2.4.2.

Given the extensive scope of the aim and the need for user's guidance, the type of support selected is a **methodology**. A methodology is defined by Collins (2017) as "a system of methods and principles for doing something, for example for teaching or for carrying out research". In case of this thesis, the methodology should provide guidance to plan the knowledge reuse cycle in order to optimise company's reuse of knowledge. There are two main roles involved in applying *k*-MORE: users of the methodology and input providers for the methodology. The **users** of the methodology are managers or knowledge management practitioners (knowledge managers). Designers and other employees are **input providers** for the methodology. They are also the users of the knowledge management methods and guidelines to perform the knowledge reuse cycle which are implement in the company as a result of applying the *k*-MORE methodology.

The name of the proposed methodology is ***k*-MORE**, which stands for **k**nowledge **M**anagement for **O**ptimised **RE**use. Figure 4-1 depicts the overview of the *k*-MORE methodology including the questions addressed in each one of each eight steps. Steps 4 to 7 of the methodology constitute the selection of knowledge management methods and guidelines to prepare the four phases of the knowledge reuse cycle. Steps 1 to 3 are conducted in advance in order to define company's goals for knowledge reuse (step 1 "Defining Goals"), acquire and visualise company's knowledge (step 2 "Visualising") and analyse the company as well as its individuals characteristics and perceptions (step 3 "Analysing"). Finally, the guidelines to keep the knowledge reuse cycle running as it was planned during the daily work in the company (after the application of *k*-MORE) are defined is step 8 "Maintaining".

In the *k*-MORE methodology, the preparation of the phases of the knowledge reuse cycle takes place in the **opposite direction** of the knowledge reuse cycle of Markus (2001). The reason for that is that the methodology is not created to support the knowledge reuse cycle itself but the planning of it. The planning takes place backwards by first defining the goal to

be achieved, i.e. the conceptual design of the company's KB and knowledge sources (step 4 "Packaging") and then establishing the processes to fill (step 5 "Capturing and Documenting), use (step 6 "Reusing"), and promote the reuse of knowledge (step 7 "Distributing").

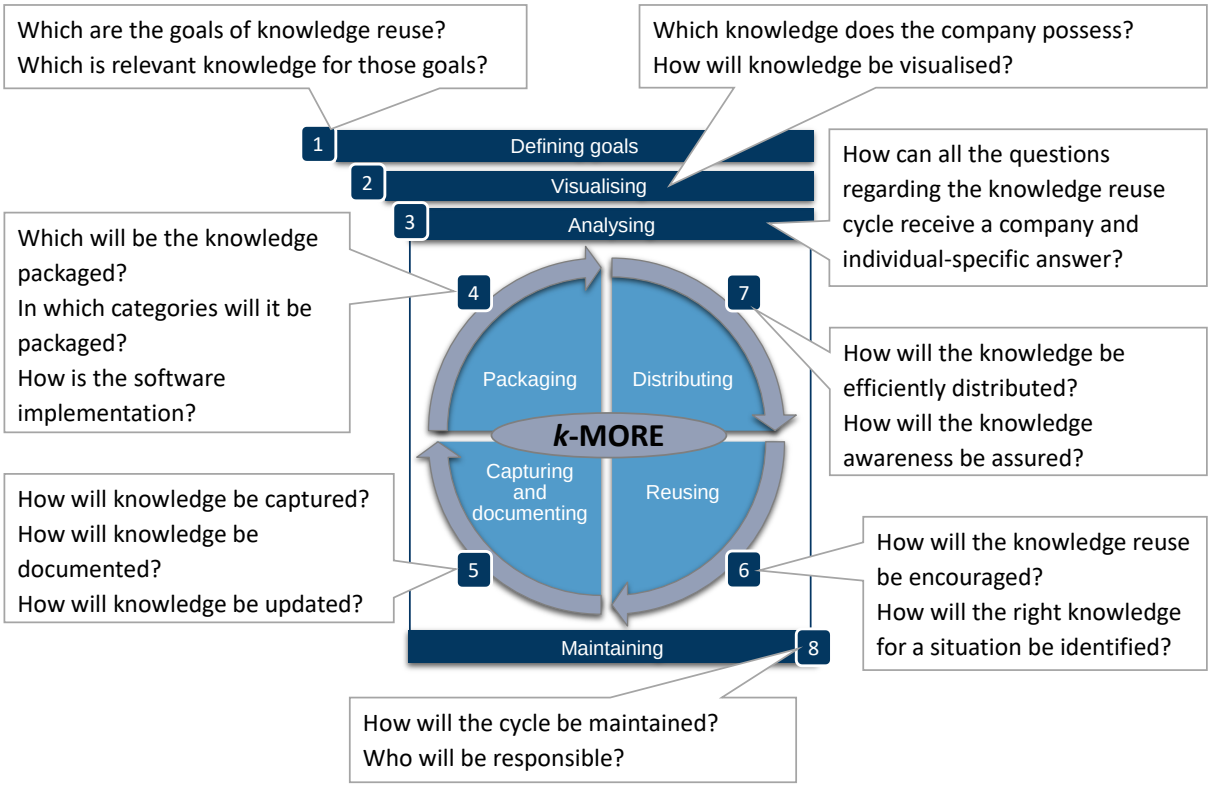


Figure 4-1: Overview of the k-MORE methodology including the questions addressed in each step

The *k*-MORE methodology provides practical support to plan the knowledge reuse cycle from scratch. Any engineering design company can apply the methodology independently of its current implementation of knowledge management methods, goals for knowledge reuse or understanding of what is "knowledge". A feasible focus for the methodology application and the planning of the knowledge reuse cycle is defined in step 1 "Defining Goals". Furthermore, the methodology considers both knowledge personalisation and codification approaches at the same time, which is a realistic approach in practice.

The steps of the *k*-MORE methodology cover the three fields of action described by North and Kumta (2014, p. 38) for knowledge management (see Subsection 2.1.4). The strategic knowledge management is addressed by step 1 "Defining Goals" and step 3 "Analysing". The operative knowledge management is addressed by step 2 "Visualising" and with the planning of the knowledge reuse cycle in steps 4 to 7 as well as the step 8 "Maintaining". Information management and data management are covered by the methods selected as the outcome of applying the methodology.

The most innovative aspect of the methodology is the **individualised analysis** that is performed in step 3 "Analysing". Two parallel analysis are conducted (company-specific and

individual-oriented) and the results influence the selection of knowledge management methods for the phases of the knowledge reuse cycle in steps 4 to 7. The *k*-MORE methodology assures that the knowledge reuse cycle is prepared in a way that suits better the three pillars of a knowledge management strategy defined by Reinmann-Rothmeier and Mandl (1998) (see Subsection 2.1.4): company's processes (organisation), IT environment (technology) and individual characteristics and perceptions (people).

4.3 Elaboration

This Section describes existing means and ideas to perform the steps of the *k*-MORE methodology. The presented content is the result of combining a review of literature with the background and experience of this thesis author.

Defining Goals

In order to perform step 1 "Defining Goals" it is necessary to understand different types of company's goals and how to link them with company's knowledge. Probst et al. (2012, p. 40) suggest to differentiate between normative, strategic and operative knowledge goals. Normative goals are related to the vision of corporate policy and company's culture. Examples of normative goals are being a company leader in innovation or creating a culture of knowledge sharing. Strategic goals represent the long-term measures necessary to achieve the normative goals, such as development of new employees' competences or achieving knowledge transparency. Operative goals describe the daily activities which will be conducted for the implementation of the strategic goals. Examples can be introducing training programs to develop employees' competences or introducing expert databases.

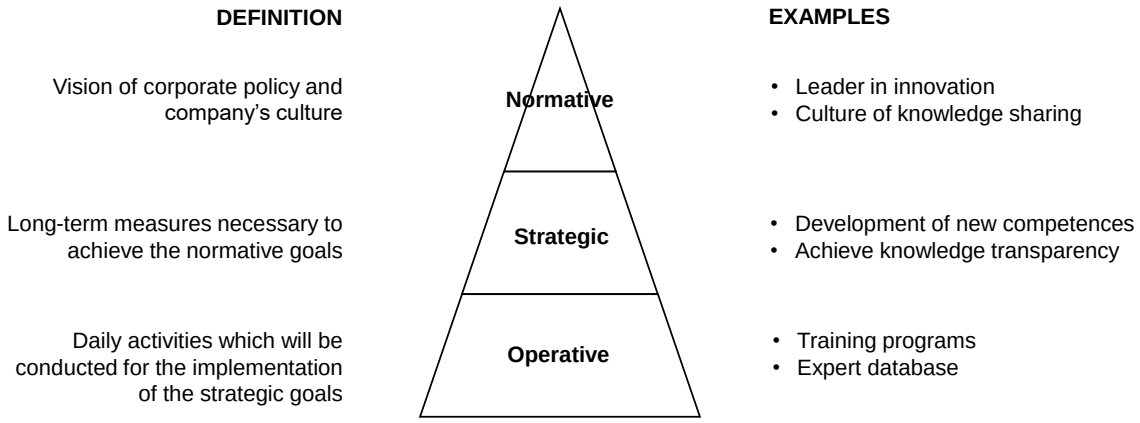


Figure 4-2: Types of company's goals (adapted from Probst et al. (2012, p. 40))

Winkler and Mandl (2007) propose to start a knowledge management project by conducting a change analysis, which consists of two phases: initialisation and requirements analysis. The goals for knowledge management are defined in the initialisation phase, which consists of three steps: strategic planning, business case and steering group. The goal of the strategic planning is developing a vision for the implementation project. At this point, only the

normative and the strategic goals mentioned by Probst et al. (2012) can be defined because the definition of operative goals requires information from the requirements analysis. The strategic planning can be done with a needs assessment. A **needs assessment** is a process used to identify gaps between current company's results (what is) and the desired ones (what should be), so the most important needs to be addressed can be selected. The needs assessment can be done at different levels of the organisation by considering the needs to achieve the organisation outcomes, the outputs, the products, or the processes and inputs (Kaufman et al. 1993).

One aspect to clarify during the goal analysis is the definition of the word "knowledge", which is subjective. Dalkir (2005) propose the **concept analysis technique** in order to generate definitions for the word and align understanding. The technique consists in obtaining consensus on three dimensions of the concept: key attributes, examples and nonexamples. Participants can be given lists of definitions to inspire them to fill the categories.

Buchanan and Gibb (2007) also highlight the need of defining the **target knowledge**. They suggest to distinguish between data, information and knowledge. In order to define the scope for an information audit, Buchanan and Gibb (2007) propose Earl's taxonomy (Earl 2000) to focus on four key information strategy components (management, technology, systems, content) combined with the concepts of "perspectives" (strategic, process, resource) providing a view of the organisation.

Visualising

In order to obtain an overview of the company's target knowledge in step 2 "Visualising", knowledge maps can be used. **Knowledge maps** provide a visual orientation to locate, evaluate or develop knowledge in an organisation by depicting relationships and structures of company's domains (Eppler 2004; Eppler and Burkhard 2007). By creating a visual knowledge architecture, it is possible to perform analyses from different perspectives. Eppler (2004) distinguishes five types of knowledge maps:

- Knowledge source maps: this type of map structures the company experts according to criteria such as kind of expertise, proximity or seniority. A typical analysis that can be done in this type of map is identifying somebody who can calculate a company valuation.
- Knowledge asset maps: they visually qualify the stock of knowledge of individuals, teams or organisations. A typical analysis that can be done in this type of map is identifying how many simulation engineers have been in the company for more than five years.
- Knowledge structure maps: this type of maps depict how different parts of a knowledge domain relate to one another. This representation supports the comprehension and interpretation of an expert domain. A typical analysis that can be done in this type of map is identifying the skills required to run a project, how they relate to each other and what are the available courses to acquire them.
- Knowledge application maps: they represent the knowledge required for a certain process phase or situation. A typical analysis that can be done in this type of map is identifying who to talk to if quality tests are inconclusive.

- Knowledge development maps: this type of map depicts roadmaps to develop certain competences. A typical analysis that can be done in this type of map is identifying how to prepare the company to develop a product for a new market.

Different types of maps can also be combined in one single map depending on the company's requirements for knowledge visualisation and analysis. For example, a knowledge application map can be combined with a knowledge source map in order to show relevant knowledge for a process phase and at the same time show the knowledge location (Eppler 2004).

There are various visualisation techniques to create knowledge maps such as e.g. mind mapping, clustering, matrices, pyramids or hierarchic trees. Wickel et al. (2013) propose an MDM-based knowledge map converted to a force-directed graph for companies of the engineering sector (see Figure 4-3). Multiple Domain Matrices (MDM) provide the structure to establish relations between more than two knowledge domains. In their case, Wickel et al. (2013) relate the domains employees, their knowledge and their tasks. The domain knowledge is split in four subdomains: knowledge of products, knowledge of procedures, technical knowledge, and internal or external networks. The goal of creating the knowledge map is visualising company's knowledge in order to evaluate it as a basis for measures to meet challenges such as changing markets and technologies that require a continuous knowledge development.

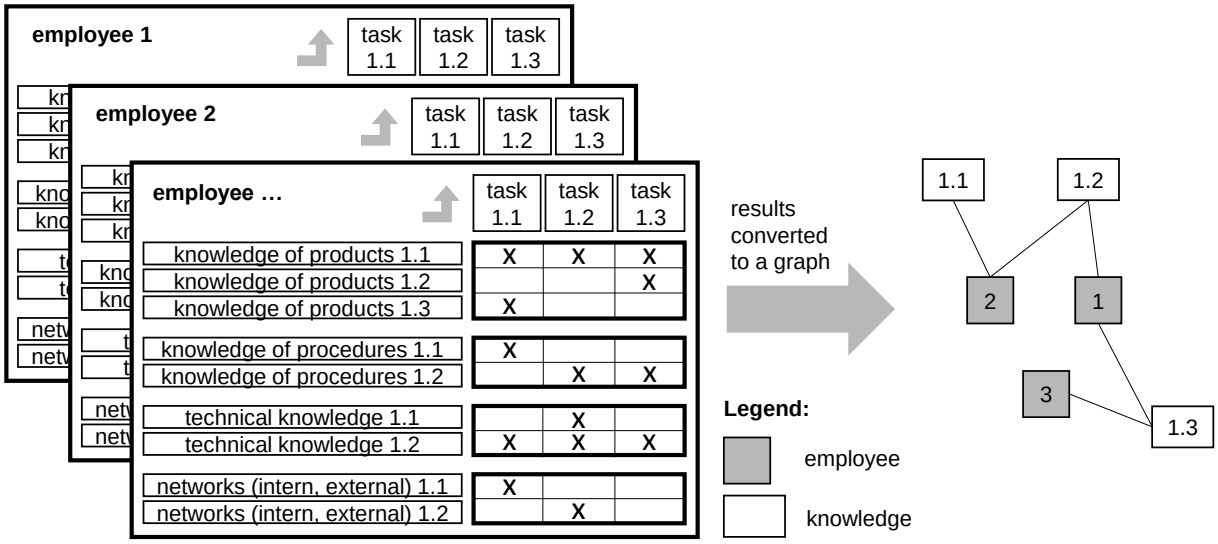


Figure 4-3: Creating a knowledge map of a company by addition of MDMs (adapted from Wickel et al. (2013, pp. 12–14))

Analysing

A structural analysis can be done to the knowledge map in step 3 "Analysing" in order to identify relevant aspects of inter-domain and intra-domain networks. The analysis criteria are based on **graph theory** and they consist of quantifying e.g. nodes, edges or distances in the graph. Table 4-2 shows analysis criteria that can be applied to knowledge maps. The

significance of the analysis criterion and the interpretation of results are case specific. Software support is required to conduct multiple and flexible analysis (Lindemann and Maurer 2007).

Step 3 "Analysing" also includes the analysis of individual characteristics and perceptions. This can be done using the **WCM** as a theoretical basis. The WCM was developed and presented in Section 3.3. The model depicts 21 factors influencing knowledge processes for individuals. The factors can be used as a checklist to create a questionnaire for their evaluation by different employees.

Table 4-2: Analysis criteria for knowledge maps (extract from Lindemann and Maurer (2007, p. 356))

Analysis criterion	**Explication**
Active sum	Quantity of outgoing relations
Activity	Division of active sum by passive sum
Articulation node	Only node connecting two sub graphs
Biconnected component	Sub graph only connected by articulation node or bridge edge
Bridge edge	Only edge connecting two sub graphs
Criticality	Multiplication of active sum and passive sum
Distance	Specifies the distances between nodes in a structure
End node	Node possessing only incoming (passive) relations
Feedback loop	Circular sub graph
Hierarchy	Node branching out in different levels
Isolation	Nodes without any relation to other parts of a structure
Locality	Surrounding nodes of a central node because of existing edges
Passive sum	Quantity of incoming relations
Proximity	Specifies the distance from other nodes in the graph
Reachability	Node can be reached from other nodes by dependency paths
Shortest path	Shortest connection between two nodes by edges
Spanning tree	Sub graph connecting all system nodes
Start node	Node possessing only outgoing (active) relations
Strongly connected part	All nodes can mutually be reached by a specific path
Triangularisation / Sequencing	Sequential or block order of nodes

Planning the Reuse Cycle

There are numerous knowledge management methods to support the four phases of the knowledge reuse cycle. Some methods provide isolated support to perform one phase of the knowledge reuse cycle such as e.g. storytelling for knowledge capture and documentation or e.g. communities of practice for knowledge distribution. Other methods provide integrated support (usually software-based) to perform various phases of the knowledge reuse cycle such as PROSUS or CoMem. Those methods have already been introduced in Sections 2.2.2 and 2.3.3.

Given the high variety of available methods, an overview of those is required as a basis for the methods' selection conducted in steps 4 to 7 of *k*-MORE. Information about each method adequacy to handle different phases of the knowledge reuse cycle and different companies'

situations is also required so the selection can be company-specific and individual-oriented. This information was structured in a methods' catalogue to be used in practice.

The **methods catalogue** was developed as part of the student project of Beul (2018) and it contains 68 methods collected from main knowledge management books and publications. The amount of methods included was kept to the minimum in order to achieve a manageable size for the catalogue. The catalogue presents several categories representing characteristics of the methods (see Figure 4-4):

- Addressed influencing factors: it indicates which influencing factors from the WCM are positively influenced by the method. It answers the following question: "the handling of which influencing factor can be especially improved through the application of the method?" The absence of a cross does not necessary mean that the method is not contributing to handle the factor but it means that its influence is more remarkable for other factors.
- Supported phase of knowledge reuse cycle: it refers to the phases of the knowledge reuse cycle supported by the method. The four phases of the knowledge reuse cycle are considered and one additional phase for maintaining is included. The knowledge management methods included in the phase for maintaining are methods to incorporate new knowledge to the company that can be added to the knowledge reuse cycle along time.
- Specially supported knowledge type: it indicates for which type of knowledge the method is especially recommended. The taxonomy of knowledge types used was presented in Carro Saavedra et al. (2017b).
- Implementation time: it gives an idea of the necessary time to achieve a full integration of the method in the company. It depends on e.g. current structures, culture or extend of the implementation. The value currently given in the catalogue is indicative. Each company should reconsider the value according to their understanding.
- Implementation effort: it gives an idea of the necessary resources to implement the method in the company. It depends on e.g. costs derived from trainings, software licenses or the amount of employees involved. The value currently given in the catalogue is indicative. Each company should reconsider the value according to their understanding.

Figure 4-4 shows an extract of the methods catalogue. The complete catalogue of 68 methods is presented in Appendix 9.7.4. The assignment of characteristics within the different categories is based on the judgement of this thesis author and Beul (2018) and it was discussed with the company involved in Case Study IV of the evaluation (see Section 5.6).

METHODS CATALOGUE																																														
Method	Addressed influencing factors																				Supported phase KRC					Specially supported knowledge type														Imp. time			Imp. effort		
																										Origin		Nature			Concret. level		Situation of knowledge acquistion			Subject									
	IT structure	Organisational structure	Physical structure	Knowledge affinity	Learning aptitude	Knowledge breath	Knowledge depth	Perceived risk	Perceived benefit	Knowledge as power	Past experiences	Commitment	Trust	Workload	Culture	Personal relationships	Social skills	Personality	Mind openess	Strategic alignment	Strategic leadership	Cap. & doc.	Packaging	Distributing	Reusing	Maintaining	External	Internal	Explicit	Implicit	Tacit	General	Specific	Experience	Contact	Human ability	Product	Process	Contacts	Environment	Short-term	Mid-term	Long-term	Low	Medium	High
Advanced trainings knowledge					X	X	X					X								X	X			X		X	X	X					X								X				X	
Advanced trainings social skills					X							X					X	X	X	X	X			X		X	X	X				X									X				X	
Balanced scorecard																				X	X					[illegible]																				
[illegible]hmarking (of KM methods)								X																																						

Figure 4-4: Extract of methods catalogue

Complementing the methods catalogue, a **method description sheet** was developed for each method. The structure of the description sheet is based on Lindemann (2009) with some modifications. The original categories of situation and impact, suggested by Lindemann (2009), were substituted by advantages and disadvantages of the method. This change was done for the following reasons: 1) situation and impact are covered with the categories associated to the method in the methods catalogue, and 2) advantages and disadvantages provide relevant information for companies to support the method selection. The method description sheets of the 68 methods are presented in Appendix 9.7.4. Figure 4-5 shows the description sheet for the method triad conversation.

Triad conversation

Goal	**Advantages**	**Disadvantages**
Transfer of experience knowledge from experienced persons to inexperienced persons	Avoid misunderstandings between interlocutors thanks to the moderators' guidance	A third person (moderator) is required
Tools/Procedure 1) Bringing the two interlocutors together 2) Moderator ensures that the narrator's flow of words is not interrupted and that the novice has the opportunity to ask questions of understanding 3) Moderator asks questions about the content in order to uncover implicit knowledge and ensure the transfer of this knowledge from expert to novice 4) Securing the results with concluding agreements on the implementation or application of knowledge		
Hints Third person must remain neutral		
Source for further information Dick et al. (2016)		

Figure 4-5: Method description for the method "triad conversation"

Maintaining

A maintenance plan is required to assure the application of the methods, actions and roles defined to conduct the knowledge reuse cycle. As Goncalves (2012, p. 9) stated, "knowledge management should always be work-in-progress, never a finite project".

Orth et al. (2011, pp. 20–21) recommend three **actions** to evaluate the success of the implemented knowledge management methods in order to maintain them:

1) Conduct lessons learned regarding the implementation of methods to perform the knowledge reuse cycle. Thus, the team can reflect on each method application and continuously establish new actions to improve it.
2) Repeat the initial analysis. Since the initial analysis included an initial evaluation of the company's knowledge management implementation, a periodic re-evaluation constitutes a practical controlling instrument.
3) Balance Score Card. Company's vision and strategy have to be analysed in order to reflect if the methods applied to support knowledge reuse keep contributing to the current company's goals.

Based on 15 pilot case studies, Orth et al. (2011, pp. 49–51) also establish the following **factors** for the successful implementation and maintaining of knowledge management methods in industry:

- Support from management. Management leaders should show their commitment to the method's implementation by prioritising it compared to other activities and with their presence in meetings and discussions.
- Clear vision and goals. The vision and goals can be generally defined such as "promote working together" or "improve internal communication" but they should be clearly communicated.
- Long trip – small steps. Implement methods in small manageable tasks which can progressively increase along time.
- Project leader with clear responsibilities and budget. A project leader is the reference person to address any issues during the method implementation and maintaining. He or she has also the overview of progress, goals and resources so the implementation can be conducted efficiently.
- Communication of utility. Employees must be convinced of the utility of the method so they adopt a positive attitude and contribution.
- Participation of employees. Employees must be integrated and take part on the decisions taken in all steps of knowledge management, from analysis to maintaining.
- Use the potential of existent IT-tools. Not always new fancy tools are required and existent resources can be used to achieve significant improvements.
- Process orientation. Knowledge management activities have to be integrated in company's processes so they are naturally adopted and conducted.
- Clear and systematic procedure. It showed very successful results in the pilot case studies.
- Personal trainer (external guide). External guidance looks after the knowledge management method implementation and maintenance despite the daily workload of employees and it assures therefore its adequate consideration.

Step 8 "Maintaining" of *k*-MORE defines guidelines to plan the maintaining the knowledge reuse cycle based on the abovementioned success factors.

4.4 Realisation: the *k*-MORE Methodology

The following Subsections describe in detail the steps of the *k*-MORE methodology. Subsection 4.4.1 presents the first step, "Defining Goals". The second step, "Visualising" is explained in Subsection 4.4.2. Then, the step "Analysing" is presented in Subsection 4.4.3. Subsection 4.4.4 shows the planning the knowledge reuse cycle that is done by planning its four phases ("Packaging", "Capturing and Documenting", "Reusing" and "Distributing") in steps 4 to 7 of the *k*-MORE methodology. The final step of *k*-MORE, "Maintaining", is presented is Subsection 4.4.5. Figure 4-6 presents the overview of the methodology and the questions addressed in each step. This Section concludes suggesting an approach for knowledge package and reuse in Subsection 4.4.6. The integration of the *k*-MORE approach for knowledge package and reuse is optional during the application of the *k*-MORE methodology.

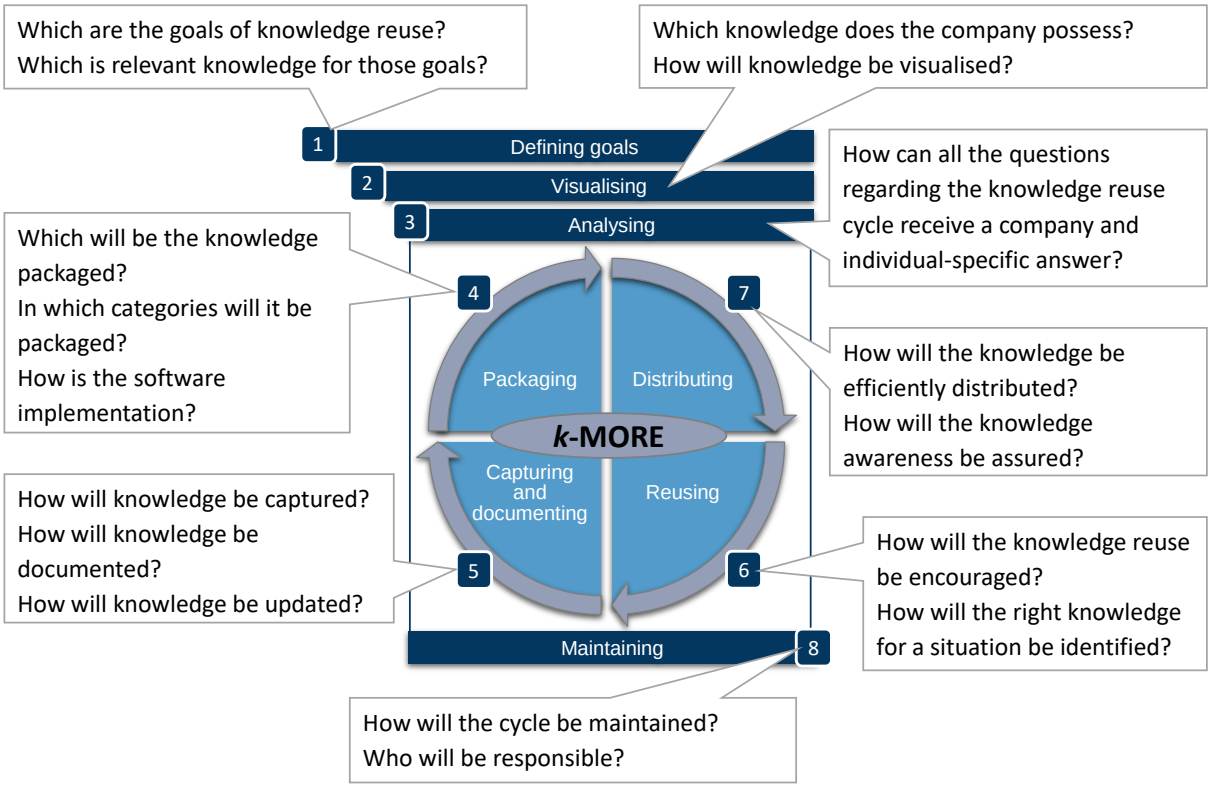
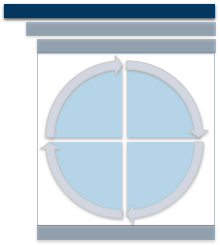


Figure 4-6: Overview of the k-MORE methodology including the questions addressed in each step

This Section presents the steps of the methodology as a practical guideline and the text does not include references to literature. The theoretical basis and correspondent references on which the methodology is based are included in Section 4.3 "Elaboration".

4.4.1 Step 1 “Defining Goals”



Step 1 “Defining Goals” of *k*-MORE methodology proposes a procedure with several techniques in order to help the user understand and define which of all company’s knowledge should be systematically reused because its reuse contributes directly to the consecution of company’s goals. This step is essential to establish a feasible scope for the next steps of *k*-MORE.

Goals

Step 1 “Defining Goals” pursues three goals:

- **Reduce** the **effort** and **complexity** in the application of *k*-MORE. Planning and maintaining a systematic knowledge reuse cycle implies an effort for the company. In order to keep a viable and profitable knowledge reuse cycle, only a part of company’s knowledge can be reused and only a part of company’s stakeholders and projects can be analysed.
- **Establish** the right **focus** in the application of *k*-MORE. The knowledge considered for systematic reuse should be the relevant knowledge to achieve company’s goals. Reflecting on the goals and needs of the company, the relevant knowledge and stakeholders for knowledge reuse can be identified.
- **Assure consistency** in the application of *k*-MORE. The term knowledge has a different meaning in the mind of every person. In order to keep consistency during the implementation of the *k*-MORE methodology, it is very important to establish a common meaning for the term knowledge.

Procedure

Step 1 “Defining Goals” consists of six activities, which are depicted in Figure 4-7. The detailed methods, inputs, outputs and necessary documentation to conduct the activities are presented in Appendix 9.7.1.

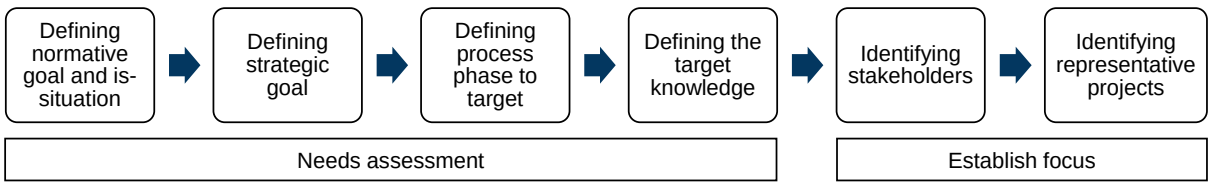


Figure 4-7: Procedure for step 1 “Defining goals”

The first four activities are conducted in the framework of a **needs assessment** using the template included in Appendix 9.7.1. The needs assessment is a process used to identify gaps between the current company’s results (what is) and the desired ones (what should be), so the most important needs to be addressed can be selected. The need is in the case of *k*-MORE the need for knowledge reuse, and the knowledge to be reused must be identified.

The needs assessment starts by **defining** the **normative goal** of the company and **describing** the **is-situation**. Normative goals are related to the vision of corporate policy and company's culture. Examples of normative goals are being a company leader in innovation or creating a culture of knowledge sharing. This activity takes place in a group discussion between company's managers. The description of the *types of goals* (Appendix 9.7.1) supports the group in the discussion. During the description of the is-situation, the group discusses the activities which are currently being done in the company in order to achieve the defined normative goal. This part includes a critical reflection on the way those activities are currently performed in order to understand barriers for achieving the normative goal. In the end, the template of *needs assessment* is filled with the description of the normative goal and the is-situation.

The next activity is defining the **strategic goal** of the company. Strategic goals represent the long-term measures necessary to achieve the normative goals, such as development of new employees' competences or achieving knowledge transparency. The *knowledge audit framework* (Appendix 9.7.1) supports the definition of the strategic goal by providing an overview of the actions which can be done regarding knowledge in the company. Thus, knowledge managers can reflect if their priorities are on identifying, assessing or supporting knowledge processes. They can also focus on one/some of the processes. The group discussion based on the *knowledge audit framework* leads to the definition of the strategic goal for the company regarding knowledge.

At this point, the is-situation and the desired-situation of the *needs assessment* are complete. It is time to define the knowledge which needs to be considered for systematic reuse (referred as target knowledge). This starts with the **definition** of the **phase/s** of the **product development process** (PDP) to **target**. If the company has a standard PDP, this is used as reference process for the group discussion. If no company-specific PDP is available, the *standard PDP* of Pahl and Beitz is used (Appendix 9.7.1). Using the PDP process as a reference, the group considers whether the target knowledge is concentrated in certain phases of the PDP. The target phases are marked directly on the reference PDP used.

The final activity of the needs assessment is the **definition** of the **target knowledge** using the concept analysis technique in the template for *definition of knowledge target* contained in Appendix 9.7.1. The technique consists in obtaining consensus on three dimensions of the concept to be defined: key attributes, examples and nonexamples. Participants can be given lists of definitions to inspire them to fill the categories. In the case of the knowledge key attributes, the *knowledge pyramid* (Appendix 9.7.1) and the *taxonomy of knowledge dimensions* (Appendix 9.7.1) serve as support for the group discussion. The examples and nonexamples are company-specific. Particular effort has to be invested in the definition of nonexamples. A good nonexample is the one that seems like an example at first glance but for some reason it is not. An explanation can be written in brackets aside of the nonexample in order to clarify why the nonexample cannot be considered knowledge.

Once the needs for knowledge reuse have been identified, it is established the focus for further analysis company. This means identifying related stakeholders and identifying representative projects.

Identifying stakeholders takes place by filling the *stakeholders' portfolio* (Figure 4-8 and Appendix 9.7.1). The stakeholders to be considered should either possess the target knowledge defined or have the capacity to influence positively the company's normative goal by reusing efficiently the target knowledge. Stakeholders can be departments or business areas of the company, or external knowledge sources like clients, providers, partners, etc. The selected focus phase of the PDP serves as orientation in the search for potential stakeholders. First of all, potential stakeholders for the portfolio are listed. Then, stakeholders are allocated in the portfolio during a group discussion. The portfolio considers two aspects; the amount of target knowledge possessed by the stakeholder, and the stakeholder's capacity to influence the normative goal of the company. Each aspect is characterised as low or high. Depending on the combined characterisation of the two axes, stakeholders are allocated to one of the four areas of the portfolio. Each area defines considerations for the stakeholder in further steps of *k*-MORE. If the knowledge possessed is low and the capacity to influence is low, the stakeholder is out of scope and does not need to be considered in further steps. If the knowledge possessed is high and the capacity to influence is low, the stakeholder's knowledge will be acquired in the step "Visualising" of *k*-MORE. If the knowledge possessed is low and the capacity to influence is high, the stakeholder's influencing factors for knowledge reuse will be analysed in the step "Analysing" of *k*-MORE. In case the knowledge possessed is high and the capacity to influence is high, the stakeholders will be considered for both the analysis of influencing factors for knowledge reuse as well as knowledge acquisition.

Stakeholders' portfolio

Questions to fill the portfolio

- Which is the capacity of each stakeholder/department to **influence** on the company's **normative goal** (defined in the needs assessment)?
- Which is the **amount** of **target knowledge** (defined in the definition of knowledge target) of each stakeholder/department?

Interpretation of results:

- **Analyse**: the influencing factors for knowledge reuse of the stakeholder/department in this field of the portfolio will be analysed in the step "Analysis" of *k*-MORE
- **Acquire:** the knowledge of the stakeholder/department in this field of the portfolio will be acquired and visualised in a knowledge map in the step "Visualising" of *k*-MORE

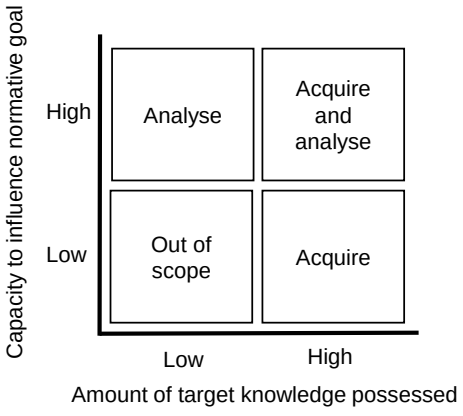


Figure 4-8: Template of the stakeholders' portfolio

The final activity of the step "Defining Goals" is the **identification** of **representative projects**. Tasks, type of knowledge and way of working of representative projects provide a general impression of the typical work in the company. Representative projects will be the focus of knowledge acquisition. By focusing on real projects the term knowledge remains tangible and clear boundaries for the acquisition are established. A maximum number of three projects is recommended, but the number depends on the characteristics of the projects and

the analogies to other projects in the company. The selected projects are documented in the template for *definition of representative projects* contained in Appendix 9.7.1.

Outcomes

Step 1 "Defining Goals" has four main outcomes; one per template of the ones included in Appendix 9.7.1. The outcomes are:

- Filled ***needs assessment*** template. Figure 4-9 presents an exemplarily filled template in which the target knowledge is defined out of the discrepancy between the described is-situation and the desired-situation.
- Filled ***definition of knowledge target*** template. Figure 4-9 presents an exemplarily filled template including key attributes, examples and nonexamples. If it is considered necessary, the examples and nonexamples could be more company-specific. The *definition of knowledge target* is a reference document during all the implementation of *k*-MORE. The document can be extended with further examples and nonexamples if those are identified during knowledge acquisition and visualisation.

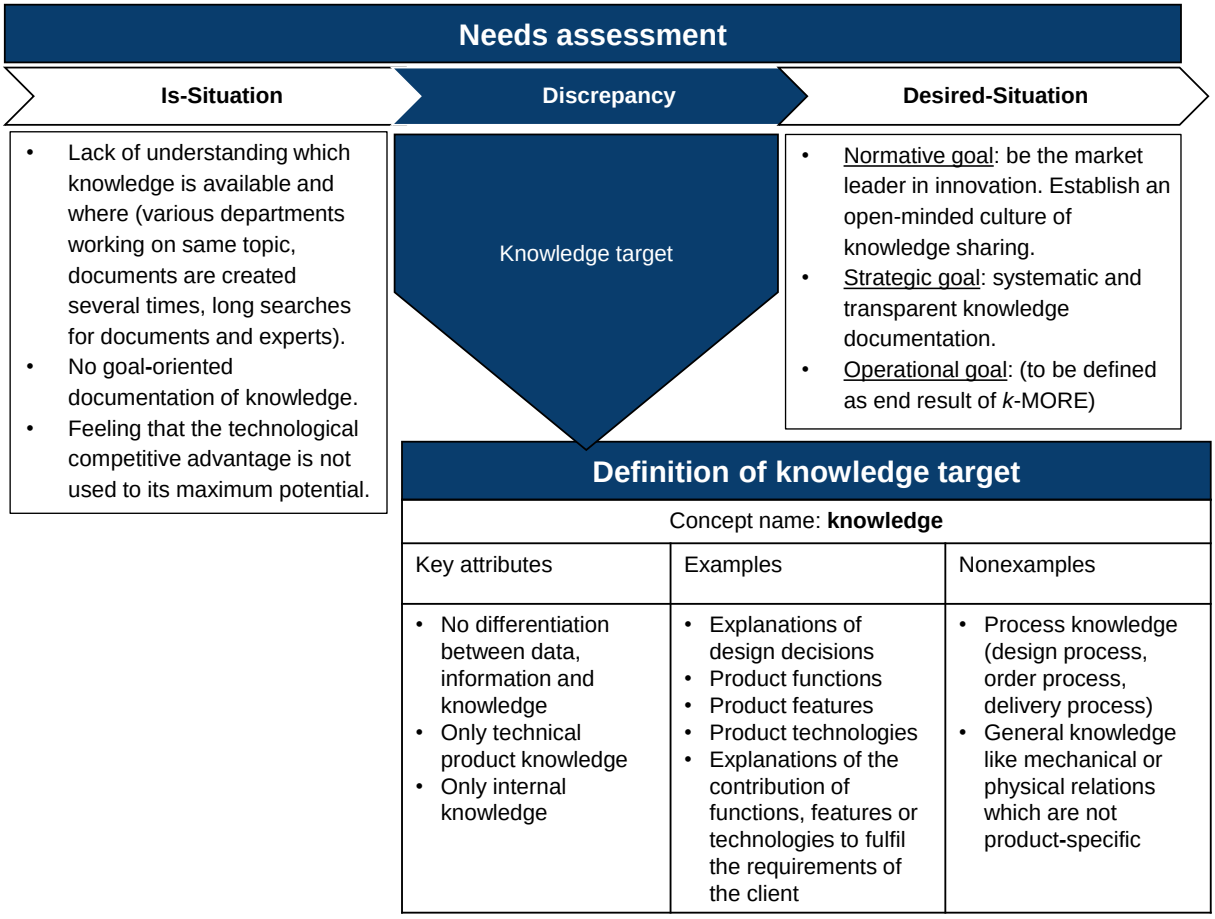
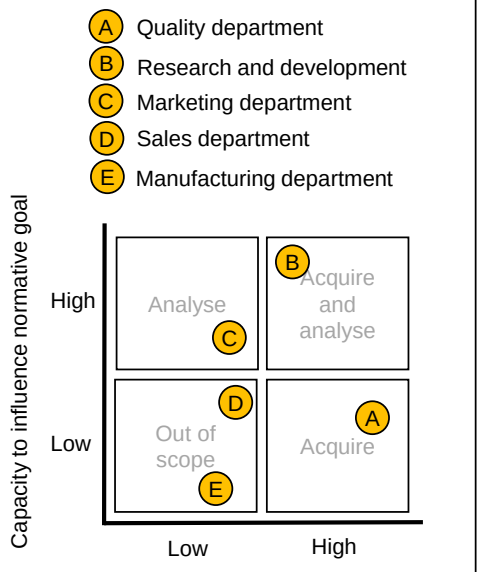


Figure 4-9: Exemplarily filled templates for needs assessment and definition of knowledge target

- Filled ***stakeholders' portfolio***. Figure 4-10 presents an exemplarily filled portfolio allocating five stakeholders. Following the same example of Figure 4-9, five departments are selected as stakeholders because they are potential owners or users of the knowledge target, which is technical internal knowledge (see Figure 4-9). In this example, the research and development department possesses the target knowledge and it has the capacity to influence the normative goal of the company, which is being the market leader in innovation (see Figure 4-9). The quality department possesses a high amount of target knowledge but its capacity to influence the normative goal is rather low. The marketing department can considerably influence the normative goal but it possesses rather few target knowledge. Sales and manufacturing are in this example out of the scope for further analysis.
- Filled ***definition of representative projects***. Figure 4-10 presents an exemplarily filled template. In this case, three products are selected as representative for three processes involving the departments which will be considered for analysis or/and knowledge acquisition in further steps of *k*-MORE.

Stakeholders' portfolio



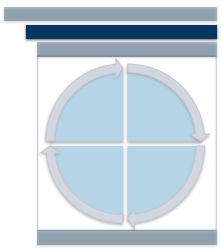
Definition of representative projects

Product developed	Departments involved	Characteristics	Similar to…
I	A, B, C, D, E	• Typical development process for innovative products • Stage-gate process	All developments of big innovations
II	A, B	• Typical improvement of top products • Change process	All improvements of top products already on the market
III	B, C	Development of new technologies	• Developments of mechanical technologies • Software technologies not included

Figure 4-10: Exemplarily filled templates for stakeholders' portfolio and definition of representative projects

4.4.2 Step 2 "Visualising"

Step 2 "Visualising" of the *k*-MORE methodology proposes the acquisition and visualisation of target knowledge by means of a knowledge map. The transparent knowledge structure achieved with the knowledge map allows a systematic analysis in the next step of *k*-MORE.



Goals

Step 2 "Visualising" pursues three goals:

- **Identify** the **location** of **target knowledge**. Unknown knowledge or knowledge that cannot be found cannot be reused. Identifying knowledge owners or storages is the first step for planning how this knowledge can be efficiently captured and reused.
- **Facilitate** a structured knowledge **acquisition**. The knowledge elicitation has to be carried out in a way that is easily applicable for the company assuring knowledge consistency and completeness.
- **Establish** a **basis** for **a global systematic analysis**. The visualisation in form of a knowledge map is structured and it does not only represent the knowledge location but also its context and relation to other elements in the company. This allows extensive analysis of company's structures.

Procedure

Step 2 "Visualising" consists of six activities which are depicted in Figure 4-11. The detailed methods, inputs, outputs and necessary documentation to conduct the activities are presented in Appendix 9.7.2.

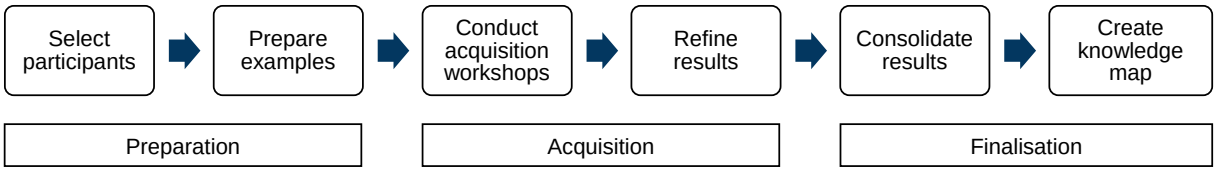


Figure 4-11: Procedure for step 2 "Visualisation"

The procedure is divided in three phases. First, the preparation of the knowledge acquisition takes place by selecting participants and preparing examples of what is to be acquired. Then, the knowledge acquisition takes place starting with one or various workshops, depending on the company's area and level of detailed required. The initial knowledge acquired in workshops is refined in iterative interviews or questionnaires. During the finalisation, the results of the acquisition are consolidated and the knowledge map is created.

The first activity in the preparation phase is the **selection of participants** for the knowledge acquisition workshops, i.e. the first knowledge providers. This is done in a discussion between company's managers. The outcomes of step 1 "Defining Goals" play a key role in this activity. The participants are selected from the stakeholders identified in step 1 "Defining Goals". The combination of the knowledge and working areas of selected participants should provide a good overview of the target knowledge and of the tasks included in the representative projects defined in step 1 "Defining Goals". A minimum number of 3 and maximum of 6 participants per workshop is recommended for the acquisition workshop. The number of workshops planned depends on how wide are the areas of knowledge acquisition.

In case further details are necessary, more knowledge providers can be identified at the end of the acquisition workshops. Those participants will contribute to refine the workshop results.

The selected participants are addressed in order to **prepare** company-specific **examples** of the knowledge map, which will be used as a reference during the acquisition workshops. The examples are prepared using the structure of the *metamodel of knowledge map*, which is depicted in Figure 4-12 (also is Appendix 9.7.2).

The proposed knowledge map depicts five connected elements (person, task, document, competence, storage) in which the task is placed as central element. The element "task" refers to tasks performed during the design process. The differentiation of knowledge elements in competences and documents clarifies the understanding of what is documented and what not. Moreover, documents are depicted as inputs or outputs of the task by means of the directional edges "is used in" and "generates". The storage place of each document in the company is also represented through the edge "is contained in" and so is the owner of a competence by the edge "possesses".

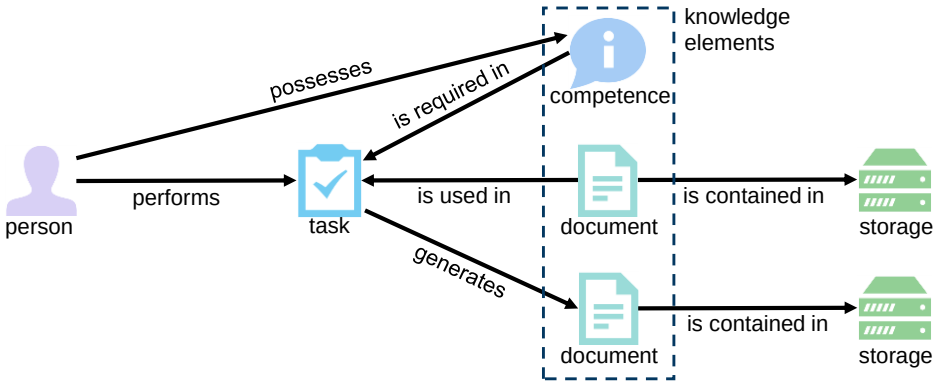


Figure 4-12: Metamodel of knowledge map

The company-specific examples of the metamodel are presented and discussed with the participants at the beginning of the acquisition workshops. They serve as reference to keep a consistent level of detailing in the elements described during the workshop. Figure 4-13 shows an exemplarily company-specific example.

This metamodel of the knowledge map is proposed in this step of *k*-MORE and the corresponding analysing rules for it are presented in step 3 "Analysing" of *k*-MORE. However, the company might find useful additional links and elements in the map. As Wiig (1995, p. 168) highlights, "there is no correct way of generating a knowledge map. Tailor your maps to your specific topic and purposes". Thus, the company has also the possibility of extending the metamodel and customising the knowledge map if required. If this is the case, the corresponding analysing rules for the new elements must be also added in step 3 "Analysing" of *k*-MORE.

Once the preparation phase is completed, the **knowledge acquisition** starts. The first acquisition is carried out in **workshops**, each one with 3 to 6 participants. The approximate duration of each workshop is 4 to 5 hours. During the workshop, the participants identify and

explain the persons (or roles), their tasks and associated knowledge elements, as well as the storages which are involved in the representative projects. The focus is set on roles and tasks related to target knowledge. The *process for the acquisition workshop* from Appendix 9.7.2 supports the workshop organiser in the task. The goal is to obtain information to create a first version of the *mapping matrix* (Appendix 9.7.2). After the workshop, the knowledge manager formalises the information using the *mapping matrix* template.

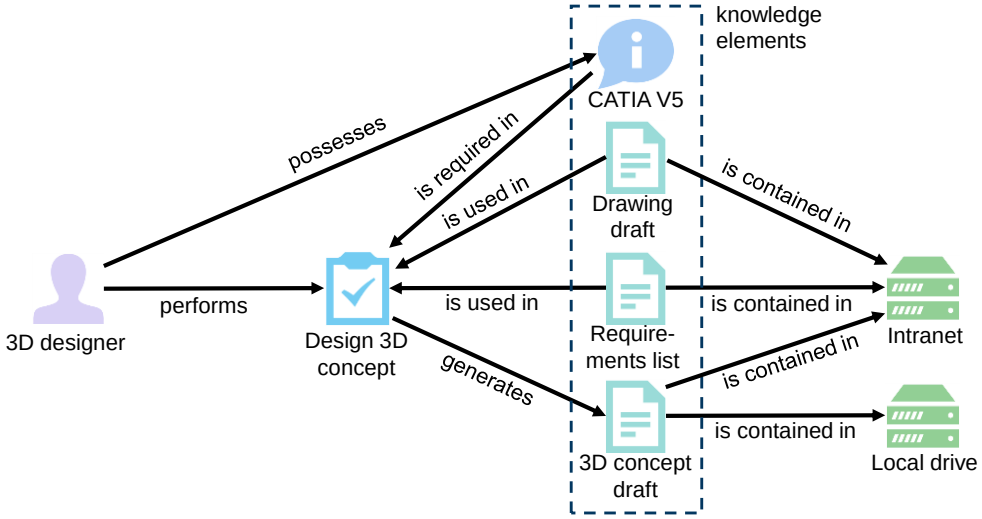


Figure 4-13: Company-specific example of elements of the knowledge map

Once the workshop results are formalised in a digital *mapping matrix*, the process of **refining** the **results** begins. If the level of completeness and detail is adequate, the digital *mapping matrix* is sent to selected employees in order to check their roles and verify the names of the elements and the connections between them. New elements can be added if it is considered necessary. Various iterations may be necessary depending on the feedback. The knowledge manager coordinates the process and iterations. In case the level of completeness and detail is not enough, interviews with selected employees in order to define new tasks and knowledge elements are conducted. Again, the knowledge manager controls the process until the *mapping matrix* is complete. The end result of the acquisition phase is one final digital *mapping matrix* per acquisition workshop.

The digital *mapping matrices* are the input for the finalisation phase. In case more than one acquisition workshop is conducted, the results of the different workshops (already formalised in the digital mapping matrices) have to be **consolidated**. This takes place in a workshop in which representative participants of all workshops are set together. The *process for the consolidation workshop* from Appendix 9.7.2 supports the workshop organiser in the task. First of all, knowledge flows between all tasks are reviewed in order to identify inconsistencies in the names of knowledge elements. Then, the inconsistencies are discussed and a common terminology is defined. Non-represented knowledge flows are added and also new knowledge elements are defined if it is required. The workshop concludes with a reflection on the should-situation, in which should-knowledge flows and knowledge elements

are defined. If only one acquisition workshop is conducted, no consolidation is required. Just a workshop to reflect on the should-situation with the participants of the first workshop is required.

The final activity of step 2 "Visualising" is **creating** the **knowledge maps** using a graph visualisation software. Combining the input of the final digital mapping matrices, two knowledge maps are created: as-is knowledge map and should-be knowledge map. The knowledge map provides an overview of the target knowledge's location, flows and context.

Outcomes

Step 2 "Visualising" has two main outcomes:

- Filled digital ***mapping-matrix***. The mapping matrix contains the information necessary to create the knowledge map. The gathered as-is situation and should-be situation can be depicted either in one unique *mapping matrix* (using different colours for the should-be elements and flows) or in two (one as-is matrix and one should-be matrix). Figure 4-14 presents an exemplarily partially filled matrix. The matrix format is easily operated per hand. For this reason, the *mapping matrix* is a reference document for future extensions and modifications of roles, tasks and knowledge elements.

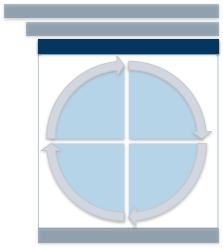
			Knowledge elements						
			Documents				Competences		
		Storages	intranet	local drive	…	Persons	Peter Julia	Julia	…
Roles	Tasks		drawing draft	collision report	…		CATIA V5	creativity	…
creative designer	create drawing draft		g		…			r	…
3D designer	design 3D model		u		…		r		…
	check collisions			g	…		r		…
…	…		…	…	…		…	…	…

Knowledge flows:
g = generates
u = uses
r = requires

Figure 4-14: Exemplarily partially filled mapping matrix

- **Knowledge maps**. Two knowledge maps (as-is and should-be) are created using the input of the *mapping matrix* or *matrices*. The knowledge map is based on the metamodel of Figure 4-12 and it is implemented using a graph visualisation software. The knowledge map will be analysed in the next step of *k*-MORE. The knowledge map is also proposed as visualisation to support the reuse during daily work as one of the knowledge based visualisations (see Subsection 4.4.6).

4.4.3 Step 3 “Analysing”



Step 3 “Analysing” of the *k*-MORE methodology constitutes the major contribution of the methodology. Two parallel analyses are conducted. One is the structural analysis of the knowledge map. The other analysis focuses on the understanding of the individual influencing factors for knowledge reuse. This is done with a questionnaire based on the factors depicted in the WCM (see Subsection 3.3.2).

Goals

Step 3 “Analysing” pursues three goals:

- **Identification** of **critical elements** to improve reuse. In order to maximize the effect of knowledge reuse, actions on critical elements have to be considered in the first place. Critical elements are for example highly used knowledge element or highly used storages.
- **Identification** of **focus groups** to plan the knowledge reuse cycle. Employees are involved with more or less intensity in different phases of the knowledge reuse cycle. A success factor to implement a continuous and efficient knowledge reuse cycle is to involve employees in the planning. Identifying focus groups for each phase of the knowledge reuse cycle is necessary in order to involve each of them in the planning of the corresponding phase of the knowledge reuse cycle.
- **Identification** of **individual perceptions** of knowledge workers. The factors influencing knowledge reuse are perceived differently by each individual. The different perceptions have to be identified, so individual actions and methods to plan the knowledge reuse cycle can be proposed.

Procedure

Step 3 “Analysing” consists of two analyses with two and three activities each. They are depicted in Figure 4-15. The detailed methods, inputs, outputs and necessary documentation to conduct the activities are presented in Appendix 9.7.3.

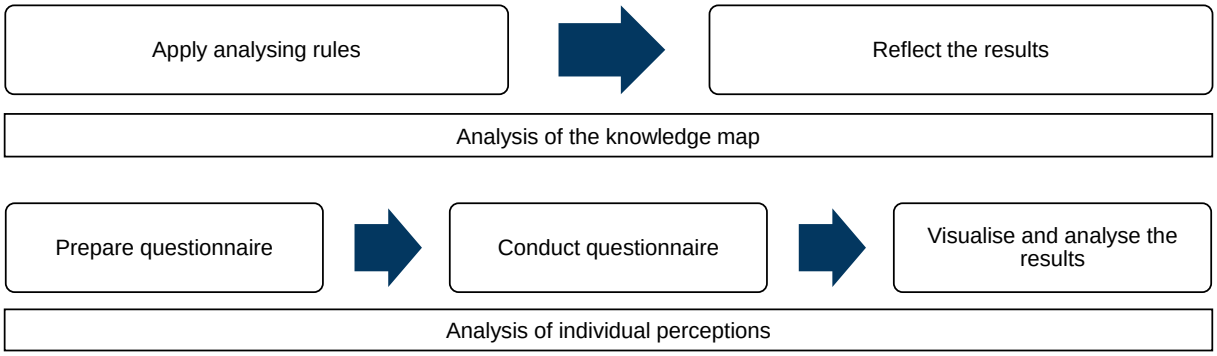


Figure 4-15: Procedures for step 3 “Analysing”

The **analysis of the knowledge map** is completed with two activities. First, **analysing rules** are applied to the knowledge map created in step 2 "Visualising" of *k*-MORE. By analysing the knowledge map, the potential critical elements are identified, which should be the target of the first actions for planning the phases of the knowledge reuse cycle. The analysing rules are presented in Table 4-3. The intention behind applying the rules is to restrict the first planning considerations just to critical elements in order to assure a feasible a progressive planning of the knowledge reuse cycle. It also assures that the first planning considerations offer the highest ratio between increasing knowledge reuse and the implementation effort for the company. Other elements of the knowledge map can be considered later. The results of applying the analysing rules can be presented in tables, as well as in graph form, if the amount of elements of the graph is appropriate for a good visualisation.

Table 4-3: Rules for the analysis of the knowledge map

Phase to consider	**Rule**
Packaging	Storages containing low number of documents
	Storages containing high number of documents
	Documents stored in many storages
	Most common terms in documents' names
	Most common terms in competences' names
Capturing & Documenting	Frequently generated documents
	Documents not frequently generated or used
	Roles which generate many documents
Reusing	Frequently used documents
	Roles which use many documents
Distributing	Frequently required competences
	Competence possessed by few roles
	Documents transferred between many roles
	Visible clusters in the knowledge map

After applying the rules, the **results are reflected**. The results of each rule have implications on planning each of the phases of the knowledge reuse cycle. The *tables for rules reflection* included as support documentation in Appendix 9.7.3 support the company in the process of understanding the meaning and reflecting the results. Table 4-4 shows the content of the *table for rules reflection* for the rule "storages containing low number of documents", results of which are to be considered in planning knowledge packaging. The implication is that poorly used storages are candidates to be eliminated. Some questions for the company to reflect on are: "are the storages really necessary?" or "is it possible to use more the storages?".

Table 4-4: Content of the tables for rules reflection (example of one rule)

Phase to consider	Rule	Measure in the knowledge map	Implication for the Reuse Cycle	Reflection
 **Packaging**	Storages containing low number of documents	Storage number of "is contained in" edges	These storages are candidates to be eliminated	• Are the storages really necessary? • Is it possible to use more the storages?

In order to offer a visual and user-friendly reflection of results, *reflection sheets* (template in Appendix 9.7.3) are prepared. The *reflection sheets* contain four categories which are directly obtained from the *tables for rules reflection* (rule, implication, phase to consider, reflection) and two categories more (results, critical elements and initial actions). Each *reflection sheet* showing the results of applying the rule is used as a base for a discussion between managers. As result of the discussion, critical elements and initial actions are defined and written down in the correspondent field of the sheet. Those do not need to be very detailed or concrete, because this is done in the next steps of the *k*-MORE methodology using *planning sheets*.

In the next paragraphs an example of the reasoning chain for the analysis of the knowledge map is presented. The example is based on the analysing rule "storage containing low number of documents" and the correspondent *reflection sheet* is presented in Figure 4-16. The results of the analysis show in total five storages (A, B, C, D, E), which contain less than three documents. The criticality and possible actions on those five storages are discussed in a session with company's managers. Storages A and B contain few documents from the documents depicted in the knowledge map but they contain numerous documents from other areas of the company. They are useful storages and their existence and use is not questionable. Thus, they are not considered for elimination. Storages C and D contain just two documents each in total. They are old established storages which were required years ago for their functionality but they could be eliminated and substituted. Storage E does not contain many documents but it is considered irreplaceable for its unique functionality. It is included as critical element for further planning because its use could be increased. Furthermore, the documents contained in storage C seem at first sight very suitable for storage E, so this idea is noted. All these conclusions based on the results are written in the field "critical elements and initial actions" of the *reflection sheet*.

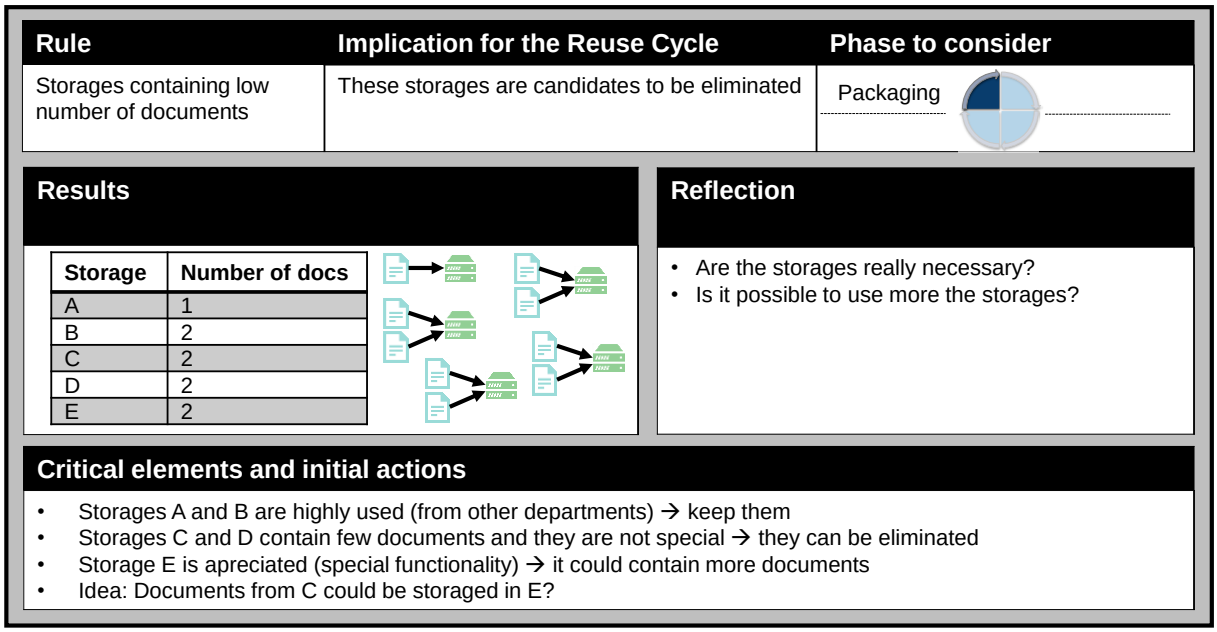


Figure 4-16: Exemplarily filled reflection sheet

The **analysis of individual perceptions** is the other analysis conducted in this step of *k*-MORE. It is done by means of a questionnaire given to selected employees based on the WCM, which was developed in Section 3.3. The model depicts influencing factors for knowledge reuse and knowledge processes experienced by individuals. The participants of the questionnaire are the ones identified for analysis in the *stakeholders' portfolio* (see Figure 4-8) of step 1 "Defining goals" of *k*-MORE (see Subsection 4.4.1). The first activity is to **prepare the questionnaire**. The questionnaire contains 21 analogue questions (one question per influencing factor of the WCM) prepared using the structure of template of *questionnaire of influencing factors (company)* included in Appendix 9.7.3. Figure 4-17 shows an example of the questionnaire for the factor organisational structure. The sheet has two parts; the information part, with the name of the factor as title; and the question part, with the title "please rate the next statement". The information part contains the following fields: statement of the influence of the factor on a knowledge process, definition of the influencing factor, definition of knowledge process, and description of an example of the current status of the factor in the company. The preparation of company-specific examples of the interpretation of the factor for the company is a very important part, which helps to the correct understanding of the definitions. The examples must be discussed and defined by company's managers and employees. The question part of the template states that the current handling of the factor in the company supports the correspondent knowledge process. Participants can answer to this statement in a 6-degree scale from completely disagree to completely agree. An optional field for comments is also included.

Organisational structure

"Company's *organisational structure* influences *knowledge transfer*"

Definitions:

- *Organisational structure* refers to your company design (hierarchies, departments, teams, etc.) and the processes established to carry out your and your colleagues' work
- *Knowledge transfer* is the process by which knowledge available within one unit of the organization (individual, team or a division of organisation) is made available to other unit(s) of the organization. It can be in written or in oral form.

Example of current organisational structure in your company:

- The company presents a hierarchical structure in three levels: management, development departments (A, B, C, D, E), development teams (A: 5 teams, B: 4 teams, C: 4 teams, D: 8 teams, E: 3 teams)

Please rate the next statement

The current handling of *organisational structure* in my company supports the *knowledge transfer* in the company

Completely disagree	Disagree	Rather disagree	Rather agree	Agree	Completely agree
☐	☐	☐	☐	☐	☐

Please justify your answer (optional)

Figure 4-17: Example of the questionnaire of influencing factors for the factor "organisational structure"

After the 21 analogue questions prepared with the template *questionnaire of influencing factors (company)*, there is a final question about the perceived relevance of the 21 factors. This final question is prepared in the *questionnaire of influencing factors (relevance)*, which is included in the support documentation of Appendix 9.7.3. In this final question, all factors are presented together because this allows a better comparison of their relevance. All factors have already been presented and described in the previous 21 questions, so explicit definitions are not necessary. Definitions can be included as additional information in hidden text boxes.

Conducting a test questionnaire with four or five participants is recommended, in order to check the understanding of definitions and examples described. Then the **questionnaire is conducted**. The expected duration per participant is around 40 minutes.

The final activity is **visualising and analysing the results**. The results are represented in boxplots, which show the perceived relevance given to each factor compared to the perceived current handling in the company. Figure 4-18 shows an exemplarily representation of the questionnaire results. The meaning of a boxplot is described in *boxplot definition*, which is included in the support documentation of Appendix 9.7.3.

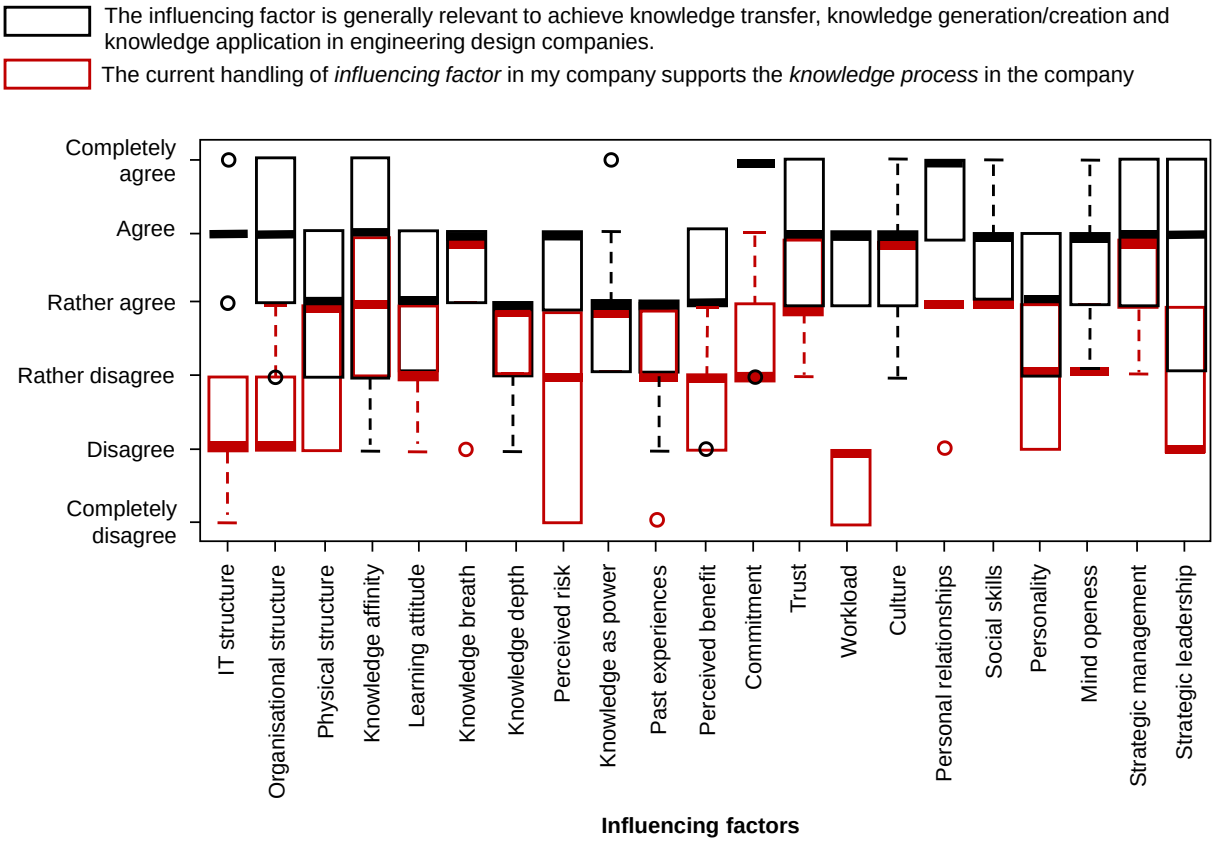


Figure 4-18: Exemplarily boxplot representation of the results of the questionnaire of influencing factors

The boxplot representation provides information regarding the shape, variability, and median of a data set. It is particularly recommended to represent skewed data. Boxplots support the *k*-MORE methodology providing a transparent overview of different perceptions of individuals regarding the influencing factors. Thus, influencing factors with unanimous answers (small IQR) will be addressed from a company perspective in the next steps (see Subsection 4.4.4), while influencing factors perceived differently (big IQR) will be individually addressed.

The results of the *questionnaire for influencing factors* are evaluated by following the *analysis flowchart* of Figure 4-19 (also included in Appendix 9.7.3). The meaning of the terms in the flowchart are:

- Gap: it indicates the distance between the median of perceived handling in the company and perceived relevance of a factor. Depending on the size of the gap, the flowchart follows different paths. The reference value for considering a big gap is established in two for the presented flowchart. This value can be defined company-specific.
- Clear gap: there is a clear gap if the difference between the lower quartile of the relevance boxplot and the upper quartile of the handling in the company is greater than zero. This is visually easy to recognise as the gap between the two boxes.

- Variation: it is depicted by the interquartile range (IQR). Variation can occur in both of the considered boxplots. In *k*-MORE, variation is considered if the IQR is greater than one. As it occurred in the case of the gap, this reference value can be defined company-specific.

Depending on the path, there are four different considerations. In some cases there is *no need for consideration* of the factor. On the contrary, for some factors a clear *urgent need for consideration* can be identified. Another option is that there is a *potential for improvement* but it is not a critical factor. The fourth option is the need for *individual consideration*. This happens when the answers present high variety, which indicates that individuals' perceptions on the same factor are very different. In this case, each one of the responses is individually analysed in order to identify the participants which present a "gap" in their answers. Their comments provide relevant hints on their source of dissatisfaction. Further information can be acquired in interviews with them. A prerequisite for this action is the traceability of participants in the *questionnaire of influencing factors*. Hence, the questionnaire cannot be anonymous.

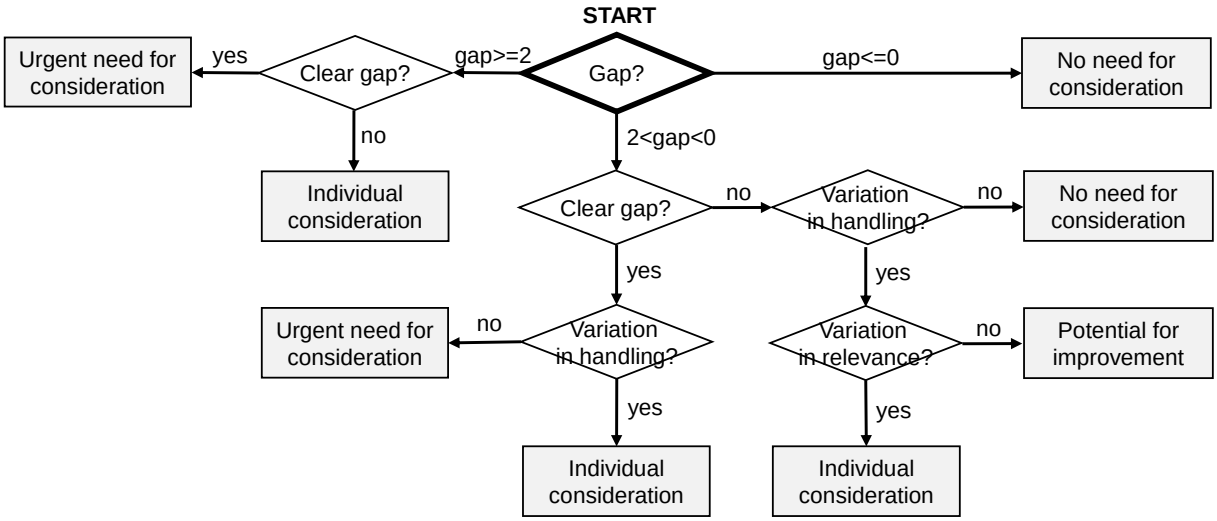


Figure 4-19: Analysis flowchart

Outcomes

Step 3 "Analysing" has two main outcomes:

- **Critical elements and initial actions.** The outcome of the reflection conducted in the *reflection sheets* and they are documented in the last category of the sheets, as it can be observed in Figure 4-16. They are input for the *planning sheets*, which will be created in the next steps *k*-MORE.
- **Needs for consideration of influencing factors**. The needs for each one of the factors are determined after applying the *analysis flowchart* to the questionnaire answers. The needs can be the following: urgent need for consideration, no need for consideration, potential for improvement or need for individual consideration. Furthermore, notes on concrete

aspects to be improved regarding the factors are extracted from the comments of the questionnaire.

4.4.4 Steps 4 to 7 "Planning the Reuse Cycle"

The reuse cycle is planned by planning its four phases in steps 4 to 7 of *k*-MORE: "Packaging", "Capturing and Documenting", "Reusing" and "Distributing". The way of planning each phase is analogous and it is presented in this Subsection.

Goals

Steps 4 to 7 "Planning the Reuse Cycle" pursue three goals:

- **Define** appropriate **actions** and **next steps** for the planning of the knowledge reuse cycle phases. Numerous elements and stakeholders are involved in the phases of the knowledge reuse cycle. All of them should be considered and involved in the planning. An iterative plan of actions and next steps is required to consider everything and still keep the planning manageable.
- **Identify** potential **methods** to perform the knowledge reuse cycle phases. Multiple methods exist to support the different phases of the knowledge reuse cycle. Selecting the most appropriate method for each company and each individual in the company is key of a successful implementation of those methods.
- **Facilitate** the definition of actions and methods in the **desired extension.** Some companies are not willing to make the effort of considering every element or stakeholder of the knowledge reuse cycle in detail. The possibility of planning the knowledge reuse cycle without going into too much detail is essential for the industrial acceptance.

Procedure

Each one of the steps 4 to 7 of *k*-MORE consists of five activities, which are depicted in Figure 4-20. The detailed methods, inputs, outputs and necessary documentation to conduct the activities are presented in Appendix 9.7.4.

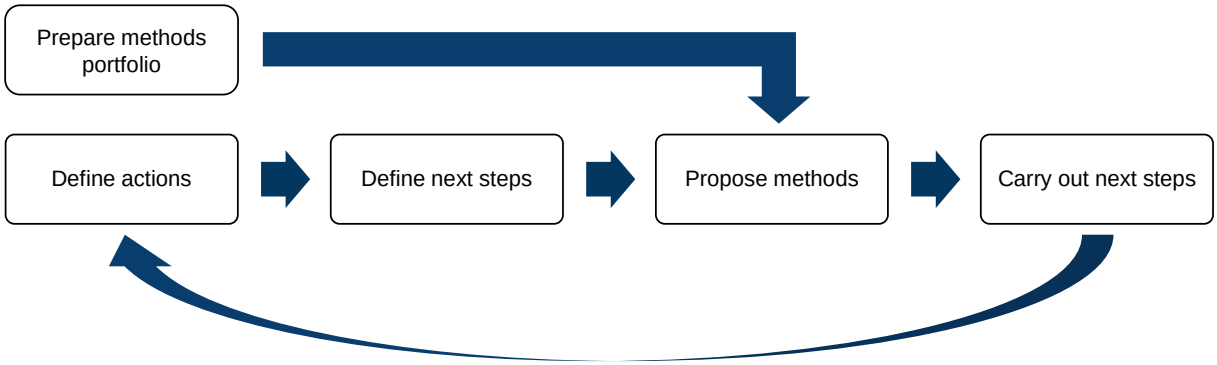


Figure 4-20: Procedure for each one of the steps 4 to 7 "Planning the Reuse Cycle"

One activity is **preparing the methods' portfolio**. The knowledge manager selects from the *methods catalogue* (introduced in Section 4.3 and contained in Appendix 9.7.4) suitable methods to address the company and individual influencing factors identified in the step "Analysis" of *k*-MORE. The knowledge manager can choose different number and combinations of influencing factors. Methods providing special support to manage some knowledge type can be also selected if required. The correspondent types of knowledge had been previously defined as attributes of the *definition of knowledge target* generated in Subsection 4.4.1. The knowledge manager includes the resultant methods in the *methods' portfolio* (template in Appendix 9.7.4). There is a *methods' portfolio* for each one of the four phases of the knowledge reuse cycle. The methods included in the portfolio are potential methods to implement the correspondent phase of the knowledge reuse cycle. Figure 4-21 shows an exemplarily *methods' portfolio* for the phase "Capturing and Documenting". In this example, the methods contained in the portfolio can address one, two or three influencing factors.

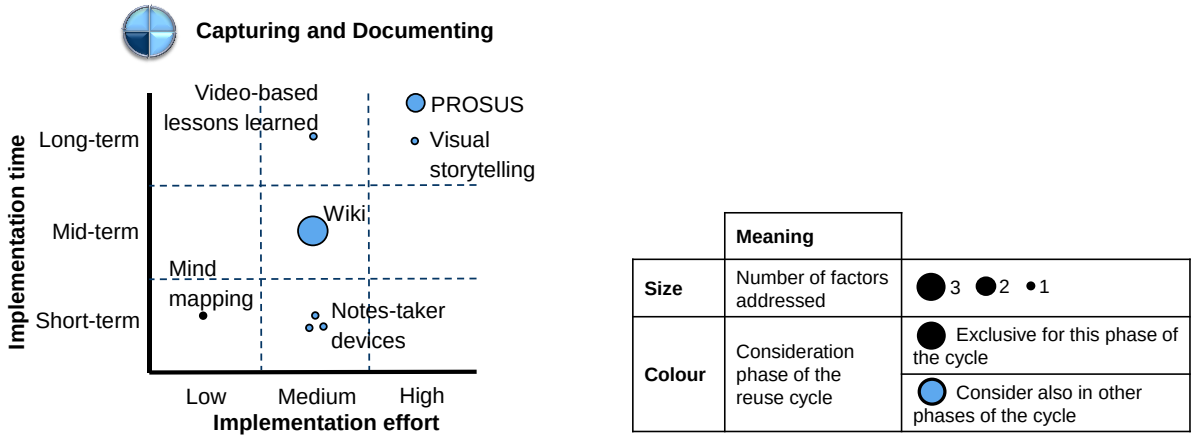
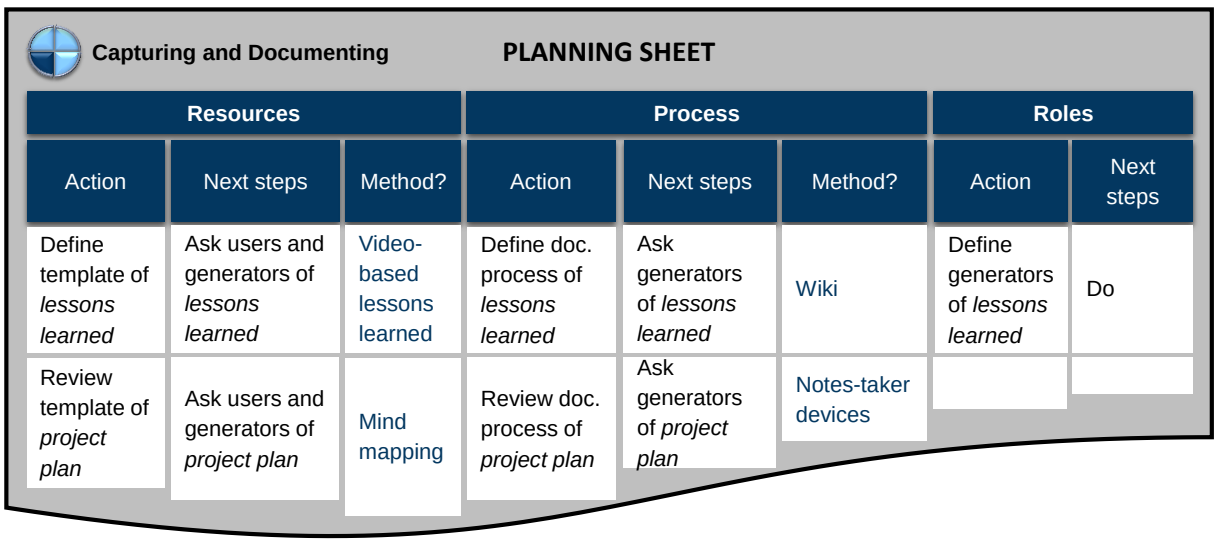


Figure 4-21: Exemplarily methods' portfolio for the phase "Capturing and Documenting"

The *methods' portfolio* depicts the methods based on two characteristics of the method: the implementation effort and implementation time. The implementation effort represents the amount of resources and work intensity expected in order to implement the method successfully. It is characterised as low, medium or high. The implementation time represents the expected time horizon for a full implementation of the method. It is characterised as short-term, mid-term or long-term. It is important to remark that the value given to the implementation effort and the time of each method is an indicative measure. These values may vary from company to company depending on the company's situation and resources. Furthermore, they are subjective, so each company can have its own understanding of their meaning for the praxis. The knowledge manager must evaluate the specific company's situation and modify the values suggested in the *methods catalogue* if it is required. The size of the method point in the portfolio indicates the number of relevant influencing factors addressed by the method. The colour indicates the amount of influence of the method on different phases of the knowledge reuse cycle. Two types of methods are differentiated: 1) methods to be applied in one phase; and 2) methods influencing more than one phase. The

first methods are easier to implement because they do not require high coordination between the knowledge reuse cycle phases. They are simpler than the other ones and they allow a modular and adaptable configuration of the knowledge reuse cycle. Since they are simpler, they are also generally more limited to address various influencing factors at the same time. The second type of methods requires coordination between different phases and they offer an overall concept for the knowledge reuse cycle. Their implementation requires more coordination effort but they usually are able to address more influencing factors at the same time.

Defining actions to start with the formal planning of the knowledge reuse cycle is the first activity in a sequence of activities, in which the *methods portfolio* will be used later on (see procedure in Figure 4-20). Actions are defined and documented in the *planning sheets* (template in Appendix 9.7.4). Four planning sheets are filled, one per phase of the knowledge reuse cycle. Figure 4-22 shows an exemplarily filled planning sheet for the phase "Capturing and Documenting". Each *planning sheet* considers three aspects, which are: resources, process and roles. Resources are all company's assets excluding persons. Examples of resources are documents, competences or storages. A process represents a series of steps in which an activity is performed by a person or several persons. Roles are the persons who are assigned as responsible of a process or a resource. For each one of the three aspects, actions are defined based on the critical elements and initial actions written in the *reflection sheets*. An action represents something that is to be done or achieved. In the category resources an example of action can be to establish a new template for a document. In the category process an example of action can be to define a standard documentation process. In the category role an example of action can be to define a template supervisor, who will be on charge of evaluating and assuring the correct use of the template. The three categories have to be considered in order to assure that all possible actions are reflected and no action is missing. However, it is not necessary to write down an action for each category. If no action is defined, the field action of the corresponding category of the *planning sheet* remains empty.



Capturing and Documenting **PLANNING SHEET**

Resources			Process			Roles	
Action	Next steps	Method?	Action	Next steps	Method?	Action	Next steps
Define template of *lessons learned*	Ask users and generators of *lessons learned*	Video-based lessons learned	Define doc. process of *lessons learned*	Ask generators of *lessons learned*	Wiki	Define generators of *lessons learned*	Do
Review template of *project plan*	Ask users and generators of *project plan*	Mind mapping	Review doc. process of *project plan*	Ask generators of *project plan*	Notes-taker devices		

Figure 4-22: Exemplarily planning sheet with proposed methods from the methods' portfolio of Figure 4-21

After defining actions, the **next steps** to conduct those actions are defined. Next steps describe the immediate necessary step in order to complete the action. For example, if the action is to establish a new template for a document, a reasonable next step is to talk with generators and users of the document, in order to discuss about a new template concept. If the action is clear and it can be done by the knowledge manager without involving others in the company, the reasonable next step is to carry out action.

At this point, the *planning sheets* are filled with actions and next steps. Then, the knowledge manager **proposes methods** to carry out the defined actions. As a basis, the knowledge manager has the previously prepared *methods' portfolios.* The methods proposed will be discussed with the stakeholders pointed as discussion partners for next steps. Various methods can be proposed per action. It is not required to propose methods for all the actions. The knowledge manager decides for which actions are methods proposed. Special attention is required for methods which are influencing various phases of the knowledge reuse cycle. Those methods have to be considered and discussed in all phases. Figure 4-23 shows an overview of the inputs required to fill the *planning sheets* including in which step of the *k*-MORE methodology they were generated.

Once the *planning sheets* are completely filled out, the knowledge manager **carries out** the **next steps** described in the sheets. Since numerous stakeholders are involved in the knowledge reuse cycle, it is expected that next steps imply discussions with people in the company. The goals of these discussions are to verify the need for the action, to increase the understanding on what is to be improved and to discuss the suitability of methods for implementing the action. The methods presented for discussion are those which have been proposed by the knowledge manager in the previous activity. The *methods descriptions* included in Appendix 9.7.4 provide information about the methods such as goal, advantages, disadvantages, procedure, tools and hints. This information supports the discussions between knowledge manager and the involved stakeholders. The results of the discussions can be the definition of new actions, so that the loop from defining actions to carry out next steps starts again. This process continues **iteratively**, as it is shown in Figure 4-20, until any further discussion is required and the actions just have to be done. At this point, the planning of the knowledge reuse cycle is completed.

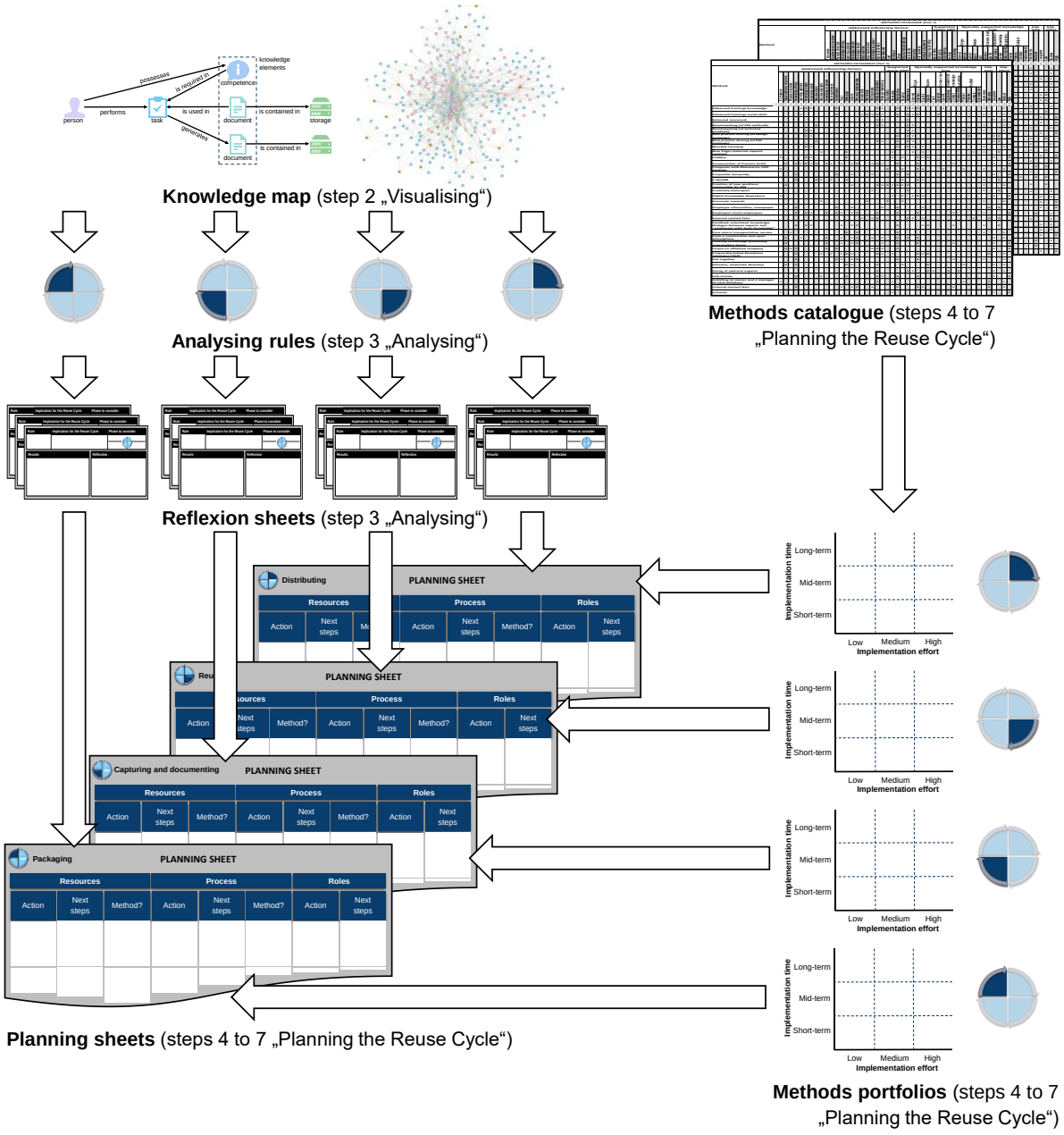


Figure 4-23: Overview of the inputs required to fill the planning sheets

Outcomes

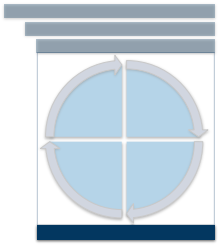
Two main outcomes for each one of the steps 4 to 7 of *k*-MORE are generated during “Planning the Reuse Cycle”:

- Filled ***methods’ portfolio*** template. The *methods’ portfolio* is filled with methods selected from the *methods catalogue*. Various *methods’ portfolios* can be prepared by applying different selection criteria to the *methods catalogue*. Furthermore, portfolios for specific

individuals can be prepared based on the influencing factors identified for them in Subsection 4.4.3.

- Filled ***planning sheets*** template. *Planning sheets* constitute an intermediate outcome of the steps during the iterations as well as the final outcome. The final *planning sheets* are those in which all corresponding next steps for the actions are "carry out the action".

4.4.5 Step 8 "Maintaining"



Step 8 "Maintaining" of the *k*-MORE methodology provides guidelines to plan the successful maintenance of the methods selected to conduct the knowledge reuse cycle. It is the final step of the *k*-MORE methodology.

Goals

Step 8 "Maintaining" pursues two goals:

- **Provide awareness** of **success factors** for methods implementation and maintenance. Cultural aspects and actions contributing to the continuous application of methods must be well known in order to consider how they are going to be introduced in the company.
- **Define actions** to **assure maintenance** of the knowledge reuse cycle. Based on the success factors, each company should establish a plan to maintain the methods, actions and roles defined in the *k*-MORE *planning sheets*.

Procedure

This step of the *k*-MORE methodology does not propose a detailed procedure but some guidelines indicating what has to be considered in the one-time action of bringing the knowledge reuse cycle to the move in order to keep the cycle moving in the future. The guidelines are the following:

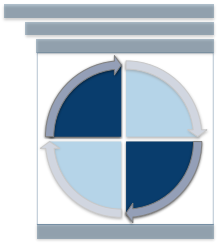
- Define the following aspects in the company (*maintenance establishment*):
    - A responsible (knowledge manager) to assure and control the maintenance of the knowledge reuse cycle.
    - A responsible person and a budget for the maintenance of each method and action defined in the final *planning sheets.*
    - How to communicate a clear vision and goals of reusing knowledge as well as clear goals for each method and action defined in the final *planning sheets.*
    - How to communicate the utility of each method and action defined in the final *planning sheets.*
    - How to get continuous support and commitment from management.
- Tasks of the knowledge manager (*maintenance controlling*):
    - Define a time-line or indicators to identify when the knowledge manager should initiate the following actions:
        - Conduct a lessons learned session for a method
        - Repeat Step 1 "Analysis" of *k*-MORE in order to identify new gaps that require again the application of the *k*-MORE to plan the knowledge reuse cycle.

- Establish a company's philosophy considering the following aspects:
  - Clear and systematic procedures.
  - Process orientation.
  - Long trip – small steps.
  - Participation of employees.
  - Use the potential of existent IT-tools.

Outcomes

- **Maintenance establishment.** Responsibilities and way of communication are documented and implemented.
- **Maintenance controlling.** The knowledge manager establishes a controlling method to be initiated and continuously performs the maintenance actions and philosophy.

4.4.6 *k*-MORE Approach for Knowledge Package and Reuse



Additionally to the *k*-MORE methodology, this thesis proposes an approach for knowledge package and reuse. The goal of this approach is to fulfil the requirements for support concerning the "Reusing" phase of the knowledge reuse cycle (requirements in Table 4-1). Existing methods, included in the *methods catalogue* of Appendix 9.7.4, do not fulfil all requirements.

The approach presented in this Subsection constitutes the specification of methods from the *methods catalogue*. The integration of this approach for knowledge package and reuse is **optional** during the application of the *k*-MORE methodology. Other methods for step 4 "Packaging" and step 6 "Reusing" can be selected from the *methods catalogue*.

Goals

The goals of the *k*-MORE approach for knowledge package and reuse emerge from the requirements for the support concerning the "Reusing" phase of the knowledge reuse cycle (requirements in Table 4-1). The goals are:

- **Facilitate** the **formulation** of a **search question**. Active search for knowledge requires a question or query to start the search process, but this is not always easy for designers. The proposed approach should allow a knowledge search without the need of formulating a search question.
- **Provide individualised search and reuse solutions** independently of the participation of designers in previous projects. Personality plays a very important role on the individuals' satisfaction with knowledge packaging structures and reusing methods. The proposed approach should combine different solutions in order to satisfy all kind of users.

Concept

The main idea is combining a **Knowledge Base (KB)** with periodical **lessons learned sessions.** The KB is the central element to package and search for explicit knowledge in form

of project documents and written lessons learned. The periodical lessons learned workshops promote knowledge transfer and contribute to transform implicit knowledge into explicit knowledge.

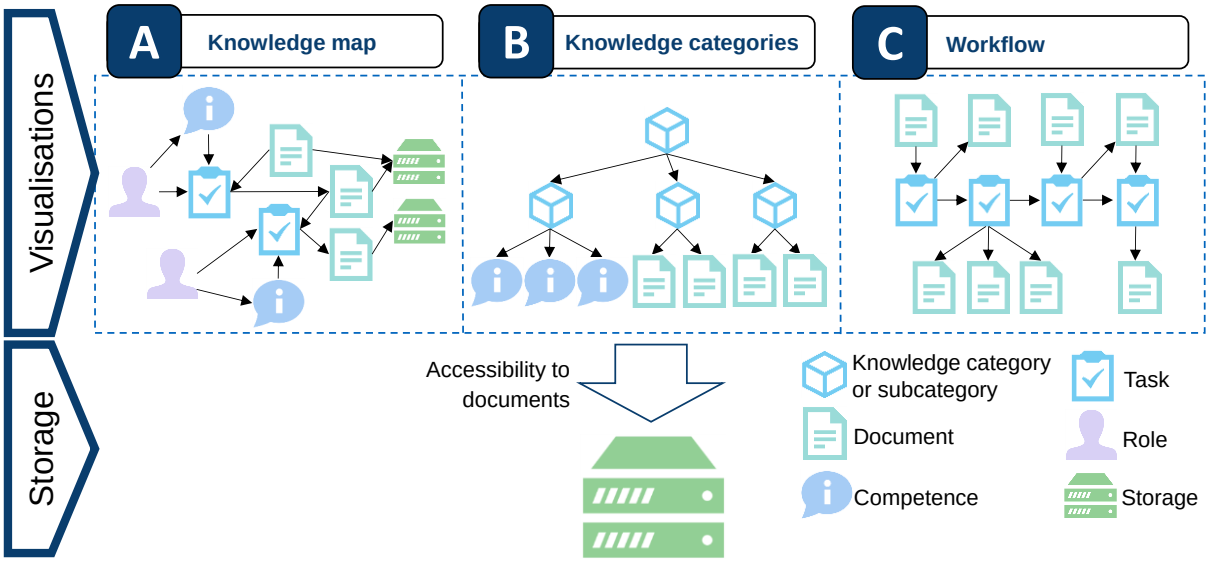


Figure 4-24: Visualisations of the Knowledge Base

The main elements of the KB are the physical storages of the documents and the visualisations of its content. The proposed KB concept presents its content in **three visualisations** (A, B, C), which are depicted in Figure 4-24. Visualisation A is the knowledge map created in step 2 "Visualising" of *k*-MORE. It includes roles, tasks, competences, documents and storages. Visualisation B is an overview of the knowledge categories related within a hierarchy. It contains knowledge categories and subcategories, documents and competences. The knowledge categories result from the analysis of the knowledge map conducted in step 3 "Analysing" of *k*-MORE. Visualisation C shows the workflow of the development process linked to the documents generated in each phase of the process. Visualisation C shows the daily tasks and associated documents used and generated in them.

The combination of the three visualisations pursues three goals:

- Provide **multiple options** of **free search** for knowledge element, so each person in the company can conduct an individualised 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 the Visualisation A (knowledge map).
- Provide the **context** of knowledge generation in Visualisation C (workflow).

Graph-visualisation tools are required for the software implementation, which should control the accessibility and provide direct access to documents.

The metamodel of Visualisation A is the metamodel of knowledge map already depicted in Figure 4-12. Figure 4-25 depicts the metamodels for Visualisation B and Visualisation C.

The proposed KB supports knowledge package. Three methods are proposed to support reuse through searching in the Visualisations. The methods can be combined according to the individual preferences and situation.

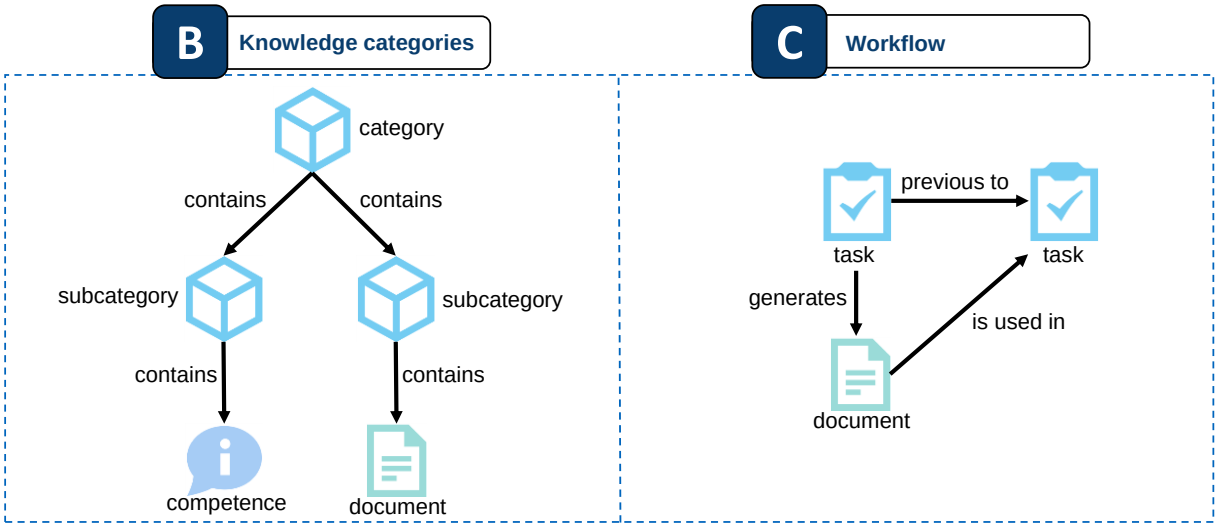


Figure 4-25: Metamodels of Visualisation B and Visualisation C

The first method is **free navigation** in the visualisations. Due to the different structures and elements of the three graphs, the user can choose a visualisation, which fits his current preferences and understanding. If the user is familiarised with the software program, oriented searches can be conducted in order narrow down the scope of the visualisations. This method was used during the DS I in the EDE II under the name of Free Search in Visualisation or FSV (see Subsection 3.4.2).

The second method is the use of **Search Scenarios**. Search Scenarios are pre-defined search configurations for the visualisations such as finding a person or a document which is used in many tasks. Search Scenarios have to be defined specifically for the search interface of the software used to implement the visualisations. The goal of the Search Scenarios is helping the user navigating in an unfamiliar software environment. Once the user has experience, he or she can come up with the search configurations on his or her own in order to guide the search during free navigation. Figure 4-26 shows exemplarily the Search Scenario “select a specific time frame” in Visualisation C designed for the search interface of the software Soley Studio.

Search scenario	
1) Select a specific time frame	
Search by	**Soley – Smart Selector: How to**
Task's start and end date	All Nodes Class ▼ IsEqualTo ▼ Task ▼ Startdate ▼ IsGreaterThanOrEqualTo ▼ (YYYYMMDD) ▼ Enddate ▼ IsLessThanOrEqualTo ▼ (YYYYMMDD) ▼

Figure 4-26: Search Scenario "Select a specific time frame" in Visualisation C for Soley Studio

The third method receives the name of **DeSiDe** (Design Situation Definition). This method is an elaborated version of the method CDS that was used in the EDE II of the DS I (see Subsection 3.4.2). DeSiDe consists in suggesting potential knowledge for reuse in a design situation without the need of formulating an active search. The appropriate knowledge is provided based on the characteristics of the design situation. Depending on those characteristics, the knowledge type, amount and representation to consider in a design situation vary. The elaboration of the characteristics is presented in Carro Saavedra et al. (2017a). Eleven characteristics with the correspondent characterisations of those are proposed (Figure 4-27). The characteristics can be extended based on company specifications. The hypothesis behind the method is the "mapping hypothesis", which says that for the same design situation, the same knowledge may be useful for reuse (Carro Saavedra and Lindemann 2015).

Characteristic	Measurement parameter
Level of experience	Novice
	Expert
	Competent
Status in the company	Project manager
	Team manager
	Technical worker
Type of group work	Independent
	Communication
	Cooperation
	Interdependent
Level of product complexity	Low
	Medium
	High
Level of familiarity with the product	None
	Low
	Medium
	High

Characteristic	Measurement parameter
Design phase	Product planning
	Conceptual design
	Embodiment design
	Detailed design
Type of activity	Synthesis
	Analysis
	Decision
Restriction on design time	Low
	Medium
	High
Purpose of reusing knowledge	Replication
	Innovation
Stages to apply the reuse	Preparation
	Recapitulation
	Cope with the past
Personality	Extraversion or intraversion
	Sensation or intuitition
	Thinking or feeling
	Judging or perceiving

Figure 4-27: Characteristics of design situations

In order to enable the mapping between design situations and knowledge, the elements of the KB are characterised with attributes. The attributes are the characteristics of the knowledge contained in the KB. Knowledge attributes of a document can be for example the design phase in which it was generated, the document size or the document author. The existence of patterns between the characteristics of design situations and the knowledge attributes is the claim behind the "mapping hypothesis". Those patterns are company-specific, therefore, successful cases of knowledge reuse have to be tracked in the company in order to determine replicable mapping rules. This could be done by applying artificial intelligent methods such as neural networks.

Lessons learned are not created neither documented during normal project work. The systematic generation of lessons learned requires investing time and applying methods. Schacht and Maedche (2016) propose to "conduct lessons learned sessions not only as recapitulation at the end of a project, but also at its beginning and during its runtime as preparation to next steps." Intermediate lessons learned sessions contribute to transfer and therefore reuse the team´s knowledge on the own project (intra-project learning). The final lessons learned session serves to validate the used knowledge and to propose it for reuse in upcoming projects, as well as it serves for personal knowledge acquisition for each team member (inter-project learning).

This thesis suggests the periodical execution of lessons learned sessions and the documentation of those in a predefined template, which is to be included in the KB. Visualisation B (knowledge categories) of the KB contains a category called lessons learned, in which the results of each lessons learned session must be documented. The time frame between sessions must be company-specific.

Procedure

There are two ways of preparing the proposed **KB visualisation**:

- A→B→C. First, Visualisation A (knowledge map) is created following the instructions indicated in step 2 "Visualising" of *k*-MORE (see Section 4.4.2). Based on the knowledge map and following the analysing rules for packaging referring to common terms of step 3 "Analysing" of *k*-MORE, Visualisations B is created. Visualisation C is independent from A and B, and its creation is optional. If created, it is done in real time during company's projects. Visualisations A and B are extended based on the new input of C so the process turns to C→A→B, which is explain below.
- C→A→B. First, Visualisation C is created out of running projects. Once one or several projects are completed and visualised, Visualisation A is created. In order to convert C to A, all versions of the same document in C are synthesized in one general document for A (the link associated to the document is the last version in C) and the same happens for repeated tasks. Other elements of the knowledge map such as roles or storages are extracted from the attributes of the elements of Visualisation C. Competences have to be collected once the knowledge map had been created. Finally, Visualisation B is created based on the knowledge map and following the analysing rules for packaging referring to common terms of step 3 "Analysing" of *k*-MORE.

In the first way (A→B→C), Visualisations A and B contain an overview of knowledge created previously to the point of implementation of the approach. In the second way (C→A→B), the knowledge contained in the visualisations is only knowledge related to the projects considered in Visualisation C from the point in time of the implementation of the approach.

In order to apply the methods for "Reusing", the company should distribute the KB visualisations and assign the required credentials. The knowledge suggestion using the DeSiDe method can be done using the pull or push principle. Following the pull principle, the designer/s working in the design situation can select the characteristics manually and receive knowledge suggestions based on that. Following the push principles, an automatic characterisation of the design situation could be done. Some suggestions are for example recognising characteristics such as "status in the company" or "level of experience" through the personal computer account or recognising the characteristic "design phase" and "restriction of design time" based on a centralised project plan (e.g. Gantt Chart of the project).

The procedure suggested for the **lessons learned sessions** of a project consists of four activities, as it shown in Figure 4-28. The detailed methods, inputs, outputs and necessary documentation to conduct the activities are presented in Appendix 9.7.5. The procedure is based on the methodology proposed by Schacht and Maedche (2016) for recapitulation sessions, which was simplified in some aspects and more detailed in others in order to facilitate its direct application by practitioners. There are two roles involved in the lessons learned session procedure. The first role is the knowledge manager or lessons learned expert, who possesses the methodological knowledge to run the workshops and to document the lessons learned. The second role is the topic expert, who has experience in a specific field and therefore, possesses knowledge.

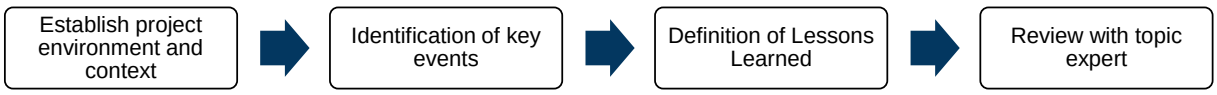


Figure 4-28: Procedure for the lessons learned sessions

First, the project environment and context are gathered by the knowledge manager who submits a questionnaire to team members. The questionnaire considers aspects such as project results, resources, stakeholders or benefits. At the end of the questionnaire team members are asked to reflect upon some questions which will be addressed in next steps. The questionnaire to establish project environment and context is contained in Appendix 9.7.5. The identification of key events and definition of lessons learned take place in one workshop with team members. The knowledge manager starts the workshop with a presentation of the questionnaire results in order to set a common project environment and context understanding. Then, the participants have to write down on colour-coded cards what do they want to reduce, eliminate, maintain, increase and/or create in the project. The answers are clustered and discussed in order to define key events of the project. A key event is a situation, recurrent habit or implicit assumption which is decisive for the success or failure of a project.

Examples of key events are “changes in the project scope definition” or “not sticking to rules and agreements previously adopted”. Using the *lessons learned documentation* template (contained in Appendix 9.7.5), the team discusses lessons learned for each key event as well as necessary actions to apply the lessons learned. Finally, the collected lessons learned and actions are discussed with topic experts such project managers or specialist who comment on them and provide feedback about the viability of the actions’ implementation.

Outcomes

- **KB visualisations**. The KB visualisations are the reference tool for knowledge reuse in the company. They have to be regularly updated by knowledge managers.
- **Search Scenarios** for the specific software program in which the visualisations are implemented. Different software programs offer different functionalities and present different interfaces. The Search Scenarios are instructions in order to look easily for the most common knowledge element. These instructions have to be prepared for the specific software used.
- **System to implement the DeSiDe method for “Reusing”.** By following the pull principle, templates to select the characteristics of design situations have to be prepared. By following the push principle, the automatic recognition of the values for the characteristics has to be implemented in the computers systems of the company.
- Filled ***lessons learned documentation*** template. A lessons learned template is filled after each lessons learned workshop, and it is included as document in the visualisations of the KB. Figure 4-29 presents an exemplarily filled line with one lessons learned.

Lessons learned documentation

Topic	Key event	Best Practice (BP) or Problem (P)	Lesson Learned	Description	Action	Topic Expert Feedback
Presentations	Objectives of the presentations are not clear for the audience	P	The content of project presentations should be adjusted to the audience	The presentation of methodology and process is more interesting for the supervisors, and the presentation of results is more interesting for the client company	The team suggests to present exclusively methodology and process to supervisors, and results to the client company	Presenting both aspects is necessary. A standard structure for presentations helps avoiding confusion. We suggest to start with the results and let the methodology for the end

Figure 4-29: Exemplarily filled line of a lessons learned documentation template

5. Evaluation of the *k*-MORE Methodology

This Chapter presents the Descriptive Study II, in which the proposed methodology and approaches for knowledge package and reuse are evaluated on five case studies. The plan for the evaluation is explained in Section 5.1. Software and tools used for the implementation of some parts of the methodology are presented is Section 5.2. The five case studies are described from Section 5.3 to Section 5.7. The Chapter concludes in Section 5.8 with a reflection on the fulfilment of requirements of the proposed support.

5.1 Evaluation Plan

Blessing and Chakrabarti (2009) describe three types of evaluation: support, application and success. **Support evaluation** involves continuous testing during the development of support in order to ensure that the support is developed to such an extent that it can be evaluated in application and success. The goal of the **application evaluation** is the assessment of the applicability and usability of the support. The goal of the **success evaluation** is the assessment of the usefulness of the support, which means how successful the support is fulfilling the formulated requirements. Support evaluation is a prerequisite for application evaluation and it is also useful to explain the results. Application evaluation is a pre-requisite for success evaluation.

Five case studies were conducted for the evaluation of *k*-MORE. Three case studies were part of the support evaluation and two case studies were conducted for application and success evaluation. Table 5-1 shows an overview of the case studies and the parts of the methodology covered in the evaluations. Case Study I was conducted in a company of furniture development. The focus of the evaluation was the process to create a company's knowledge map, which corresponds to step 2 "Visualising" of *k*-MORE. Case Study II was conducted in an electronic company. The first three steps of *k*-MORE were the focus of the evaluation. Case Study III was conducted in an academic project in collaboration with an automotive company. The focus of this case study was the development and evaluation of the *k*-MORE approach for knowledge package and reuse. Case Study IV was conducted in collaboration with a company which develops construction elements like windows, doors and facades. In this case study, the final steps 1 to 7 of the *k*-MORE methodology were applied in the company, discussed and evaluated with the company's participants by means of questionnaires. Case Study V was conducted in an academic project collaboration with a transportation company in order to develop a bike-sharing concept for city of Munich. During this case study, the *k*-MORE approach for packaging knowledge in a Knowledge Base (KB) with three visualisations was applied. Furthermore, the approach for reusing knowledge by means of combining different search methods on the proposed KB was evaluated by means of questionnaires and experiments.

Table 5-1 Overview of the case studies for the evaluation

Case Study		Evaluation type			Evaluated support					
					***k*-MORE methodology**				***k*-MORE approach for package and reuse**	
		Support	Application	Success	Step 1: Defining goals	Step 2: Visualising	Step 3: Analysing	Steps 4 to 7: Planning the Reuse Cycle	Step 4: Packaging	Step 6: Reusing
I	Furniture company	X				X				
II	Electronic company	X			X	X	X			
III	Automotive collaboration	X							X	X
IV	Construction company		X	X	X	X	X	X		
V	Bike-sharing collaboration		X	X					X	X

The following Sections present the five cases studies. In order to preserve confidentiality, the names of some companies are not included and some results are generalised. All case studies were part of a project or student theses, in which further details are documented.

5.2 Implementation

Soley Desk[2] was the software used to create knowledge maps (required in step 2 "Visualisation" of *k*-MORE) in Case Study I and Case Study IV. It is a graph visualisation software which offers customizable dashboards, interactive visualisations and targeted drill-downs. It provides transparency and overview of the graphs and it supports filtering, selecting and comparing in scenarios on them. Soley Desk presents a user friendly interface and it is

[2] More information in http://www.soley.io

intuitive for the end user. The software offers a set of metamodels for generic cases. The nodes, edges and attributes of each metamodel cannot be changed or extended in Soley Desk.

Soley Studio[3] was the software used to prepare the visualisations of the *k*-MORE KB (required for knowledge "Packaging" as proposed in Subsection 4.4.6.) in Case Study III and Case Study V. Soley Studio constitutes a development environment for graph visualisation and analysis. Compared to Soley Desk, Soley Studio offers the possibility of customising graph data and analysis through own programming of features. The interface and use of Soley Studio are more complex than the ones of Soley Desk but own feature programming was required in order to create the visualisations in the way they had been conceptualised.

SurveyMonkey[4] was the survey-design tool used to conduct the questionnaire of individual influencing factors (required in step 3 "Analysing" of *k*-MORE) in Case Study II and Case Study IV.

Microsoft Excel was the software used in all case studies to prepare templates and to prepare input data for the Soley graphs. It was also used to depict the questionnaire results and analysis of individual influences for knowledge reuse applied in step 3 "Analysing" of *k*-MORE in Case Study II and Case Study IV.

5.3 Case Study I - Furniture Company

This case study was conducted in the context of the project "Strategic development of company's knowledge with knowledge maps" in 2015. It is part of the support evaluation for the **step 2 "Visualising"** of the ***k*-MORE** methodology. Subsection 5.3.1 presents the initial situation and motivation. The application and its results are presented in Subsection 5.3.2. Finally, the results are discussed in Subsection 5.3.3 and lessons learned are derived.

5.3.1 Initial Situation and Motivation

The furniture development company is a local small-size company (less than 50 employees) specialised in ergonomic furniture. The company is on charge of the complete development process, from idea generation to manufacturing. They are also on charge of marketing and sales. The company offers a portfolio of six products with various variants.

A future goal for this company is the foundation of a subsidiary service company in order to advise their clients about office layouts and thus be able to offer a product-service system concept. The new company will require product and process knowledge from the current company and therefore, a strategy for effective knowledge transfer is required. Some considered measures to transfer current knowledge are transferring employees from the current company to the new company, documenting current tacit knowledge and training of new employees by current employees. In order to prepare the transfer strategy in a systematic way, a clear overview of the current company's knowledge is required.

[3] More information in http://www.soley.io

[4] More information in https://www.surveymonkey.de/

The **knowledge overview** should be created by means of a **knowledge map**, which corresponds to the step 2 "Visualising" of *k*-MORE. Previous research works conducted in Maurer (2014) served as reference to plan the knowledge acquisition process and the metamodel of the knowledge map.

5.3.2 Application

Relevant knowledge to transfer to the subsidiary company was product knowledge and organisational knowledge. Given the small size of the company, all departments except production possess the required knowledge and therefore, all departments but production were considered for the knowledge acquisition. The knowledge map should offer a complete overview of all company's activities previous to product production. The product development process was used as a reference for the acquisition of product knowledge. Activities not included in the development process such as sales or marketing processes were additionally considered in order to acquire organisational knowledge.

The plan for **knowledge acquisition** consisted on one initial workshop with representatives from the main company's areas in order to define roles, tasks and associated knowledge element. The links between the knowledge element and the tasks, i.e. which knowledge element was used or generated during a task, were planned to be acquired in personal interviews with the respective roles.

The initial **workshop** was conducted in one and a half hour with five participants. A final amount of 25 roles and 46 related tasks were collected. The time was not enough in order to collect the correspondent knowledge element during the workshop. Therefore, it was decided to acquire them directly during the interviews. This was done following the method proposed in Wickel et al. (2013), which proposes to use previous interviews as source for knowledge element in each new interview. The reason is assuring consistency in the names of knowledge element.

Five **interviews** were conducted in order to complete the knowledge element and relate them to the correspondent tasks. A template in matrix form was prepared for documentation during the interview. Each participant divided his or her tasks in several activities and then, explained which knowledge element were used and generated in each activity. The breakdown of tasks into activities was done in order to facilitate the elicitation of knowledge for the interviewees. The interviews had a duration between one and one and a half hour. In total, 80 activities were collected and 220 different knowledge element.

The knowledge map was implemented in Soley Desk. The map presented three differentiated clusters, which were not linked to each other:

- Roles, activities and knowledge related to product development. This cluster presents numerous common knowledge element like for example 3D documents, MS office competence, norms or instructions.
- Roles, activities and knowledge related to external parties like partners, suppliers or clients. The common knowledge element in this cluster is contact information of the target group.

- The role of "director of sales" and its correspondent activities and knowledge element.

5.3.3 Discussion and Lessons Learned

The goal of this case study was the development of a strategy for knowledge transfer between the current company and the subsidiary company. The goal was achieved applying the methodology described in d'Albert et al. (2015), which is not part of this thesis. The relevant part of the case study for *k*-MORE is the development of the knowledge map. The methodology for the development of the knowledge map with an initial workshop followed by interviews was generally helpful but several aspects revealed need for improvement.

One hour and a half for the **initial workshop** was too short. Although the five participants were focused during the definitions of roles and associated tasks, there was no time to define knowledge element associated to the described tasks. This happened because roles and tasks were put in common and briefly discussed in group. The discussion is a very important part of the workshop since it assures the common understanding and consistency of the terms. Thus, it cannot be eliminated. In order to enable the acquisition of all necessary knowledge element during the workshop, more time is planned for this workshop in the final step 2 "Visualising" of *k*-MORE. This aspect is especially remarked in this phase of *k*-MORE, because companies are usually very resistant to invest time for knowledge acquisition. Investing two hours more at the beginning of the process can assure correctness and completeness, as it will also be observed in Section 5.4 with the experience made in Case Study II.

The time planned for each **interview** was appropriate and enough to acquire the required input. The breakdown of tasks in activities was useful for the participants but it caused an undesired side effect. Since the activities were very detailed, the associated knowledge element were also very specific, which originated a few number of common knowledge element in the final knowledge map. This effect could have been avoided if knowledge element had been defined in the initial workshop. Building on knowledge element defined in previous interviews was not always possible for the interviewees because of lacking context and partner to discuss real meaning of the terms. This difficulty cause the effect that many new knowledge element were defined in each new interview. If those new defined knowledge element were different to previous ones could not be assured, since the individual interviews did not provide a frame for discussion with the other interviewees.

5.4 **Case Study II – Electronic Company**

This case study was conducted in Diebold (2016). It represents the support evaluation of **step 1 "Defining Goals"**, **step 2 "Visualising"** and **step 3 "Analysing"** of the ***k*-MORE** methodology. Subsection 5.4.1 presents the initial situation and motivation. The application and its results are presented in Subsection 5.4.2. Finally, the results are discussed in Subsection 5.4.3 and lessons learned are derived.

5.4.1 Initial Situation and Motivation

The electronic company is a global company employing around 1500 persons worldwide. The company is distributed in five business units and the case study took place in the unit of Innovation Management, in an area which involves around 200 employees. The goal of this unit is developing innovative technologies and solutions which can be then transferred to the other business areas in which the products are prepared for the introduction in the market. This company's focus is on research and development. Production is mostly done by external companies.

Knowledge is a trigger for innovation and the company possesses lots of it after years of research and development. However, they currently lack understanding of which knowledge is available and where, which leads to inefficient knowledge reuse. In order to avoid these inefficiencies, the company wants to **create a centralised KB** in which knowledge is structured, transparent and goal-oriented documented during company's activities. Several steps of the *k*-MORE methodology are needed to achieve this goal. Especially in focus are step 2 "Visualising" in order to create a knowledge map and step 3 "Analysing" in order to derive a way of structuring and measures for reusing knowledge in a centralised KB..

The initial amount of employees and knowledge to consider in this case is higher than in Case Study I. The experience of Case Study I was that considering too many types knowledge lead to high time-consumption and high complexity of the knowledge map. In order to avoid these effects, step 1 "Defining goals" of *k*-MORE should be developed and implemented. The goal is to establish a focus for knowledge acquisition so it remains manageable. Thus, the amount of participants in the knowledge acquisition is reduced to those who possess the types of knowledge relevant to achieve the main company's goals.

5.4.2 Application

The case study started with step 1 "**Defining goals**" of *k*-MORE by applying a needs analysis. In the is-situation, the company lacked on understanding which knowledge was available and where. This lack of transparency led to inefficiencies in company's processes: different departments are working on the same problem and they do not know from each other, documents are created multiple times, searches for experts and documents are long, and knowledge gets lost when employees leave the company. The desired-situation was defined by the company's goals. The normative goal of the company was to be market leader in innovation and its strategic goal was to achieve structured knowledge documentation. Based on those, the target knowledge was defined using the template for *definition of knowledge target* including key attributes, examples and nonexamples (see Figure 5-1). The *taxonomy of knowledge dimensions* supported the definition process. Key attributes regarding the dimension subject were: technical product knowledge and market knowledge. Considering the dimension origin, only internal knowledge, already possessed by the company, was considered. As for the dimension nature, explicit and tacit knowledge are considered for acquisition with a higher level of detail on explicit knowledge. Tacit knowledge is acquired for completeness but it can remain at a more abstract level. In order to achieve the required transparency, no distinction between data, information and knowledge was considered

because restricting the knowledge acquisition to some of the terms would only provide a partial understanding of the current knowledge location. The defined examples and nonexamples can be observed in Figure 5-1.

Definition of knowledge target		
Concept name: **knowledge**		
Key attributes	Examples	Nonexamples
• Only technical product knowledge and market knowledge • Only internal knowledge • Detailed explicit knowledge and general tacit knowledge • No differentiation between data, information and knowledge	• Explanations of design decisions • Product functions • Product features • Product technologies • Explanations of the contribution of functions, features or technologies to fulfil the requirements of the client	• Process knowledge (design process, order process, delivery process) • General knowledge like mechanical or physical relations which are not product-specific

Figure 5-1: Definition of target knowledge for case study II

The *stakeholders' portfolio* revealed that there were three departments who possessed the target knowledge: product management, quality management, and research and development. Those departments participated in the knowledge acquisition conducted following step 2 "Visualisation" of *k*-MORE. Five departments have the capacity of influencing the company's normative goal and therefore their perception and needs for knowledge reuse were analysed during the implementation of step 3 "Analysing" of *k*-MORE.

In order to conduct the **knowledge acquisition**, the company established the following requirements:

- As many employees as possible should take part of the knowledge acquisition.
- Since the knowledge acquisition takes place during the regular working hours at it cannot be assigned to any official project, the time invested per employee should be kept to a minimum. A duration of 45 minutes per person is considered acceptable.
- The knowledge flows between departments should be visualised.

Given the requirements, the workshop-based process proposed in step 2 "Visualising" of *k*-MORE was considered too time-consuming for the company and therefore, it was substituted for a knowledge acquisition using surveys. Excel templates were prepared for documentation of the elements for the knowledge map according to the metamodel of Figure 4-12. The templates were reviewed together with three employees who filled them and estimated a filling time of around 20 minutes. The surveys were sent per email and a time period of four weeks was given to send them back. Reminders were sent during this time period. At the end of the four weeks the return rate was of 7,4 %. Those results did not provide enough input to create a complete knowledge map but given the low return rate it was clear that a new acquisition method was required. Due to the lack of remaining time to apply a new method, the knowledge acquisition was cancelled.

The **analysis of individual influences** for knowledge reuse was conducted in an online survey based on the 21 factors of the WCM and it was implemented in the survey design tool

SurveyMonkey. The questionnaire was an initial version of the *questionnaire of influencing factors* of step 3 "Analysing" of *k*-MORE, in which the company-specific factors and the relevance referring to the same influencing factors were asked in the same page of the questionnaire. A five-level Likert scale was used for the assessment. The questionnaire was tested by four employees who estimated a time duration of 30 minutes to complete it. The time frame to answer the questionnaire was three weeks. The return rate was of 35%, obtaining 31 complete questionnaires. The results show that perceived risk of reusing knowledge and use of knowledge as power are the less influencing factors. Infrastructure factors and strategic factors are the most critical ones. Company's culture is also seen as an aspect with potential for improvement. These results indicate clearly that the need for this company is reusing explicit knowledge, and that a critical aspect is the standardisation of processes and structures associated to it. Tacit knowledge, its location or its informal exchange does not seem to be a critical issue. Therefore, a concept for a KMS which focused on the infrastructure to store and reuse documents was proposed. The concept was based on the structure proposed by Maier (2007). A table was prepared indicating which analysing rules provide information in order to plan aspects of which module of the KMS concept if they were applied on a finalised knowledge map. Figure 5-2 shows an overview of the rules and relations.

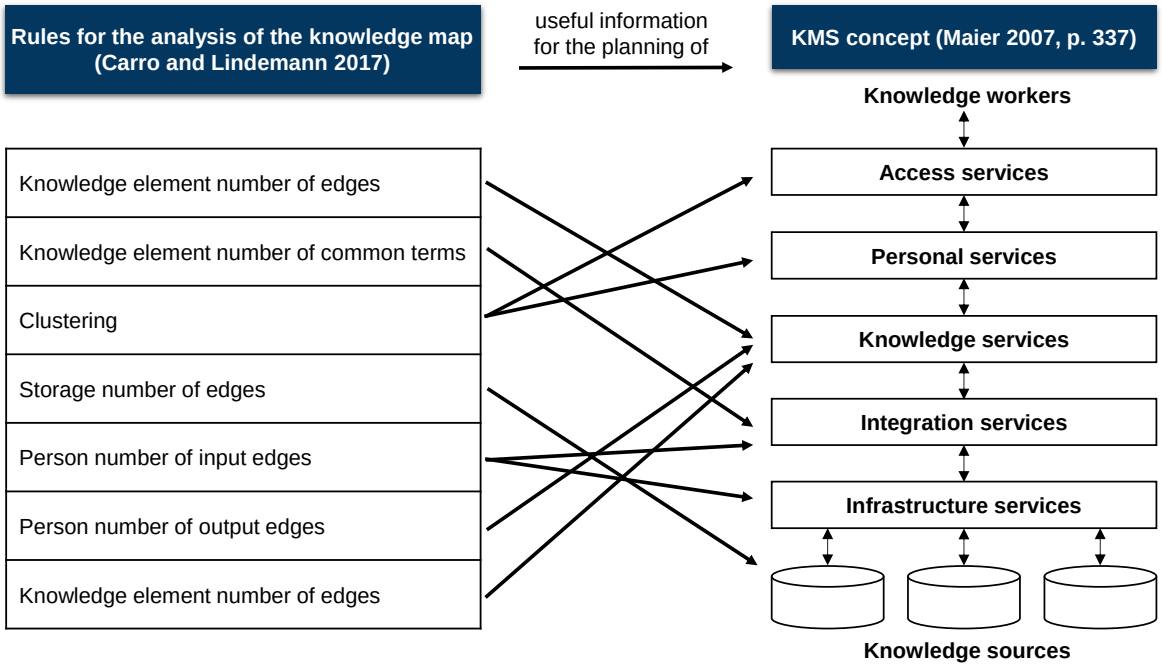


Figure 5-2: Influence of the rules for the analysis of the knowledge map on planning the KMS concept

5.4.3 Discussion and Lessons Learned

The goal of this case study was the development of a concept for a centralised company's KB. The three steps applied of the *k*-MORE methodology were beneficial to achieve this goal.

Step 1 "Defining goals" was helpful in order to establish the direction and requirements for the case study. Support documentation such as the *types of goals* and the *taxonomy of knowledge dimensions* enabled focused discussions and achieving a fast consensus on the definitions of company's goals and knowledge target. The *taxonomy of knowledge dimensions* might be confusing if its purpose is not understood. Therefore, it is important to emphasise that not all dimensions have to be considered or selected in order to define attributes for the knowledge target. The taxonomy is just offering an overview to support the discussion. The *stakeholders' portfolio* was helpful to identify the participants required and thus establish the boundaries of the case study.

The metamodel of the knowledge map proposed for the **knowledge acquisition** was considered appropriate. The failure in finalising the knowledge acquisition revealed that a survey is not a suitable method for acquisition, at least not for the initial phase. The following reasons for the failure of surveys were discussed with the company: filling the template took longer than expected, the excel template was not enough user-friendly and it did not motivate participants to fill it, and there was not enough communication and insistence from the managing board. Based on these conclusions, it seems that the return rate could be improved preparing a user-friendly software interface and increasing the commitment of the management board. However, knowledge completeness cannot be assured using surveys. In order to assure the acquisition, workshops are suggested in the final *k*-MORE methodology. Conducting workshops also provides an image of commitment to the goal of knowledge acquisition, which improves the integration of further knowledge providers. Furthermore, workshops contribute to achieve better consistency of the terms included in the knowledge map.

The **analysing rules** proposed in the table prepared to plan the modules of the KMS concept could not be applied due to the lack of a finalised knowledge map. The rules and their implications were theoretically discussed with managers from the company. This discussion set the basis for the development of the final *reflection sheets* included in step 3 "Analysing" of *k*-MORE methodology.

The online questionnaire for **analysis of influencing factors** provided useful results. The fact that strategic leadership and strategic alignment were considered as critical factors is consistent with the situation experienced in the attempt of knowledge acquisition (the lack of adequate communication, integration and alignment towards a company's goal led to low participation and in the end failure achieving the goal). The questionnaire layout and implementation was considered user-friendly. A tendency to assign the middle value of the five-level scale was observed. In order to avoid this effect and assure conclusive results, a six-level scale was selected for the final questionnaire in the *k*-MORE methodology. Other effect that could be observed in the answers was that the difference in the assessments of company's handling and factor relevance were mostly constant. This might have occurred because the handling and relevance of a factor were assessed in the same page of the questionnaire, which did not enable the comparison of factors to each other. In order to avoid this effect, two questionnaire layouts were developed for the final *k*-MORE methodology: *questionnaire for influencing factors (company)* and *questionnaire for influencing factors (relevance).* Moreover, this distribution of the questionnaire also reduces the duration, which various

participants found too long. Some difficulties understanding the factors' definition and implications were observed. For example, the difference between knowledge affinity and learning capacity was not always clear, or perceived risks could not be imagined. In order to avoid misunderstandings, a new definition for knowledge affinity was created. Furthermore, the preparation of examples of how the influencing factors are handled in the company was included in this step for the final *k*-MORE methodology. The examples are included in each page of the *questionnaire for influencing factors (company)* in order to improve the understanding of the implications of the factor.

5.5 Case Study III – Automotive Collaboration

This case study was conducted in Montesa Rausell (2016). It represents a support evaluation of the ***k*-MORE approach for knowledge package and reuse**, and the procedure to conduct lessons learned sessions. Subsection 5.5.1 presents the initial situation and motivation. The application and its results are presented in Subsection 5.5.2. Finally, the results are discussed in Subsection 5.5.3 and lessons learned are derived.

5.5.1 Initial Situation and Motivation

The case study was conducted in a collaboration project between the Chair of Product Development of the Technical University of Munich and the BMW Group. The aim of the project was the generation of innovative ideas for the interior of a MINI car. The project lasted six months and it was carried out by a team of ten students who had a common working space and a car available for prototyping and testing. The team should apply various start-up and agile methodologies during their work.

This project served as a platform to explore the wishes and problems of a product development team when it comes to knowledge management. Furthermore, it offered knowledge from a real project. The case study should serve for various purposes in this thesis: 1) establish a basis for the development and support evaluation of concepts for knowledge packaging; 2) support evaluation of the procedure to conduct lessons learned sessions; 3) create a KB with real project knowledge for hypothesis testing as part of the DS I of this thesis (see Subsection 3.4.2).

5.5.2 Application

The case study started with the **observation** of **team's work**. The team worked with a repository in the cloud, which was organised in several parallel folders and subfolders. Around 600 documents were used and generated during the project. The content of those documents was diverse, containing customer questionnaires, product sketches and end-designs among others. Reflecting on the usability of the repository, team members stated that they were not upset about it, but neither were they happy with it. They were aware that a lot of time was being consumed looking for documents and clicking through the folders. Furthermore, they missed the context in which documents were generated and they found unclear to understand how product ideas were developed during the project. Implicit

knowledge regarding design aspects and organisational aspects was not verbalised or included in those documents.

The observations and discussions within the project were combined with requirements for KBs stated in literature in order to elaborate a **list of requirements** for the team's knowledge repository. In total, 14 requirements were defined: 1) adjust to demand, 2) process oriented, 3) consider various project phases and time frames, 4) consider various definition levels, 5) consider different perspectives, 6) simplicity in use, 7) added value must be perceptible, 8) search function must be supported, 9) useful for as many end-users as possible, 10) visual structure with multiple representations, 11) all terms and type of relationships must be distinguishable and properly explained in a legend, 12) need of keeping it updated, 13) fast to register and use knowledge, and 14) flexible to allow development iterations.

Then, a **concept** to **structure** the **KB** was developed. The concept consisted on showing an overview of the project's knowledge in two visualisations: one visualisation showing knowledge categories in hierarchical trees; and one visualisation showing the project documents used and generated in the project timeline. The visualisations were implemented in Soley Studio. Metadata was assigned to each document represented in the visualisation with the intention of supporting search functions. Those metadata (also referred as attributes in Soley) are presented in Table 5-2 on an example of the document named "Cardata_Test".

Table 5-2: Example of definition of the metadata attributes

Name	Cardata_Test	**Concept**	Background & decision support
Description	Poster to check the interest of MINI customers in the use of car data	**Category**	Feedback
Size	1,4KB	**Subcategory**	Social Media
Status	Finished	**Phase**	2nd iteration
Type	Powerpoint	**Sub-phase**	2nd concept
Author	Paula	**Idea related**	MoodMusic
Registration date	10.08.2016	**Subcategory related**	Marketing

The **visualisation of knowledge categories** contained three hierarchical trees with the concepts **"**background and decision support", "ideas" and "lessons learned". Each concept contained a classification of documents (considered explicit knowledge) in categories and subcategories. The upper part of Figure 5-3 shows the hierarchy developed in the case of the concept "background and decision support". Many of the documents included in the KB were naturally generated during the project independently of the knowledge management actions. However, in the case of "lessons learned", the knowledge was implicit in team members and it had to be first elicited in order to include it in the KB.

The second **visualisation** represents the **project phases** in a **timeline**. In this visualisation, documents are related to the phase of the project in which they were used or generated. Combining the two visualisations, all documents are associated at the same time to a concept, a category, a subcategory and a phase of the project. The relation between both visualisations is presented in Figure 5-3.

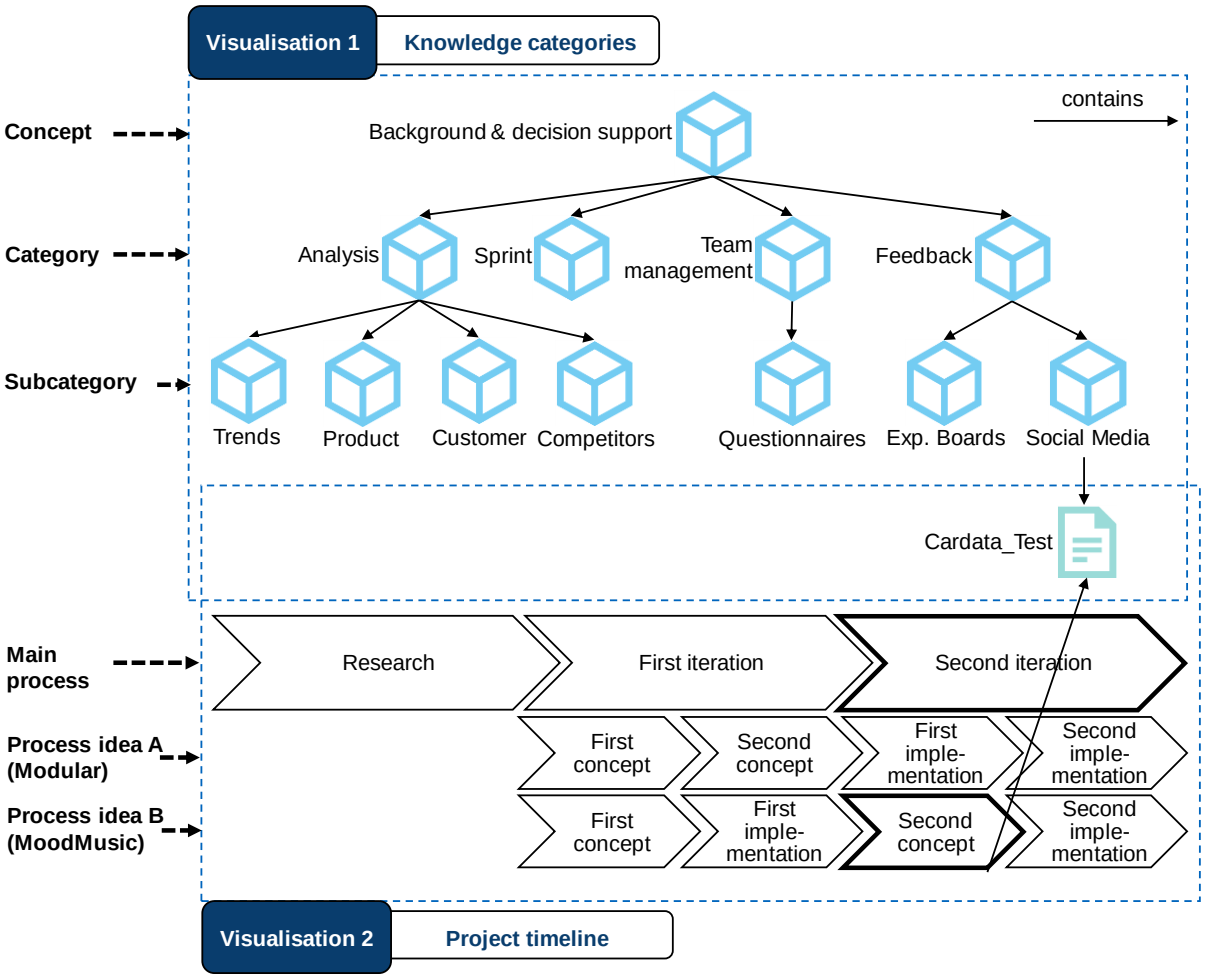


Figure 5-3: Knowledge visualisations of the Knowledge Base

The **elicitation** and **documentation** of **lessons learned** was done in workshops with team members. Two lessons learned workshops were conducted during the project; one in the middle of the project and one at the end of it. The methodology used during the workshop was the one presented in Subsection 4.4.6. The first workshop was conducted as planned and it originated 15 Lessons Learned. The lessons learned were mostly regarding management issues such as "working in small teams increases the effectiveness in decision-making" or "a prioritisation of stakeholders is required to avoid confusion in cases of conflicting requirements". Based on those learnings, the team defined improvement actions, which were to be applied during the rest of the project. The second lessons learned workshop was also successfully conducted, and it generated 28 Lessons Learned. The team reflected on their application of the improvement actions defined in the first lessons learned workshop. Most of

the actions were successfully applied, two actions had been a major challenge for the team (reflecting on them led to various new lessons learned) and one action was not implemented because in the end it was not considered necessary. The team reflected on the 28 generated lessons learned and they summarised the main learnings of the project in three best, worst and ugly aspects.

The KB developed in this case study was used to conduct the EDE II presented in Section 3.4.2. The experiment is not included in this case study but in the DS I of this thesis. This is because the aim of the experiment was not testing the proposed support but testing a hypothesis regarding the preferences for knowledge search support of different user profiles.

5.5.3 Discussion and Lessons Learned

This case study pursued various goals: 1) establish a basis for the development and support evaluation of concepts for knowledge packaging; 2) support evaluation of the procedure to conduct lessons learned sessions; 3) create a KB with real project knowledge for hypothesis testing as part of the DS I of this thesis. The first goal was achieved by observing team's work, reviewing literature and discussing with the team. The *k*-MORE procedure to conduct lessons learned workshop was beneficial to derive lessons learned. The KB created during the project supported adequately the experiments conducted for the DS I of the thesis.

The proposal for **knowledge packaging** in two visualisations supports the understanding of the knowledge used and generated in the project. The visualisation in knowledge categories is helpful to facilitate a fast access to a known type of knowledge. The visualisation in the project timeline is helpful to understand the context in which documents were generated. However, just the project phases do not seem enough to provide adequate context. A time line of the concrete tasks conducted in each project phase is required for a complete contextualisation. For this reason, tasks were included as nodes in Visualisation C of the final *k*-MORE approach for knowledge package and reuse. A consequence of including the tasks in the visualisation is that the knowledge acquisition cannot be retrospective, because the association of knowledge to the correspondent tasks must be done during the project.

The experiment conducted for the DS I of this thesis offered support evaluation for a KB that combines the proposed visualisations with search methods. The KB was well understood and could be applied. Participants' feedback was used to reflect on the fulfilment of the requirements established for the KB. It could be determined that the KB fulfilled eleven requirements. The requirements number 2, 12 and 13 could not be completely fulfilled. The process-oriented aspect (requirement 2) was not fulfilled because the KB does not present any automatic link to the development process, the designer is the one who decides when to use it during the development process. The need of keeping it updated (requirement 12) was not fulfilled since there is no automatic way of updating it, it has to be done manually. Register and using knowledge was considered fast (requirement 13) for some users but slow for others, so this requirement was partially fulfilled.

The methodology used during the first **lessons learned workshop** was understandable and helpful. The techniques applied supported a broad participation and deep reflection. However, the team showed a tendency to perceive stronger the negative project issues (which could be

improved) than the positive ones (the aspects in which they were succeeding, and they could celebrate). Furthermore, same topics were repeated by different team members. In order to avoid repetitions and to enhance the identification of positive project aspects, the methodology was changed. The second lessons learned workshop included a preliminary questionnaire to be filled by team members prior to the workshop. Thus, the workshop moderator could filter team members' opinions and start the workshop with a summary of those, in which also positive project aspect were exposed. This preliminary step was included in the final *k*-MORE procedure to conduct lessons learned sessions which is presented in Subsection 4.4.6.

The results of both lessons learned workshops were considered useful for different purposes. The first lessons learned workshop contributed to reuse the team´s knowledge on their own project. The second lessons learned workshop served to validate the used knowledge and therefore propose it for reuse in upcoming projects, as well as it served for personal feedback for each team member. The value for the own job of lessons learned workshops was highlighted by team members, who wished that they have had more intermediate sessions during the project. For this reason, it is suggested to conduct sessions regularly during the project. The time frame between sessions should be decided in each project according to its specific needs.

5.6 Case Study IV – Construction Company

This case study consists of the application and success evaluation of **steps 1 to 7 of the *k*-MORE methodology**. Lucas (2018) focuses on visualising knowledge in a knowledge map and analysing it. The focus of Beul (2018) is on the analysis of the individual influencing factors for knowledge reuse. Based on both analyses, the knowledge reuse cycle was planned. Subsection 5.6.1 presents the initial situation and motivation. The application and its results are presented in Subsection 5.6.2. Subsection 5.6.3 presents the results of an evaluation questionnaire conducted to participants from the company. Finally, the results of the case study are discussed in Subsection 5.6.4 and lessons learned are derived.

5.6.1 Initial Situation and Motivation

This case study was conducted in the company Schüco, which counts with more than 4750 employees worldwide. The company develops and sells system solutions for windows, doors, façades, sliding systems, security technology and sun shading. The company is industry leader providing technologies and services following a business-to-business model, in which manufacturing companies in the field of metal or plastic are the trading partners between Schüco and the final customer, who are architects and building companies. Special focus is placed on product innovation and internal efficiency, for which an optimal interaction between the areas of sales, product development and marketing is required.

Knowledge management is very important for the company's business model. The company needs to exchange product knowledge with manufactures, to obtain market knowledge in order to fulfil new market needs, and to exchange knowledge with clients in order to work on their feedback. All on a big portfolio of standard and customised products. In order to

improve the company's knowledge management, Schüco has recently created the department "Global Knowledge Management". The goal of the new department is achieving efficient knowledge reuse in the company, as well as efficient internal knowledge exchange during development projects and efficient knowledge exchange with external parties. The initial action in order to achieve those goals was **planning the knowledge reuse cycle**, which should be done following the *k*-MORE methodology from steps 1 to 7.

Especially interesting for the company was getting an overview of the departments considered central for knowledge reuse and exchange: sales, product development and marketing. This should be done following step 2 "Visualising" of *k*-MORE in form of an interdepartmental knowledge map. The company also wants to understand the current perception of the efficiency in knowledge reuse and to identify urgent needs to improve it. This should be done with the questionnaire based on the WCM following step 3 "Analysing" of *k*-MORE.

5.6.2 Application

The case study started with step 1 "**Defining goals**" of *k*-MORE. Step 1 was conducted in a workshop with knowledge managers from the company. First, the needs analysis was applied. The is-situation was that the company is currently not the technology leader in all its products, the company wants to offer more services to its clients, and the company wants to understand better and to get more information about markets in different countries. The desired-situation was defined by the company's goals. The company has two normative goals: one is outside-oriented, which is becoming leader in innovation, technology and service; and the other one is inside-oriented, which is establishing an open, fast and focused internal way of working. The strategic goals were the evaluation of current reuse and exchange of knowledge as well as the methods used for that, and the identification of the needs for knowledge reuse and exchange. The *knowledge audit framework* supported the discussion in order to define the strategic goals. The knowledge required in order to achieve those goals cannot be limited to any specific phase of the product development process. Therefore, knowledge related to the complete product development process was considered. No specific knowledge attribute was highlighted in the *taxonomy of knowledge dimensions*; all dimensions should be considered in the analysis and acquisition. The reason for that is that the company set more the focus on the internal stakeholders for the case study than on the types of knowledge to consider. It was clear from the beginning for company's managers that three departments possess and use the major amount of knowledge which could influence company's goals. Therefore, the *stakeholders' portfolio* including other departments was not applied in this case, and the preselected three departments were the focus of the case study, both for knowledge acquisition as well as for analysis of knowledge reuse. "Defining Goals" concluded with the definition of three representative development projects for the company on the template *definition of representative projects*.

The **knowledge acquisition** for step 2 "Visualising" was conducted in several workshops of four hours duration. First, three workshops (one per department) were conducted with four to seven participants per workshop. Company-specific examples of the *metamodel of knowledge map* were previously prepared and then presented as examples at the beginning of the workshops. The representative projects which had been defined in step 1 "Defining Goals" of

k-MORE on the template for *definition of representative projects* were only considered as representative for one department. Therefore, the other two departments had to define their own representative projects at the beginning of their correspondent workshops. Roles, tasks and knowledge element were acquired during the workshops following the *process for the acquisition workshop*. Some steps of the process were modified in order to fit the preferences manifested by the group during the workshop. Some of those modifications are for example that representative projects were not used for the tasks or knowledge element definition, or in some cases elements were defined by the group instead of individually. Table 5-3 presents an overview of the modifications conducted. The consequences of those modifications are discussed in Section 5.6.4.

Table 5-3: Modifications to the planned process for the acquisition workshop

Process for the acquisition workshop	**Department 1**	**Department 2**	**Department 3**
Representative projects as support	Not used	Not used	Not used
Assign responsible for each role	Not done	Yes	Not done
Individual identification of tasks	In group	Yes	Some in group and some individually
Individual identification of knowledge element	In group	Yes	Yes
Representation of knowledge element in matrix form	Yes	No	No
Relating knowledge element to tasks	After the workshop	During the workshop one-to-one. The rest after the workshop	During the workshop one-to-one. The rest after the workshop

After the workshops, a digital *mapping matrix* was prepared in Excel form for each department. A person from each department was selected in order to review, complete and consolidate the matrix. This person was in charge of contacting other participants from the department in case their input was necessary. Thus, the *mapping matrix* of each department was finalised.

The results of the different workshops were put in common for consolidation in a consolidation workshop with two participants from each one of the analysed departments, following the *process for the consolidation workshop*. During this workshop, common knowledge element were identified and their names were consolidated. This was conducted

working in couples from different departments going through the same printed *mapping matrix*. After that, the current knowledge exchange between departments was described. This was done working in group on posters, in which the knowledge element of one department were presented, while the other departments could associate those to their tasks. Only the relations which were not already included in the reviewed *mapping matrices* were marked on the posters. Then, also the should-be situation of knowledge exchange between departments was defined. This took place again in group work working directly on the posters. Figure 5-4 shows an example of the procedure on the posters. Priority was given to the knowledge exchange during the product development process. For this reason, the knowledge element of the product development department were ordered according to the chronological product development process, as it shown in Figure 5-4. The group missed two types of relations which were not originally included in the *metamodel of the knowledge map:* "document *contributes to* competence" and "department *requires* document". Those two new relations were defined and marked on the posters.

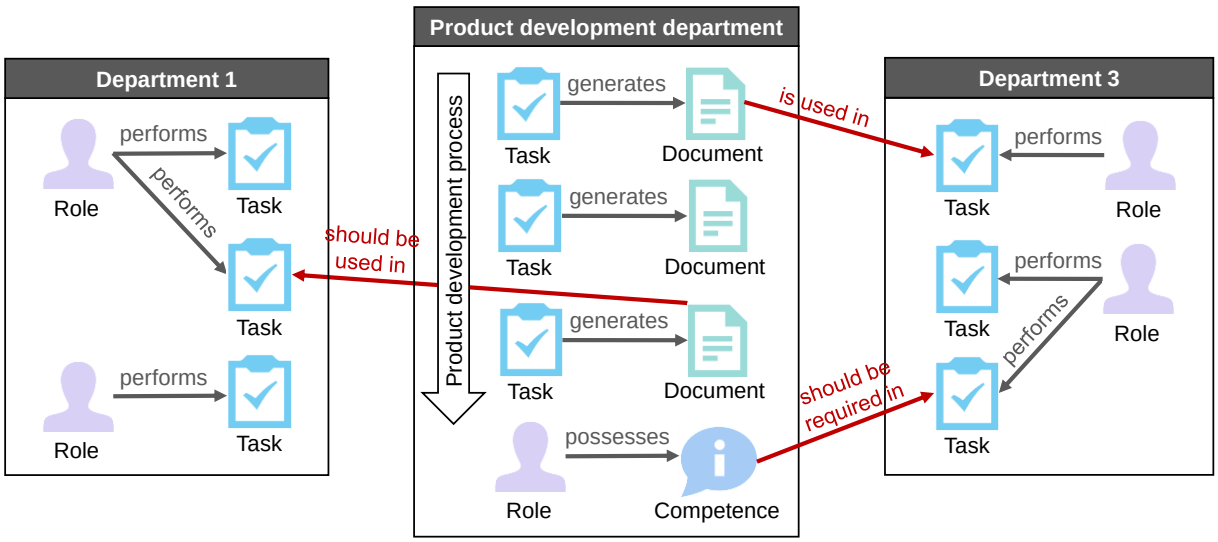


Figure 5-4: Definition of is and should-be knowledge exchange between departments

Using the results of the consolidation workshop, the *mapping matrix* of each department was finalised. The matrices contain the current and should-be situation of knowledge reuse. Two knowledge maps were created with the input: as-is knowledge map and should-be knowledge map. The as-is knowledge map contained 34 roles, 116 tasks, 187 Knowledge Elements (48 competences and 139 documents) and 35 storages. 115 relations and 4 Knowledge Elements were added for the should-be knowledge map. The knowledge map was implemented in Soley Desk.

The **knowledge map** was **analysed** in the step 3 "Analysing" of *k*-MORE with the analysing rules included in the *tables for rules reflection.* The results of applying the rules to the knowledge map were discussed with company's managers in a one hour session using the *reflections sheets*. Thus, critical elements and initial actions from their point of view were defined. Details of the results are documented in Lucas (2018).

The **analysis of individual influences** for knowledge reuse was conducted in an online survey which was implemented in the survey design tool SurveyMonkey. The participants belonged to the same three departments as for the knowledge acquisition. The *questionnaire of influencing factors* of step 3 "Analysing" of *k*-MORE was used as guideline. The questionnaire had 23 pages in total; one initial page as introduction, 21 pages asking about the perception of each influencing factor in the company, and one last page in order to evaluate the general relevance of each of the 21 considered factors. Examples of how the factor is currently influencing in the company and how the company is currently handling it were prepared together with company's knowledge managers. The examples were iteratively presented and discussed with other company's employees until they were considered clear enough for the questionnaire. The time frame to answer the questionnaire was one week. The return rate was of 47%, obtaining 24 complete questionnaires (6, 8, and 10 respectively per department).

The results of each department were represented in boxplots and evaluated following the *analysis flowchart*. The boxplots clearly showed differences in the perceptions of the departments. The evaluation for department 1 showed a general satisfaction with the current handling and no factor was rated for urgent consideration. Department 2 perceived the current handling by the company as generally poor and therefore numerous factors presented an urgent need for consideration. Department 3 considered the current handling generally acceptable with flaws handling some of the factors. Figure 5-5 shows the boxplots for four factors of department 2 and department 3, including the needs derived out of them. The results are generalised in order to preserve secrecy. The complete results are documented in Beul (2018). Discrepancies in the perception of some factors (like for example in the case of factor 4 of department 2 in Figure 5-5) required the analysis of participants' comments. For example in the case of IT structure, the folders' structure or server speed were criticised, while other methods like digital communities were positively considered. This information supports the definition of concrete actions and possible methods for the *planning sheets*. Other example is the case of the factor knowledge as power in department 3. Discrepancies were observed since some employees do not consider this a problem while others admit that this phenomena is experienced in the company. The discrepancy reveals the need to dig deeper on the problematic for those who see it as a problem. Therefore, discussing with them should be added as an action in the *planning sheets*. Despite the differences observed between departments, three influencing factors presented overall a need for improvement: IT structure, knowledge affinity, and workload.

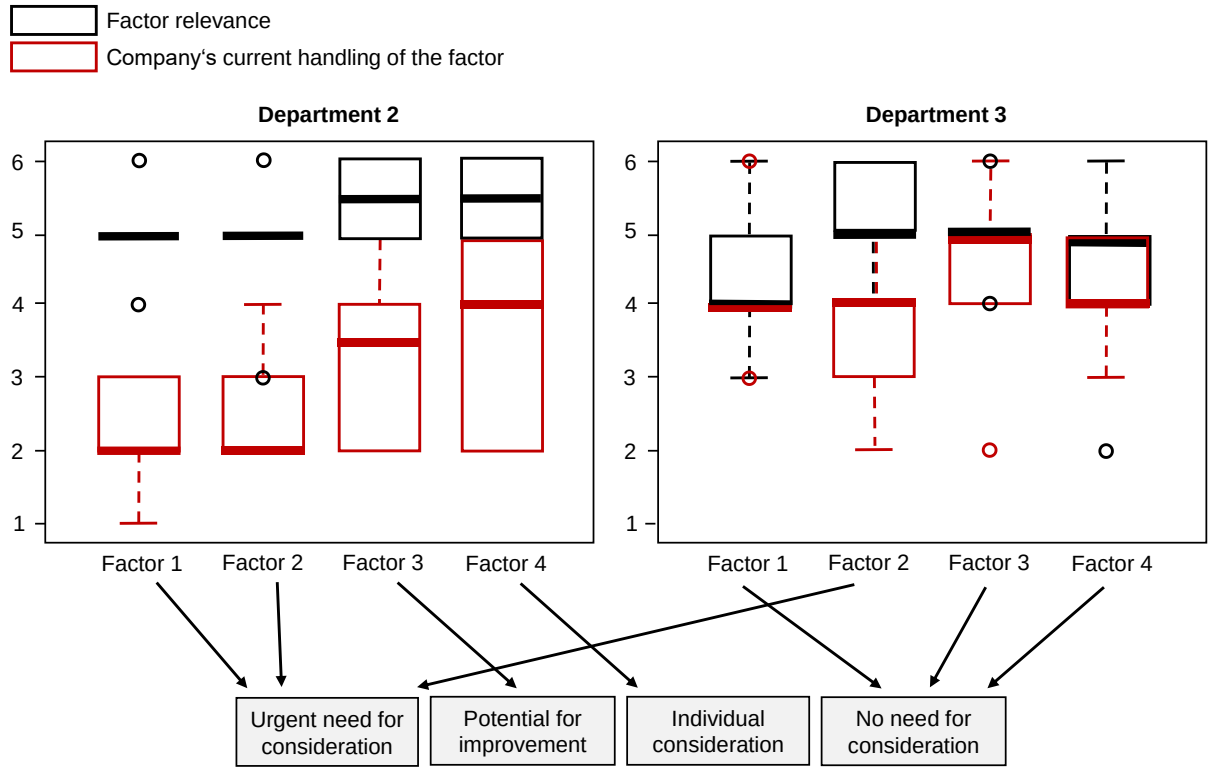


Figure 5-5: Boxplots for four factors of department 2 and department 3

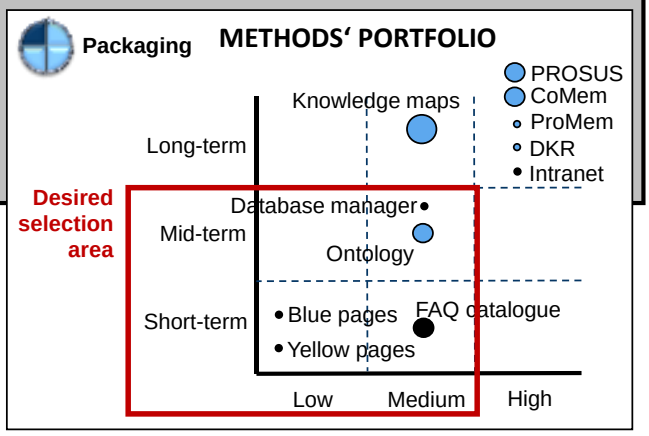
After applying step 3 "Analysing" of *k*-MORE, steps 4 to 7 were conducted in order to **plan the knowledge reuse cycle**. For each one of the four phases (packaging, capturing and documenting, reusing, distributing), a *planning sheet* and a correspondent *methods' portfolio* were prepared. The critical elements and initial actions defined in step 3 served as input to prepare the *planning sheets* including concrete actions on resources, process and roles, as it is proposed in the template. In order to prepare the *methods' portfolios*, only methods which could influence one, two or three of the overall influencing factors were selected from the *methods catalogue*. The consideration of the three overall influencing factors (IT structure, knowledge affinity, and workload) was done for simplicity because the time frame of the case study was not enough to perform more individualised considerations. However, since the analysed departments presented different needs of addressing the influencing factors, department-specific *methods' portfolios* can be prepared applying the selection criteria in the *methods catalogue* in future iterations on the *planning sheets*. Methods from the *methods' portfolios* were suggested for discussion/implementation of the actions defined in the categories resources and process of the *planning sheets*. The company decided to exclude from the portfolios methods with long-term implementation time or high implementation effort. Therefore, only methods from the other quadrants of the portfolio were considered for addition to the *planning sheets*. The methods' portfolios for all steps of the knowledge reuse cycle are documented in Beul (2018).

Figure 5-6 shows the *planning sheet* and *methods' portfolio* prepared for step 4 "Packaging". The content is generalised to preserve the company's confidentiality. All elements required in order to carry out the next steps are marked with numbers (1 to 5) and they can be identified in the knowledge map. Methods such as Frequently-Asked-Questions (FAQ) catalogue, ontology or yellow pages are suggested as candidates to conduct the defined actions. Those methods are located in the desired area of the portfolio. FAQ catalogue and ontology are the most efficient handling the influencing factors because they address two factors from the three selected. Yellow pages is a method which can be fast and easily implemented. The *planning sheets* for all steps of the knowledge reuse cycle are documented in Lucas (2018).

Packaging — **PLANNING SHEET**

Resources			Process			Roles	
Action	Next steps	Method?	Action	Next steps	Method?	Action	Next steps
Remove documents from static storages (1)	Ask users and generators of documents (2)	FAQ cata-logue	Define access to new storages	Ask users of documents (2)	-	-	-
Clarify the original storage of documents with many storages (3)	Ask users and generators of documents (4)	-	-	-	-	Inform of existence of various storages	Inform users and generators of docu-ments (4)
Categori-sation of documents	Define categories (5)	Ontology	Define storage and access through categories	Ask users and generators of documents (6)	Onto-logy	-	-
Categori-sation of competen-ces	Consolidate competences of the knowledge map	Ontology	Define updates and access through categories	Do	Yellow pages	-	-

(1) 88 documents cointained in 3 static storages
(2) Users and generators of (1) in knowledge map
(3) 15 documents with many storages
(4) Users and generators of (3) in knowledge map
(5) 3 preliminary categories identified
(6) Select representative users and generators in knowledge map



	Meaning	
Size	Number of factors addressed	3 2 1
Colour	Consideration phase of the reuse cycle	Exclusive for this phase of the cycle
		Consider also in other phases of the cycle

Figure 5-6: Planning sheet for step 4 "Packaging"

5.6.3 Evaluation

The results of the case study were evaluated by company's employees, who participated either in the process of knowledge acquisition or in the analysing survey, or in both. The results were presented in two analogous sessions of two hours with around 20 attendants per session. After the presentation and discussion round, the attendants answered a questionnaire for evaluation of the *k*-MORE methodology. In the first session 14 participants filled the questionnaire (P1 to P14 of Appendix 9.10.2), and in the second session 7 participants filled the questionnaire (P15 to P21 of Appendix 9.10.2). The questionnaire had four sections: 1) need for knowledge reuse in industry; 2) results of the *k*-MORE methodology; 3) applicability of the *k*-MORE methodology; and 4) personal information. The template is included in Appendix 9.10.1. The complete documentation of results is included in Appendix 9.10.2.

Table 5-4 to Table 5-7 show the quantitative results of the evaluation. The tables show the amount of participants who selected each one of the possible answers. A number was assigned to each answer in a scale from 1 to 5, from "completely disagree" (1) to "completely agree" (5). The average of each question is calculated based on the scale and the number of responds obtained for the question.

Table 5-4 shows the results regarding the **needs for knowledge reuse** in industry. The participants clearly considered that reusing knowledge increases the efficiency of the product development process and also the quality of the developed products. Therefore, reusing knowledge should be something desired in industry. The current company's strategy for knowledge reuse is evaluated as slightly inefficient, although there is no consensus on this aspect. The current amount of knowledge reuse in the company is evaluated as low. In their comments, participants highlighted the paradoxical situation of how low is the consideration of knowledge reuse compared to its importance.

Table 5-4: Evaluation of need for knowledge reuse

		Completely disagree	Disagree	Neutral	Agree	Completely agree	Number of responds	Average
Q1.1	**Reusing** knowledge increases the efficiency of the product development process	0	0	1	5	15	21	**4,67**
Q1.2	**Reusing** knowledge increases the quality of the products developed	0	0	1	10	10	21	**4,43**
Q1.3	The current company's **strategy** for knowledge reuse is efficient	1	6	9	4	1	21	**2,90**
Q1.4	The current **amount** of knowledge reused in the company is sufficient	3	15	3	0	0	21	**2,00**

Table 5-5 shows the evaluation of the **results of the *k*-MORE methodology** on the case study. All the evaluated results fulfil their goals. No major differences are observed between the performances of each of the elements of the methodology. In their comments, some participants criticised the theoretical perspective of the methodology, highlighting that the focus for knowledge reuse should be on implementing software solutions. Other participant thinks that the methodology increases transparency and usability of reusable knowledge but he/she is not sure if this is enough to achieve reuse in practice.

Table 5-5: Evaluation of the results of the k-MORE methodology

		Completely disagree	Disagree	Neutral	Agree	Completely agree	Number of responds	Average
Q2.1	The **knowledge map** provides a transparent overview of the company's knowledge in the selected areas	0	0	7	11	2	20	**3,75**
Q2.2	The **critical elements** and **actors** identified by analysing the knowledge map enable to establish a manageable focus to plan the knowledge reuse	0	0	7	10	3	20	**3,80**
Q2.3	The **planning sheets** are helpful tools to support a structured planning of knowledge reuse	0	2	3	13	2	20	**3,75**
Q2.4	The **employees' survey** based on the Worker-Centered Model enables a clear identification of individual factors influencing knowledge reuse	0	1	7	10	2	20	**3,65**
Q2.5	The **methods' portfolios** provide a good base to select suitable methods to perform the phases of the knowledge reuse cycle	0	1	3	15	1	20	**3,80**

Table 5-6 shows the evaluation of the **expected results** after finalising the iterations required on the *planning sheets* in order to plan the knowledge reuse cycle. The expected results present an average improvement of almost 1 point on the efficiency of the company's strategy (2,9 in Q1.3 compared to 3,85 in Q2.7), and an average improvement of more than 1 point in the amount of knowledge reused (2,0 in Q1.4 compared to 3,24 in Q2.8).

Table 5-6: Evaluation of the expected results of the k-MORE methodology

		Completely disagree	Disagree	Neutral	Agree	Completely agree	Number of responds	Average
Q2.7	I believe that the company's **strategy** for knowledge reuse will be efficient	0	1	4	12	3	20	**3,85**
Q2.8	I believe that the **amount** of knowledge reused in the company will be sufficient	1	3	8	8	1	21	**3,24**

Table 5-7 shows the evaluation of **applicability of the *k*-MORE methodology**. The methodology is clearly considered understandable, helpful, scalable and widely applicable, both to other fields and other company's sizes. The implementation effort seems the most critical aspect but it is still positively evaluated. One participant remarked that especially the questionnaire of influencing factors, the *methods catalogue* and the *methods' portfolios* are very helpful elements of the methodology.

Table 5-7: Evaluation of the applicability of the k-MORE methodology

		Completely disagree	Disagree	Neutral	Agree	Completely agree	Number of responds	Average
Q3.1	The **methodology** is understandable	0	1	4	10	4	19	**3,89**
Q3.2	The **methodology** provides a helpful guide to plan knowledge reuse in industry	0	1	3	14	3	21	**3,90**
Q3.3	The **methodology** is scalable (it can be applied at different level of detail depending on the needs)	0	0	5	13	3	21	**3,90**
Q3.4	The **effort** to implement the methodology is appropriate	0	2	11	5	2	20	**3,35**
Q3.5	The **methodology** is applicable independently of the company's field	0	0	5	11	5	21	**4,00**
Q3.6	The **methodology** is applicable independently of the company's size	0	1	4	11	5	21	**3,95**

5.6.4 Discussion and Lessons Learned

The goal of this case study was planning the knowledge reuse cycle. This goal was successfully achieved through the application of steps 1 to 7 of *k*-MORE.

Step 1 "Defining goals" was useful as introduction on the topic. Especially useful for the definition of the strategic goals was the *knowledge audit framework,* which helped to determine that not only knowledge reuse but also knowledge exchange should be considered. Furthermore, it was established that evaluating the performance of knowledge activities was more relevant than understanding how they are carried out right now. No restrictions on the definition of knowledge were done in the steps "Defining process phase to target" and "Defining target knowledge". The reason for that seemed to be that company's managers had already intuitively decided to set the boundaries of the case study based on the analysed stakeholders (focus on three departments). Therefore, they did not see necessary to establish more restrictions based on the *standard PDP* or the *taxonomy of knowledge dimensions*. Other reason might be misunderstanding the purpose of the *taxonomy of knowledge dimensions*. It is important to emphasise that not all dimensions have to be considered or selected in order to define attributes for the knowledge target. The taxonomy is just offering an overview to support the discussion. During the case study it could be observed that the lack of a more restrictive knowledge target caused inefficiencies, such as time-waste in acquisition of irrelevant elements for the defined company's goals or misunderstandings in the meaning of the word "competence". The extracted lesson learned is that companies applying *k*-MORE should critically reflect on assigning restrictions on the *standard PDP* and the *taxonomy of knowledge dimensions* and they should try to be as restrictive as possible defining the knowledge target. The meaning and relevance of that must be strongly highlighted in future applications so it is not overseen. The term "competence" was especially confusing during the knowledge acquisition workshops. Therefore, a change is suggested to the template for *definition of knowledge target*. The change is to include an explicit differentiation of the definition of knowledge as document and knowledge as competence.

The **workshops for knowledge acquisition** conducted in step 2 "Visualising" of *k*-MORE worked successfully. The *process for the acquisition workshop* based on acquiring first roles, then associated tasks and finally knowledge element supported adequately the three workshops and the workshop's duration was appropriate. The *metamodel of the knowledge map* was understandable and useful, as well as the company-specific examples of the metamodel. Some aspects of the *process for the acquisition workshop* were modified in the different workshops as it was shown in Table 5-3.

The definition of roles, tasks and knowledge element was done in the three cases without referring to the representative projects. This does not necessary mean that representative projects are not useful. They were not required in this case because the participants had a clear general idea of the roles, tasks and knowledge element existing in their departments, so they did not experience any difficulty formulating them in abstract terms. However, representative projects might be useful in other cases. Responsible persons to define individually the tasks and knowledge element corresponding to the roles were only assigned in the case of department 2. The other departments decided to proceed in group work, since they did not find an appropriate way of assigning the roles. Department 1 proceeded in group

during all the workshop. In the case of department 3, individual responsible for the tasks' definition of a role were assigned spontaneously when during the discussion it was clear who was the right participant to do it. Since the individual definition worked well, department 3 decided to proceed individually with the identification of knowledge element. Generally, the individual definition originated more elements in faster time than the group discussion. Thus, the individual definition as it is planned in the *process for the acquisition workshop* of step 2 "Visualising" of *k*-MORE seems efficient and it is recommended as it is. Afterwards, it is very important to share the results with the group in order to avoid repetitions and to keep the same level of abstraction in the formulation of the elements.

The representation of knowledge element directly in matrix form during the workshop was only done with department 1 and it was not completed during the workshop. This way of representation turns complex when the amount of knowledge element increases. During the workshop it seems more realistic to present and pin directly close to the tasks' cards the knowledge element marked with "u" of used or "g" of generated. Thus, the relations between the knowledge element and the tasks are already collected. After the workshop, the results of the workshop can be prepared in digital *mapping matrix* and more relations between tasks and knowledge element can be completed. It is strongly recommended to highlight before conducting the workshops that further work (interviews, questions) will be required after the workshop, so participants are not frustrated when they have to invest more time on this.

The definition of documents as knowledge element and their relation to tasks was conducted without any problem. This was not the case of the competences, which definition and identification of relations to roles and tasks were both challenging for participants. First, the expected formulation and abstraction level to define "competence" was unclear, which originated discussions during the workshops. Once the competences were defined, participants tend to associate most competences to most roles through the relation "role *possesses* competence" of the *metamodel of knowledge map*. A possible reason for that is that the term "competence" suggests the implicit meaning of "being competent" and all roles in the company wish to be seen as competent. But if most roles possess most competences, the knowledge map becomes meaningless and any significant results can be derived out of the analysis related to the competences. In order to avoid this effect, the use of a different term such as "ability" or "non-documented knowledge" instead of "competence" could be considered. The problem could also be solved with the already mentioned addition to step 1 "Defining Goals" of including an explicit definition of the term competence on the template for *definition of knowledge target*. Another change in the acquisition process is suggested, but it increases the time required for knowledge acquisition. The change is to conduct two separated workshops for the definition of knowledge element; one for the documents and one for the competences. Thus, each workshop would be focused on one of the types of knowledge element, providing only definitions and examples for the correspondent type, which could avoid confusion for the participants.

Storages for the documents were defined by the participants during the workshop. The participants had difficulties understanding the term "storage" and which elements could be considered as one. In order to avoid misunderstandings, it is recommended to define the term "storage" during step 1 of "Goals Definition" of *k*-MORE. Furthermore, it is also suggested to

prepare a list with possible storages so the participants just have to select from the list when they define documents used or generated. A predefined list of storages would provide various benefits: it facilitates the task for the participants, it assures consistency in both the terminology and level of abstraction.

The **consolidation workshop** followed the *process for the consolidation workshop*. The work in couples from different departments during the first part of the workshop was useful and efficient. The participants decided to include also elements of the should-situation in the matrix. This was not planned but it seemed natural for the participants, so it is recommended for future applications. Then, the results of the should-situations were just translated to posters in the second phase of the workshop. Putting in common the knowledge exchange between departments using posters was useful and efficient. The newly defined relation to the *metamodel of knowledge map* "document *contributes to* competence" did not add value in this case because it was only defined for two isolated cases. Therefore, it was not considered in the final knowledge maps. Generally, the relation might be an interesting aspect to consider for competences' development in the company, but the fact that a competence can be increased by reading documents is conceptually questionable. Thus, the possibility of adding such relation to the *metamodel of knowledge map* is an open discussion point. The other newly defined relation, "department *requires* document" does not add new information because it can be defined with the existing chain of relations through "document *is used in* task", "role *performs* task" and "role *belongs to* department". This type of relations add unnecessary complexity to the knowledge map so the recommendation is to stick to the original *metamodel of the knowledge map*. Participants tend to define new relations and workshop moderators have to pay attention in order to keep the definition of relations to the ones of the *metamodel of the knowledge map*.

The **analysis of the knowledge map** conducted in step 3 "Analysing" of *k*-MORE provided manageable results. The *reflection sheets* proved to be a very useful tool to support the understanding of the implications of the results and to support a systematic discussion. The discussion session with company's knowledge managers was straight forward and it provided clear results. The session participants did not have the information to answer all reflection questions, but they pointed the need to ask further persons in the company when they considered it necessary. Some questions were not considered as critical, so no initial action was determined. Those were exactly the expected results of the session.

The online questionnaire for **analysis of influencing factors** conducted in step 3 "Analysing" of *k*-MORE originated useful results. The participants considered the questionnaire understandable, the examples helpful, and the layout user-friendly. Some participants found the questionnaire too long. Reducing the length of the questionnaire and maintaining at the same time as basis the WCM does not seem feasible. Therefore, the recommendation for future applications in industry is to make sure that the expected duration is clearly communicated and to assure that employees have the time frame to fill it, so there is no frustration due to the duration. Going through the free comments provided by the different departments, it seems that the participants from department 3 have a better understanding of the factors and a more elaborated argumentation line to discuss them. The results of this department show strong differences in the evaluation of different influencing factors. The

other departments presented a tendency to evaluate all factors either generally negatively or generally positively. Department 3 has also the highest return rate of the three departments. The reasons for that were discussed with companies' knowledge managers. They think that the awareness of the need for knowledge reuse in department 3 was higher and therefore, they were more engaged to fill the questionnaire and they had previously discussed their opinions on the topic, which led to their better understanding and reflection. Given the positive effect observed in the case of department 3, it is strongly recommended to foster awareness and discussions about knowledge reuse with all participants before the questionnaire is conducted.

The visualisation in boxplots was helpful to provide a clear overview of the situation per department. The *analysis flowchart* supported adequately the identification of different types of needs, from which a manageable number was identified. There was one major challenge in the application of the methodology. If an influencing factor requires *individual consideration*, interviewing the employees who manifest the need should be included as an action in the *planning sheets*. But in order to preserve the employees' privacy, the questionnaire was anonymous. Therefore, the employees who manifested disconformity could not be tracked and consequently they could not be asked. In order to avoid this situation, it is recommended to communicate the benefits of the lack of anonymity and to encourage employees to voluntarily provide their identity when they fill the questionnaire. In case this is not achieved or not desired, volunteers can be requested after the analysis of results.

The fact that three overall critical influencing factors were identified was very positive from two points of view. On one side, it indicates a consistent understanding of the influencing factors considered in the WCM. On the other side, it provides the company with a manageable focus for overall planning of the knowledge reuse cycle, which was highly appreciated as first step in the planning.

The process and elements of steps 4 to 7 of *k*-MORE were beneficial to **plan the knowledge reuse cycle**. The *planning sheets* provided structure to specify the previously defined critical elements and initial actions. The three categories of the *planning sheets* (resources, process and roles) were helpful to expand the spectrum of considerations. The results of the evaluation questionnaire confirm this impression, since 15 out of 20 participants considered that the *planning sheets* are helpful tools to support a structured planning of knowledge reuse, while 3 do not have an opinion and only 2 participants do not see them as helpful. In their critiques, the participants consider the *planning sheets* too theoretical and they think that knowledge reuse has to be implemented through software solutions. The theoretical perspective of the *k*-MORE methodology was discussed with company's knowledge managers, who think that specific software solutions are necessary but that the value of the *k*-MORE methodology is the overall company's consideration. Knowledge managers considered that it is natural from the point of view of an employee that he or she wants an artificial intelligent system for knowledge retrieval in order to support his or her specific tasks. However, this is not feasible in all cases and the advantage of the *k*-MORE methodology is identifying in which cases specific software solutions are required, in which cases it is not recommended due to the balance effort/benefit, and which cases other methods are more appropriate. Thus, knowledge managers consider positive the theoretical perspective of the methodology, which starts the planning at a high level of abstraction within the

company. The responds of the evaluation questionnaire also indicate a tendency for managers to consider the methodology more useful than technical experts. The questionnaire participants of session 2 were all either knowledge managers or department managers, and their rates are higher than the ones obtained from the participants in session 1. Table 5-8 presents the comparison of responds between the two sessions for some questions which presented a significant increase.

Table 5-8: Comparison between session 1 and session 2 of the average rates for some questions

		Session 1 (average)	**Session 2** (average)
Q2.1	The **knowledge map** provides a transparent overview of the company's knowledge in the selected areas	**3,54**	**4,14**
Q2.2	The **critical elements** and **actors** identified by analysing the knowledge map enable to establish a manageable focus to plan the knowledge reuse	**3,69**	**4,00**
Q2.5	The **methods' portfolios** provide a good base to select suitable methods to perform the phases of the knowledge reuse cycle	**3.69**	**4,00**
Q2.7	I believe that the company's **strategy** for knowledge reuse will be efficient	**3,77**	**4,00**
Q3.2	The **methodology** provides a helpful guide to plan knowledge reuse in industry	**3,79**	**4,14**

The *methods catalogue* was considered very useful because it provides a fast and clear overview of existent methods contributing to knowledge reuse. Usually companies do not possess this information and the catalogue presents it in a structured and summarised way. The *methods' portfolios* were also helpful because they provided a focused overview of the catalogue. This was confirmed in the evaluation questionnaire, since 16 out of 20 participants considered that the *methods' portfolios* provide a good base to select suitable methods to perform the phases of the reuse cycle, while 3 do not have an opinion about it and only 1 participant does not see them as helpful.

Summarising, Case Study IV validated the **applicability** of steps 1 to 7 of the *k*-MORE and the **usability** of the obtained results. Company's knowledge managers considered the results helpful and they stated that "the application of *k*-MORE supported them in order to define concrete aspects for further work which are based on solid evidence and not just on gut feeling". Two factors were critical for the successful application of the methodology compared to previous cases studies: 1) the resources in terms of employees and time provided by the company; and 2) the implication of company's managers in the whole application process. It is very important that the same conditions are provided by companies which want to implement the *k*-MORE methodology in the future.

5.7 **Case Study V – Bike-sharing Collaboration**

This case study consists of the application and success evaluation of the ***k*-MORE approach for knowledge package and reuse**. The work of Aira Palomares (2017) focuses on "Packaging" and initial evaluation of the approach for "Reusing" during Phase I of the project. Pflieger (2017) evaluates the success of the approach for "Reusing" in academic experiments during Phase II of the project. Subsection 5.7.1 presents the initial situation and motivation. The application and its results are presented in Subsection 5.7.2. Subsection 5.7.3 presents the results of the conceptual and practical evaluations conducted by team members of both Phase I and II of the project. Finally, the results are discussed in Subsection 5.7.4 and lessons learned are derived.

5.7.1 Initial Situation and Motivation

The case study was conducted during an interdisciplinary collaboration project between the Technical University of Munich and the MVG (Münchner Verkehrgesllschaft), which is the company operating the underground, bus and tram public transportation system in Munich. The goal of the project was to develop a prototype of an electric tricycle (eTrike) to be used in a public sharing rental system operated by the MVG. The MVG already offers a sharing rental system with bicycles. The user's target group of the eTrike are physically challenged users (due to disabilities or age) and users, who want to transport cargo. The project started in November of 2016 and it lasted one year, divided in two semesters. In each semester, a team of eight students carried out the project. The first semester (Phase I) consisted on the conceptual design of the eTrike and the focus of the second semester (Phase II) was the development of a physical prototype of the eTrike. In each phase, each student was on charge of a different development area: 1) frame and lock, 2) drive unit and charge, 3) requirements and product architecture, 4) user experience, 5) operational concept, 6) board computer, 7) back-end and 8) app design.

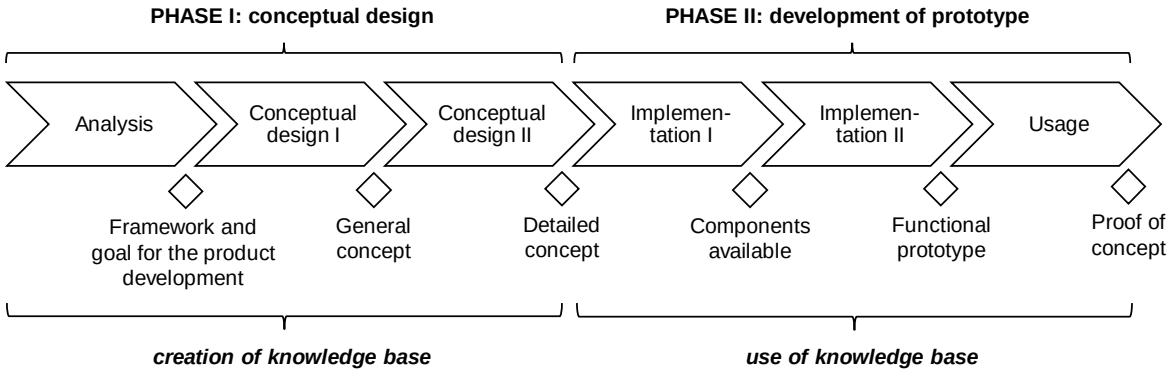


Figure 5-7: Time plan of the MVG eTrike project

In order to evaluate the **applicability** of the KB concept proposed by *k*-MORE for **knowledge "Packaging"** (see Subsection 4.4.6), the KB of the project should be created during the first

semester. Then, the **applicability and success** of the KB for **knowledge reuse** using the proposed methods for reusing (see Subsection 4.4.6) should be evaluated during the second semester of the project.

5.7.2 Application

The KB was created following the procedure C→A→B explained in Subsection 4.4.6. Visualisation C was obtained during the first six months of the running project (Phase I of Figure 5-7). This visualisation shows in a timeline all tasks associated to the documents used and generated in them. One team member had the role of knowledge manager, who supervised the knowledge acquisition and virtually implemented the three visualisations.

Some rules were established as preparation for the **knowledge acquisition**. First of all, the team members agreed on a structure for the shared folder and a naming code for all documents. This was done in order to facilitate the tracking of documents. In order to collect the information required to create Visualisation C, the knowledge manager prepared an Excel template, which included fields such as task's name, document's name, document's storage, document´s creation date, or competences to accomplish the task. This template was the central element for knowledge acquisition and all team members had access to it. At the beginning of the project each team member was responsible of documenting daily his or her tasks and documents on the template. Soon it was observed that this strategy did not work properly because team members were not rigorously filling the template and therefore, the information to create Visualisation C was getting lost. For this reason, a new strategy for knowledge acquisition was designed. In the new strategy, the knowledge manager was exclusively responsible of the knowledge acquisition. He arranged a meeting with each team member every 2/3 weeks, in which they filled together the Excel template. During the meeting they went through the shared folder and team presentations in order to gather the documents that had been generated by the team member since the last session. The review of documents was complemented with the team member´s tasks described in the catch-up meetings and documented on the virtual Kanban Board. Both catch-up meetings and Kanban Board were project management tools, which were conducted independently from the knowledge acquisition process. The catch-up meetings were conducted once a week in a 10-15 minutes session in which team members orally summarised their work since the last catch-up meeting. The virtual Kanban Board was filled with the "to-do", "in progress" and "done" tasks of all team members. However, the Kanban-Board, as it happened with the template for knowledge acquisition, was not rigorously filled and at some point the team decided to stop using it.

Apart from the acquisition of naturally conducted tasks and associated documents, the knowledge manager organised two lessons learned sessions. The results of those sessions were documented and included in Visualisation B under the category "lessons learned". The sessions were done following the procedure described in Subsection 4.4.6.

The **KB** was **implemented** in Soley Studio. The visualisations contain nodes and edges with their associated attributes. The nodes and edges are defined by the metamodels of Figure 4-12 for Visualisation A and Figure 4-25 for Visualisation B and C. The attributes for the nodes of

Visualisation C were defined during the case study in order to provide the necessary information to derive Visualisation A and to allow knowledge search through the methods of Search Scenarios and DeSiDe. As example, Table 5-9 shows the attributes defined for the node "task" of Visualisation C, including the goal pursued by each attribute. Analogously, the attributes for the nodes in all visualisations were defined.

Table 5-9: Attributes of the node "task" in Visualisation C

Attribute	**Goal**	**Explanation**
Task ID	Node identification	It provides a unique identifier for Soley Studio. This is necessary in order to create different nodes for tasks with the same name.
Name	Node identification	It gives the KB user an idea of what has been done.
Generic Task	Establish a relation with Visualisation A	Detailed tasks in Visualisation C are grouped under a generalised generic task, which is the task's node included in Visualisation A.
Phase	Enabling knowledge search for the user	It allows the user searching by project phase and it is a characteristic of the design situation required for the DeSiDe method.
Start Date	Enabling knowledge search for the user and enabling visualisation	It allows the user searching by date and it is necessary information to position the node in the workflow of Visualisation C in the real project timeline.
End Date	Enabling knowledge search for the user and enabling visualisation	

Visualisation C was created with the input from the template for knowledge acquisition. A direct access to the real documents was included, so the document opens by clicking directly on the node depicted in the visualisation. This feature enhances the functionally of the visualisation for knowledge search. Figure 5-8 shows the overview of the final visualisation.

Figure 5-8: Visualisation C for Phase I of the project

Visualisation A was created taking the following nodes' attributes from Visualisation C: generic task, generic document, storage and author. The knowledge manager generalised the terms in the cases in which it was required for better consolidation. Since Visualisation A was created out of Visualisation C, both visualisations are connected. Visualisation A represents an overview with generic denominations, and therefore, the documents' nodes are in this visualisation not linked to any real document in a storage. The competences of team members which had been collected in the template for knowledge acquisition during the entire project were in the end consolidated by the knowledge manager in order to include them in this visualisation. Figure 5-9 shows the overview of the final visualisation.

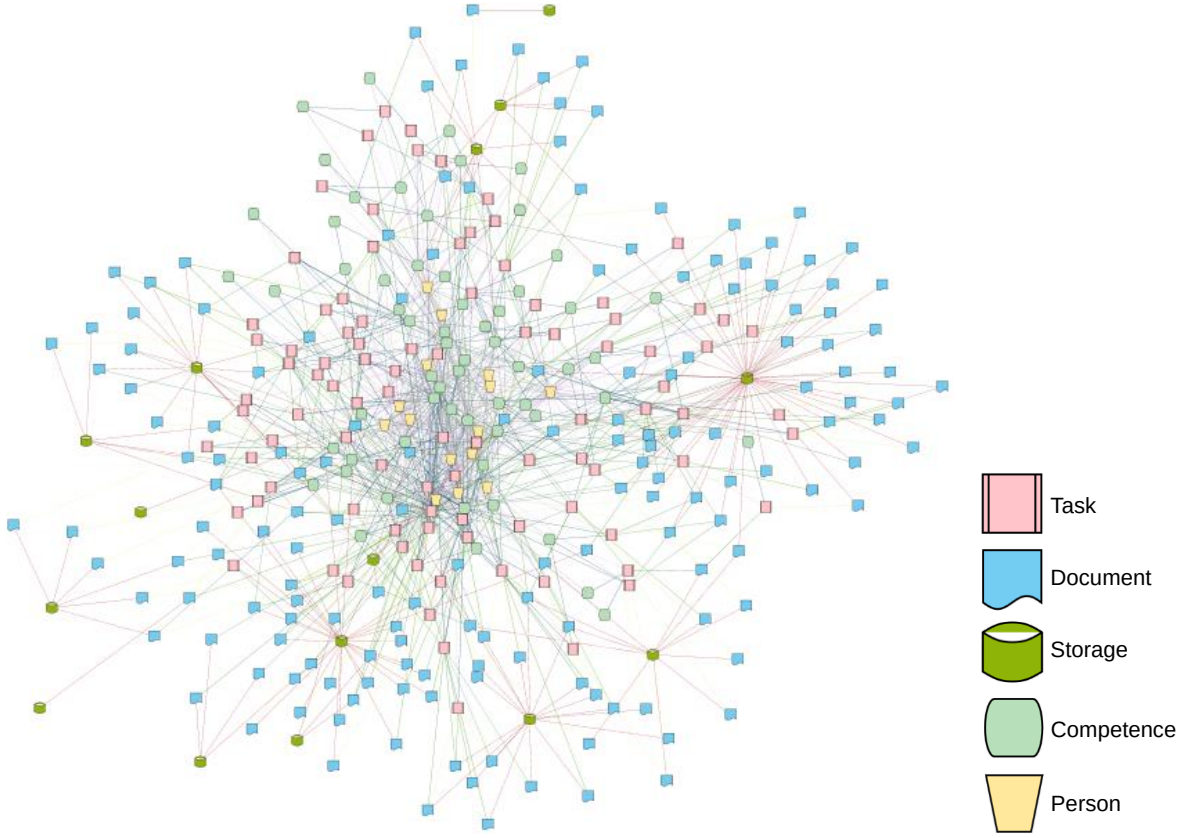


Figure 5-9: Visualisation A for Phase I of the project

Visualisation B depicts project and team's knowledge structured in categories. The visualisation contains two main groups: documents and competences. For documents, there are three categories. Category 1) provides a general overview of all projects' documents. Category 2) provides an overview of the most relevant documents. A third category was created for this project. The knowledge manager defined the subcategories of category 3) based on combining the results from 1) and 2) with his own experience and good understanding of the KB content. Categories 1) and 2) were divided in subcategories by applying the following analysing rules to Visualisation A: 1) "most common terms in documents' names" and 2) "frequently generated and used documents". All documents' nodes are linked to the last version of the real document, so the document opens by clicking directly

on the node depicted in the visualisation. Figure 5-10 shows the overview of an extract of the final visualisation. For competences, applying the rule "most common terms in competences' names" to Visualisation A did not provide conclusive results because there were not enough common terms. Thus, the knowledge manager established the categories (such as technical, soft skills, software, etc.) and included in them the competences of Visualisation A.

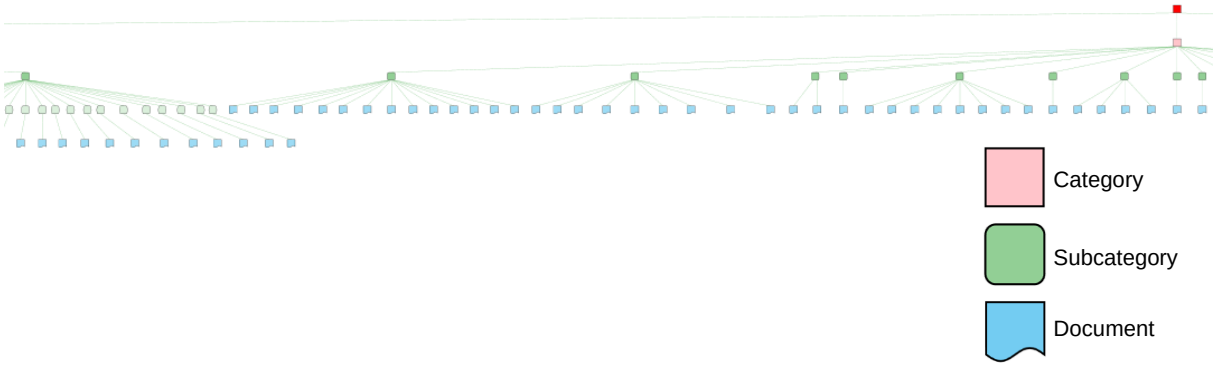


Figure 5-10: Extract of Visualisation B for Phase I of the project

Once the KB was complete, the **Search Scenarios** for knowledge reuse were prepared. For each visualisation, possible searches were listed and the way of proceeding with the selection tool of the software Soley Studio was described. Figure 5-11 shows an extract of the Search Scenarios prepared for Visualisation C.

Search scenario	
1) Obtain further information (e.g. when in process, reasons for changes) of a document identified in Visualisation A or B 2) Obtain further information (e.g. when in process, reasons for changes) of a known document	
Search by	**Soley – Smart Selector: How to**
Document's name	All Nodes Class – IsEqualTo – Document Name – IsEqualTo – (to be written)

Search scenario	
1) Select a specific time frame	
Search by	**Soley – Smart Selector: How to**
Task's start and end date	All Nodes Class – IsEqualTo – Task Startdate – IsGreaterThanOrEqualTo – (YYYYMMDD) Enddate – IsLessThanOrEqualTo – (YYYYMMDD)

Figure 5-11: Two Search Scenarios for Visualisation C

5.7.3 Evaluation

The *k*-MORE KB ("Packaging") and search methods proposed for "Reusing" were evaluated using two methods. First, a conceptual evaluation was conducted with team members of Phase I of the project. Then, a practical evaluation was conducted with team members of Phase II of the project. Both evaluations are presented in the next subsections.

Conceptual Evaluation

The *k*-MORE approach for knowledge package and reuse (presented in Section 4.4.6) was conceptually evaluated by five team members of Phase I of the project. This took place in a session, which included a presentation of the approach, a presentation of the implemented KB of the project and a discussion round. Afterwards, the team members answered a questionnaire consisting of nine questions. The template of the questionnaire is included in Appendix 9.8. The questionnaire contained questions about the utility of the different visualisations of the KB and about the contribution of the different methods to search in the KB Seven questions had four possible answers from "fully disagree" to "fully agree". The results are presented in Table 5-10. A number was assigned to each answer in a scale from 1 to 4, from "fully disagree" (1) to "fully agree" (4), in order to calculate the average rating of each question. The questionnaire included two more questions with an open answer in order to get other opinions and ideas. All details of the evaluation are contained in Aira Palomares (2017).

The results show that the visualisations are considered **useful** but with some differences between them. Visualisation B is highly appreciated. Visualisation A and Visualisation C are considered useful but they received some critiques due to the large amount of information contained, which might make them too complex and therefore, the user would require some time in order to understand them properly. One participant commented that Visualisation C "has too much information with the different versions. At first, I would like to see only the latest version and afterwards if I need older infos I will look them up in the older ones". Generally, the team members highlighted the importance of search methods which allow a goal-oriented search in order to reduce the complexity of those visualisations.

The team members clearly agreed that the proposed search methods **contribute to increase knowledge reuse**.

As suggestions to improve the KB, the team members suggested to combine the three visualisations in the software implementation and to link directly documents with persons. The team members found the particularly positive the overview that the visualisations offer and the navigation help which is provided by the combination of search methods.

Table 5-10: Results of the conceptual evaluation of the k-MORE approach for knowledge package and reuse

		Fully disagree	Disagree	Agree	Fully agree	Average
Q1	Do you think that the representation of knowledge in several visualisations facilitates the knowledge search?	0	0	3	2	**3,4**
Q2	The main goal of visualisation A (knowledge map) is to provide an overview of the relations between persons, tasks, documents, storages and persons' competences. Do you consider this information useful for your design work?	0	1	4	0	**2,8**
Q3	The main goal of visualisation B (knowledge categories) is to structure the documents and competences of the company in categories. Do you consider this information useful for your design work?	0	0	3	2	**3,4**
Q4	The main goal of visualisation C (workflow) is to show the project timeline, with the performed tasks and used/generated documents. Do you consider this information useful for your design work?	0	2	1	2	**3**
Q5	Do you think that the free search in the visualisations contributes to increase knowledge reuse?	0	0	2	3	**3,6**
Q6	Do you think that the search using the Search Scenarios contributes to increase knowledge reuse?	0	0	2	3	**3,6**
Q7	Do you think that the search using DeSiDe contributes to increase knowledge reuse?	0	0	2	3	**3,6**

Practical Evaluation

A practical evaluation of the *k*-MORE KB and search methods was conducted in Phase II of the project. The goal was to evaluate the **success** of the proposed methods to **increase knowledge reuse** and to evaluate the influence of increased reuse on the amount and quality of design solutions. The procedure designed for this evaluation is presented in Figure 5-12. First, a workshop for presentation and training on the implemented KB and *k*-MORE search methods was conducted. Second, two workshops with an experimental set-up were planned.

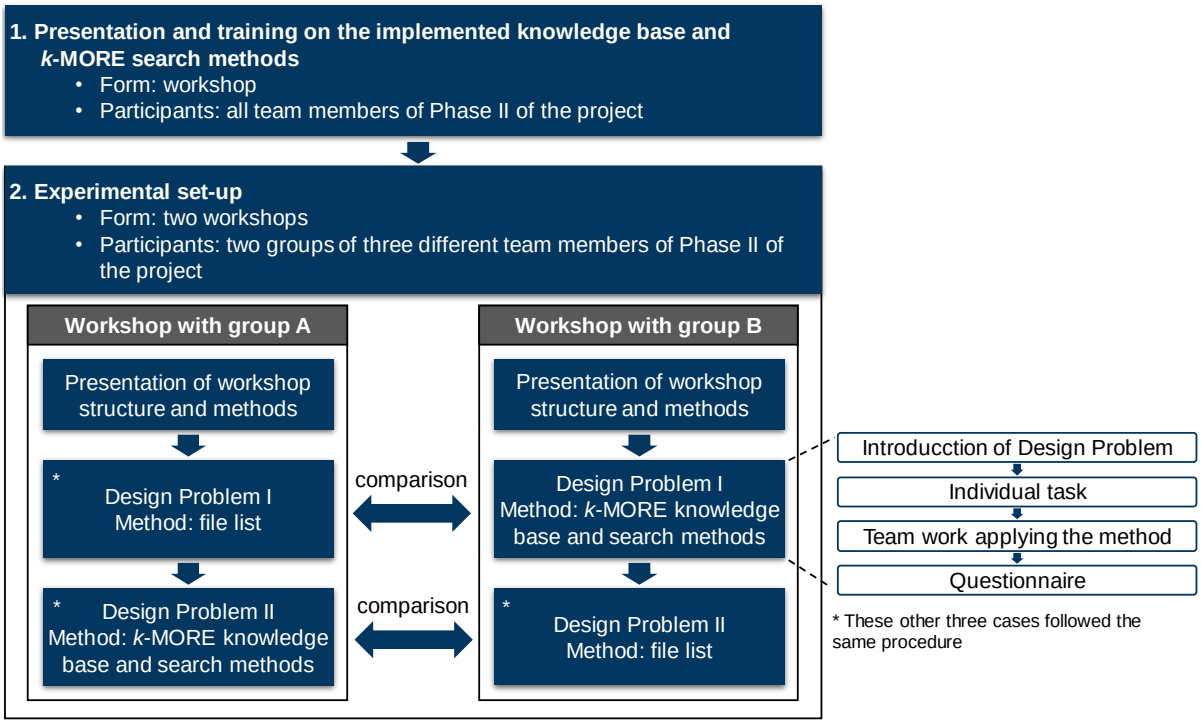


Figure 5-12: Plan of the practical evaluation

The workshop conducted in point 1 consisted of a **presentation** of the concept and of the implemented KB of the project, a Live Demo of its usage with the Soley Studio software, and two exemplary exercises to be performed by the attendants. The attendants did not have any problem understanding the presented concepts, but they had trouble interacting with the software on their own. They found it "unintuitive" and "hard to learn".

The results from this workshop were used to prepare the experimental set-up in the way that the methods application could be evaluated without interferences. Given the lack of user-friendliness of the implemented KB observed in the workshop conducted in point 1, the direct interaction with the software was kept to the minimum for the practical application in the experimental set-up of point 2. Excel templates were prepared for the participants to introduce the input in the method Search Scenarios and DeSiDe (see Appendix 9.9.1). These templates offered an intuitive interface and drop-down lists, which facilitated their use. Based on the input introduced by the participants in the Excel sheets, the workshop moderator showed the correspondent results of the search in the implemented KB and helped the participants navigating through the resultant visualisations.

Two workshops with two different groups of participants (group A and group B) were conducted for the **experimental set-up**. During the workshops, participants solved predefined design problems during a limited time frame and using the knowledge generated during Phase I of the project. The results of applying the *k*-MORE methods for knowledge reuse were compared to the results applying a control method. The control method received the name of "file list" and it consisted in presenting all files storage in a unique folder. Each file

was named as it had been established in Phase I of the project (Date_Author_DocumentName_Version). In each workshop, a group of three team members worked on two design problems (Design Problem I and Design Problem II). Each group acted once as control group (using the file list) and once as experimental group (using the *k*-MORE KB and search methods). In this way, both groups got to try both methods. This was important for the evaluation, in order to get an opinion of the participants on the comparison of the methods, which was done in a questionnaire conducted directly after the methods application. Thus, the workshops produced two results: 1) a comparison of the methods based on the team performance; and 2) a comparison of the methods based on the participants' opinions.

The **procedure** to solve the design problem was the same in the four cases and it consisted on four steps (see procedure in the right side of Figure 5-12). First, the workshop moderator introduced the design problem. Then, each participant solved an individual task, which fulfilled two purposes: 1) enhance participants' focus; and 2) measure possible fatigue and learning effects in the application of the second method, which served to validate the results of Design Problem II. Afterwards, the team worked on the correspondent design problem applying the correspondent method for knowledge reuse. A workflow (contained in Appendix 9.9.2) describing the search options and use of Excel interfaces was provided as support for the application of the *k*-MORE methods. Finally, each participant filled a questionnaire in order to provide their opinions on the methods applied.

The proposed design problems correspond to two products which are similar to the eTrike: a **eBike** and a **cargo** (four-wheeled transport unit). In both design problems, participants were asked the same questions in four different exercises. The first exercise was an individual task and the other three exercises were conducted in group. In order to assure the comparability of solutions, templates for solution documentation were prepared. The description of the design problems as well as the solution templates are contained in Appendix 9.9.3.

Each one of the two workshops had a duration of two hours. Fatigue and learning effects influencing Design Problem II were analysed based on the results of the individual tasks, which are presented in Table 5-11. Most participants provided more solutions for Design Problem II than for Design Problem I. Only one participant (P1 of group B) generated more solutions for Design Problem I than for Design Problem II. Based on these results, the effect of fatigue can be discarded and it can be concluded that some learning effects occurred. However, an average difference of respectively 1,67 and 0,67 solutions per group is not extreme. Therefore, the results of Design Problem II were considered for the overall evaluation.

Table 5-11: Results of the individual tasks

Workshop	Participant (P)	Number of solutions for Design Problem I	Number of solutions for Design Problem II	Difference	Average difference per group
Group A	P1	5	7	2	1,67
	P2	6	9	3	
	P3	7	7	0	
Group B	P1	10	8	-2	0,67
	P2	5	7	2	
	P3	7	9	2	

Exercises 2 to 4 of the design problems were conducted in group work, which resulted in one filled solution template per method (file list and *k*-MORE) per group (A and B). Therefore, a total amount of two samples per method were obtained. Analysing those samples, a comparison of team performance using the two different methods was done. A quantification of the solutions was required for the comparison. The method chosen for that was the **cost-utility analysis** (Dittmer 1995, pp. 43–56). Following this method, **assessment criteria** and **weights** for those were defined. The team performance was based on three assessment criteria: 1) number of files used, 2) number of solutions provided, and 3) accuracy of the solutions. The values assigned to the assessment criteria are presented in Table 5-12.

Table 5-12: Assessment criteria for the evaluation of team performance

Assessment criteria	Value		
	1	3	9
Number of files used	None of the documented knowledge was used	Documented knowledge was used to a certain degree	The exercise was completely solved using documented knowledge
Number of solutions provided	Very little solutions (0-3)	Few solutions (4-8)	A lot of solutions (9 or more)
Accuracy of the solutions	The exercise was not solved according to the specifications	The exercise was solved according to some specifications	The exercise was solved according to all specifications

The importance of each assessment criteria was represented by its weight, which was determined applying a pairwise comparison. The pairwise comparison of the three criteria is presented in Table 5-13, in which each row is compared to the columns. The *accuracy of the solutions* is rated as the most important criterium. This is based on the assumption that more accuracy leads to improved designs. The *number of files used* and the *number of solutions provided* are equally rated.

Table 5-13: Pairwise comparison to determine the weights for the assessment criteria

	Number of files used	Number of solutions provided	Accuracy of the solutions	**Sum**	**Normalised weight**
Number of files used	X	2	1	3	0,25
Number of solutions provided	2	X	1	3	0,25
Accuracy of the solutions	3	3	X	6	0,5
1-less important; 2-equally important; 3-more important				12	1

The upcoming paragraphs describe the **results** of each group applying each method.

Using the **file list**, **group A** used in exercise 2 two files which contained highly adequate knowledge to solve the exercise. The group provided eleven solutions, but those were incomplete. Only one out of four required aspects per solution were described, which implied low accuracy of the solutions provided. For the resolution of exercise 3, group A used one file, which did not contain all required knowledge to solve the exercise. The main solution to the exercise was accurate but only one solution was provided, and numerous aspects of the exercise were not solved. For exercise 4, group A did not use any file and they answered based on their own implicit knowledge. They generated a total number of eight solutions, which went in the right direction, but which were too vague to meet the required specifications. Table 5-14 shows the values assigned to the assessment criteria given the results obtained for the application of file list as knowledge reuse method. The values assigned to the assessment criteria are 1, 3 or 9 according to the descriptions of Table 5-12.

Using the ***k*-MORE** KB and search methods, **group A** did not use any file to solve exercise 2 and they did not provide any solution to the exercise either. For exercise 3, the group used information contained in the visualisations of the KB, which they found applying the method Search Scenario. The exercise was completely solved applying the knowledge obtained from the visualisations. A total number of ten solutions were generated and those met the required specifications. In order to solve exercise 4, the group used again information contained in the visualisations of the KB. Some information was obtained through Search Scenarios and some information was obtained conducting free search on the visualisations. A total number of ten solutions were generated and those met the required specifications. Table 5-14 shows the values assigned to the assessment criteria given the results obtained for the application of the *k*-MORE approach for knowledge reuse. The values assigned to the assessment criteria are 1, 3 or 9 according to the descriptions of Table 5-12.

Using the **file list**, **group B** used two files which contained all necessary knowledge to solve the exercise, and they extended it with their own implicit knowledge. The group provided ten solutions, which were complete and accurate. For exercise 3, the group used one file, which provided some but not all required knowledge to solve the exercise and they complemented it with their implicit knowledge. The group provided nine solutions but those were not all

possible ones, and therefore, the accuracy of the solution could be improved. For exercise 4, group B did not use any file and they relied on their implicit knowledge. Ten solutions were generated. The solutions went in the right direction, but they were too vague to meet the required specifications. Table 5-15 shows the values assigned to the assessment criteria given the results obtained for the application of file list as knowledge reuse method. The values assigned to the assessment criteria are 1, 3 or 9 according to the descriptions of Table 5-12.

Applying the ***k*-MORE** approach, **group B** used one file to solve exercise 2, which they found applying the method Search Scenario. The selected file contained the necessary knowledge to solve the exercise, which the group complemented with their implicit knowledge. The group generated ten solutions, which were complete and accurate. For exercise 3, the group used information contained in the visualisations of the KB, which they found applying the method Search Scenario. The exercise was completely solved applying the knowledge obtained from the visualisations. A total number of 14 solutions were generated and those met all required specifications. In order to solve exercise 4, the group used again information contained in the visualisations of the KB, which they obtained by free search on the visualisations. A total number of nine solutions were generated and those met the required specifications. Table 5-15 shows the values assigned to the assessment criteria given the results obtained for the application of the *k*-MORE approach for knowledge reuse. The values assigned to the assessment criteria are 1, 3 or 9 according to the descriptions of Table 5-12.

Table 5-14: Results of the workshop with group A

Method	**Assessment criteria**	**Value ex. 2**	**Value ex. 3**	**Value ex. 4**	**Sum value**	**Normalised value**
File list	Number of files used	9	3	1	13	0,48
	Number of solutions provided	9	1	3	13	0,48
	Accuracy of the solutions	3	3	3	9	0,33
k-MORE	Number of files used	1	9	9	19	0,70
	Number of solutions provided	1	9	9	19	0,70
	Accuracy of the solutions	1	9	9	19	0,70

Table 5-15: Results of the workshop with group B

Method	**Assessment criteria**	**Value ex. 2**	**Value ex. 3**	**Value ex. 4**	**Sum value**	**Normalised value**
File list	Number of files used	9	3	1	13	0,48
	Number of solutions provided	9	9	9	27	1
	Accuracy of the solutions	9	3	3	15	0,56
k-MORE	Number of files used	9	9	9	27	1
	Number of solutions provided	9	9	9	27	1
	Accuracy of the solutions	9	9	9	27	1

Table 5-16 shows the comparison of the **final performance value** of each group applying each search method. The final performance value is calculated applying the weights determined in Table 5-13 to the normalised values of Table 5-14 and Table 5-15.

Table 5-16: Comparison of results

Method	**Group**	**Final performance value** (weighted and normalised)	**Average final performance value**
File list	A	0,40	0,53
	B	0,65	
k-MORE	A	0,70	0,85
	B	1	

In each group, the final performance value was higher under application of the *k*-MORE approach than under application of the file list (0,30 more for group A and 0,35 more for group B). Group B obtained better performance values than group A (0,25 more for the method file list and 0,30 more for *k*-MORE). These results lead to an average performance value of 0,53 for the results obtained applying the file list and 0,85 for the results obtained applying the *k*-MORE KB and search methods.

After applying each reuse method, the participants answered a **questionnaire** for the **assessment** of the **method**. The answers regarding the method file list constitute the sample of the control group and the answers regarding the *k*-MORE KB and search methods constitute the sample of the experimental group. Since all participants in the workshops got to try all methods, six persons answered the questionnaire for each method. The questionnaire is presented in Appendix 9.9.4. It contained seven questions with five possible answers. A number was assigned to each answer in a scale from 1 to 5. The possible answers went from "hard" (1) to "easy" (5) for Q1 to Q5, from "bad" (1) to "good" (5) for Q6, and from "not satisfied" (1) to "satisfied" (5) for Q7.

Table 5-17 shows the participants' answers after applying the method file list.

Table *5-18* shows the participants' answers after applying the *k*-MORE KB and search methods. More details about the evaluation results are contained in Pflieger (2017).

The results show that searching knowledge using ***k*-MORE** KB and search methods is **easier** than searching in the file list. Only in the case of relevant documents, the participants consider that both methods are equally easy. The *k*-MORE KB and search methods are especially **useful** to identify relationships between different knowledge element. The *k*-MORE approach facilitates searching for relevant persons, relevant tasks and relevant competences compared to the file list, but they are not considered especially easy nor especially difficult. The adequacy of the knowledge received was assessed as the same for both methods. The satisfaction with the generated solutions is higher after the application of the *k*-MORE approach than after the application of the file list.

Table 5-17: Participants' assessment after applying the file list

		1	2	3	4	5	Average
Q1	How easy was it to find relevant documents?		1	4	1		**3**
Q2	How easy was it to find relevant persons?		6				**2**
Q3	How easy was it to find relevant tasks?	1	4	1			**2**
Q4	How easy was it to find relevant competences?	3	3				**1,5**
Q5	How easy was it to identify relationships between elements?	2	2	2			**2**
Q6	How do you rate the adequacy of the knowledge you received?	1	2	1	1	1	**2,83**
Q7	How satisfied are you with your solutions?	2	1	2	1		**2,33**

Table 5-18: Participants' assessment after applying the k-MORE KB and search methods

		1	2	3	4	5	Average
Q1	How easy was it to find relevant documents?		2	2	2		**3**
Q2	How easy was it to find relevant persons?			2	3	1	**3,83**
Q3	How easy was it to find relevant tasks?		3	1	2		**2,83**
Q4	How easy was it to find relevant competences?		2	2	2		**3**
Q5	How easy was it to identify relationships between elements?		2		3	1	**3,5**
Q6	How do you rate the adequacy of the knowledge you received?		2	3	1		**2,83**
Q7	How satisfied are you with your solutions?		2	2	2		**3**

5.7.4 Discussion and Lessons Learned

The goal of this case study was the **application** and **success evaluation** of the *k*-MORE approach for knowledge packaging and reuse. The evaluation of application was achieved through the creation of the *k*-MORE KB in a real project and the use of the proposed search methods in two workshops. The approach was applicable, but the software implementation requires substantial improvement. The evaluation of success was achieved through questionnaires and analysis of the results of application of the *k*-MORE approaches during

workshops. The *k*-MORE approach contributed to increase the reuse of documented knowledge, which increased the amount and quality of design solutions.

The initially planned process for **knowledge acquisition** could not assure that all knowledge was being acquired. Team members found annoying filling the knowledge acquisition template, probably because they did not see the knowledge acquisition of the project as part of their work. This resulted in a lack of rigour filling the template. Other project management tools which may have been useful for knowledge acquisition, like the Kanban Board, were not filled rigorously either. The main challenges were how to assure knowledge completeness and at the same time reduce the effort invested by team members for knowledge acquisition. Both challenges were overcome with the finally applied methodology, in which all responsibility of acquiring knowledge and controlling completeness relied exclusively on the knowledge manager. This methodology constitutes a high effort for the knowledge manager, but it is the one recommended for a successful knowledge acquisition. An alternative would be fully automatic acquisition in which generated and used files are tracked though a programmed system running in the background. The system should ask team members for additionally required knowledge such as tasks' names or competences when required. However, the effort programming and integrating such system in a real company seems high. The lessons learned sessions were very helpful, not only to document lessons learned for upcoming teams but also for the current team to reflect on their work. The procedure proved to be understandable and efficient.

The software Soley Studio supported adequately the **implementation** of the **visualisations** of the KB. However, each visualisation had to be created independently, since the software cannot establish connections between different graphs. A challenge for the creation of Visualisation C was positioning the tasks in the time line depending on their start and end date. Tasks and documents overlapped in the x axis in dates in which numerous nodes converge and it was necessary to program also different positions for the y axis to allow the visualisation of all nodes at the same time. In order to provide an intuitive distribution of nodes, all tasks were positioned on the upper part of the central flow and all documents were positioned on the lower part. In this way, the distribution is clear, but the visualisation presents many crossed edges, which might be confusing. For this reason, Visualisation C may not be useful until elements are hidden and other selected elements remain visible.

The results of applying the **analysing rules** to Visualisation A were not directly applicable to create Visualisation B. The resultant terms are very dependent of the terminology used to name documents, and some categories may not make sense to be applied for Visualisation B. However, the results are helpful for knowledge managers, who should go through the results and establish the knowledge categories for Visualisation B on their own.

After the **conceptual presentation** of the *k*-MORE approach for knowledge package and reuse to team members of Phase I of the project, the visualisations of the KB were considered useful and the proposed search methods were considered as helpful to increase knowledge reuse. Visualisation C was criticised due to the high number of nodes and crossed edges. This problem can be solved applying the method Search Scenarios and hiding in the visualisation the elements which are irrelevant for the scenario. Regarding the consideration of the various search methods, even though the average evaluation of all methods is the same (see Table

5-10), the individual answers show that different team members prefer different methods. This is consistent with one of the main ideas behind *k*-MORE, which is the consideration of individual differences and providing individualised solutions.

The **application** of the *k*-MORE approach by team members of Phase II of the project showed that it contributes to increase the reuse of documented knowledge, the number and the accuracy of design solutions compared to a traditional way of packaging and reusing documented knowledge such as the file list. A major challenge to proceed with the application of the methods was achieving a user-friendly user interface for the software implementation. This could not be achieved, and it might have influenced the methods' application as well as the opinions of the participants in the workshops. A fully user-friendly software implementation is required for future evaluations.

During the application of *k*-MORE, it was observed that understanding and using the KB and combination of search methods can be challenging. For example, group A did not solve the first exercise (exercise 2 of the design problem) of Design Problem II because they spent the time getting used to the KB and methods. Group B on the other hand, did not have any problem understanding and using the approach. It might have been that the order of application of the reusing methods influenced the acceptance of the method by the group. Group A perceived the *k*-MORE approach as complex because they had applied first the file list, method which they perceived a simpler. Group B started applying *k*-MORE and therefore, they accepted and applied it feeling comfortable with it from the beginning.

The Search Scenario was the most applied search method. It seemed to be the most intuitive for the participants. DeSiDe was not used at all. It was probably perceived as complex and the connection of it with the KB was unclear for the participants. For the industrial implementation of the search methods, it is suggested to clearly explain the methods' goal and to extensively train users on the methods' application.

The **questionnaires** conducted to the workshop participants after the application of each method allowed a comparison of the methods based on the participants' opinions. Participants were mostly neutral in their answers regarding both methods, though the *k*-MORE KB and search methods got in all aspects equal or higher rates than the file list. *k*-MORE was considered especially beneficial to find relevant persons and relevant competences, as well as to understand the relationships between knowledge element. An interesting observation is the question about the satisfaction with the solutions provided to the design problems. Participants are slightly disappointed with their solutions after applying the method file list and neutral after applying *k*-MORE. However, most exercises of the design problems were successfully solved and documented in the solution templates. A possible reason for this pessimistic tendency in participants' answers can be the negative user experience during the methods' application due to the lack of proper software implementation.

5.8 Conclusions of DS II: Fulfilment of Requirements of the Support

The requirements for the support were defined in Subsection 4.1 based on the findings of DS I. Different steps and proposals of the *k*-MORE methodology contribute to fulfil those requirements. Table 5-19 depicts the requirements fulfilled by each step and the degree of fulfilment based on the application and success evaluations conducted in DS II.

Table 5-19: Fulfilment of requirements of the proposed support

Requirement	**Fulfilled by**		**Evaluated in**	**Applic.**	**Succ.**
The support should enable the strategic planning of knowledge management methods to achieve knowledge reuse		*k*-MORE methodology	Case Study IV		
The support should facilitate the knowledge acquisition and visualisation		Step 2 “Visualising”	Case Study IV Case Study V		
The support should foster the implementation of habits and routines contributing to knowledge reuse		Steps 4 to 7 “Planning the Reuse Cycle”	Case Study IV		
The support should enable the analysis of individual characteristics and perceptions		Step 3 “Analysing”	Case Study IV		
The support should facilitate the formulation of a search question		Optional approach for knowledge reuse	Case Study V	Not known	
The support should provide individualised search and reuse solutions independently of the participation of designers in previous projects		Optional approach for knowledge package and reuse	Case Study V		

The complete *k*-MORE methodology fulfils the requirement of enabling the **strategic planning of knowledge management methods to achieve knowledge reuse**. This requirement was completely fulfilled, since the methodology was successfully applied in Case Study IV in order to plan strategically the knowledge reuse cycle of a real company.

Step 2 "Visualising" facilitates the **knowledge acquisition** in the company and **its visualisation**. Knowledge maps were successfully created for both Case Study IV and Case Study V. Templates and instructions support this step, making it (despite time-consuming) easily applicable. The success of the knowledge map to provide an overview is limited to the size of the knowledge map. Maps which contain numerous elements and connections might not be transparent enough to visualise knowledge.

The support should foster the **implementation of habits and routines**. The result of applying steps 4 to 7 "Planning the Reuse Cycle" of *k*-MORE is a selection of most suitable methods to implement habits and routines for knowledge reuse. Steps 4 to 7 "Planning the Reuse Cycle" were applicable in Case Study IV, since they offered the company an overview of suitable methods for selection. This research did not carry out the implementation of the methods proposed by *k*-MORE, but the methodology itself fosters their implementation. The participants in the success evaluation of Case Study IV estimate a positive impact in efficiency and amount of knowledge reuse once the methods suggested by *k*-MORE are implemented in reality.

The **analysis of individual characteristics and perceptions** is done in step 3 "Analysing". The *questionnaire of influencing factors* based on the WCM was applicable and showed significant results in order to determine individual characteristics and perceptions regarding knowledge reuse. According to the answers of participants in the success evaluation of Case Study IV, the success in identifying essential influencing factors has room for improvement if the current amount of 21 factors can be reduced.

The **formulation of a search question** is supported by the optional approach for knowledge reuse, which combines three search methods to search in a KB. The applicability of the formulated approach could not be proved because of the lack of real data and the complex software implementation. The results of the evaluation in experiments conducted in Case Study V show a partial fulfilment of the requirement; the *k*-MORE approach with three search methods offers a most extensive support for the formulation of a search question compared to other approaches which offer only one alternative, but it is questionable if the value-added is sufficient to compensate the implementation effort.

The final requirement for the support was providing **individualised knowledge search and reuse solutions**, independently of the participation of designers in previous projects. This requirement is addressed with the optional approach for knowledge package and reuse. The proposed KB with three visualisations was successfully implemented. As it was explained in the paragraph above, the implementation of the combination of the KB with the proposed search methods could be not be completed in an applicable set-up. The proposed approach offers individualised search and reuse solutions, but based on the results of the experiments conducted, the contribution of those solutions to increase knowledge reuse seems moderate at this point.

6. Discussion

This Chapter presents the thesis discussion. The methodological procedure is discussed in Section 6.1 and the results are discussed in Section 6.2.

6.1 Discussion of Methodological Procedure

The methodological procedure followed during this thesis was the **Design Research Methodology** (DRM). The DRM framework divided the research work in four stages that provided guidance and supported the author specially in understanding the needs for extensive research and needs for iterations during the research process.

The **Research Clarification** (RC) was review-based. Literature sources were sufficient to identify the need to support knowledge reuse in organisations. The literature review also provided a framework of concepts and terminology for the research work. A challenge in the RC stage was the alignment of concepts and terminology which were used for this thesis as literature showed different terms and concept interpretations. The discussion and specific definition of terms for this thesis was developed in parallel to the research work resulting in continuous iterations between the other stages of the DRM with the stage of RC. The iterations were necessary since the research work supported the understanding of terms' differences in practice. The review-based RC was complemented with the author's industrial experience. Working in research collaborations with various engineering design companies, it was observed that most companies had the impression of not reusing efficiently their knowledge but they were unable to specify what knowledge they referred to or why was its reuse inefficient. This experience confirmed the research need in practice and narrowed down the research focus to the field of engineering design.

It can be discussed that the defined research need (supporting knowledge reuse in engineering design companies) and the derived thesis objective (improving theoretical understanding and developing practical support to increase knowledge reuse in engineering design companies) were too generally defined given the subjectivity of the main research object (knowledge) and the broad application area selected (engineering design companies). On the one side, it is true that the general need and objective definition originated challenges in aligning terms and narrowing down research areas in early research stages. It was also a shortcoming to plan and conduct empirical studies that could include controllable variables and provide statistically significant results for the research community. The consequence is that the research work was mostly explorative. On the other side, the general need and objective definition addressed a fundamental problem in practice and the research conducted in this thesis led to develop widely applicable support for this problem.

A comprehensive **Descriptive Study I** (DS I) was conducted and three different methods were applied: interviews with practitioners, literature review and exploratory design experiments.

The interviews with practitioners were semi-structured interviews pursuing the aim of understanding the reasons for the lack of knowledge reuse in industry. The checklist suggested by Blessing and Chakrabarti for determining the characteristics of empirical studies

was a useful tool for the preparation of the study. The interviews length, content, type and number of participants turned out to be adequate to achieve the objective of the study. Considering the evolution of the research work into the development of a methodology to plan the knowledge reuse cycle, a different distribution of the interview questions would have been beneficial. The interview study had blocks of questions addressing different knowledge management processes. The blocks could have referred to the processes of the knowledge reuse cycle and this would have improved the consistency between findings from the interview study and the developed support at PS. However, at this early point of the research work, it was unknown that the support would be based on the structure of the knowledge reuse cycle.

A synthesis of literature review resulted in the creation of the WCM that describes the knowledge processes for individuals. A systematic literature review on factors influencing the knowledge processes described in the WCM was conducted in order to complete the model. The initial research procedure of conducting the systematic literature review in the field of engineering design had to be modified because an initial search in engineering design journals did not provide enough results. For this reason, relevant literature in the field of knowledge management was reviewed and 364 influencing factors were collected from journal papers. The factors were analysed, classified and reduced to a final amount of 21. A limitation of the procedure is the subjectivity in selecting, analysing, clustering and allocating influencing factors to the WCM. Even though clear criteria were defined to perform each one of those activities, the process requires making subjective considerations. Other researchers could have ended up with different configurations of the WCM.

Two exploratory design experiments were conducted as part of the DS I. The goal of the exploratory design experiments was to improve understanding of individuals' needs and behaviours through observation of documented knowledge reuse. Both exploratory design experiments presented an experimental set-up with few participants and uncontrolled variables. For this reason, they belong to non-experimental research, which is not sufficient to prove strong causal hypotheses, but is useful for suggesting new ideas. Designing the experimental set-up was challenging due to the lack of a fully functioning software-supported Knowledge Base (KB). Simplifications in the design of the exploratory design experiments had to be done to overcome this fact but those simplifications could have influenced the results. In exploratory design experiment I, the fact that the researcher acted as interface to provide knowledge from the KB could have influenced the knowledge requests of the participants. Even though there was no personal interaction between researchers and participants (only written interaction), a direct interaction with a machine could have given an impression of immediateness and anonymity that could have increased the amount of knowledge requests made by the participants. In the case of exploratory design experiment II, participants were required to select a preferred search method and they were explicitly told to disregard the validity of the knowledge provided by the method or the software implementation during the experiment. But those aspects could have influenced their preferences, especially in the case of the method FSV, in which the user navigated through the KB. Software, knowledge categories and method used are interconnected. Another limitation in the procedure of exploratory design experiment II was that the order in which the search methods were applied could have influenced the participants' preferences. However,

the number of participants available for exploratory design experiment II was not enough to try procedures of applying the methods in different orders and come to conclusions based on the results.

The **Prescriptive Study** (PS) followed the procedure suggested by Blessing and Chakrabarti for this stage of the DRM. The procedure supported the structured definition of requirements for support during *task clarification*. The main aspects of the support were defined during the step *conceptualisation* and those aspects established the basis to structure a literature review for the support *elaboration*. Thanks to the clear concept of support in form of a methodology and the information about existing methods to perform its parts, the *k*-MORE methodology could be developed in detail during *realisation*. This thesis author found the procedure very helpful in supporting a structured, gradual and logical development of support.

Furthermore, several iterations between PS and DS II took place in order to improve support based on learnings from case studies. A major modification in the final support resulted from the preparation of Case Study IV. The initial concept of the *k*-MORE methodology included the approach for knowledge package and reuse that was presented in Subsection 4.4.6 as unique solution to plan those phases of the knowledge reuse cycle. Several discussions during the preparation of Case Study IV revealed that limiting the approach for knowledge package and reuse to the proposal of Subsection 4.4.6 did not provide the flexibility desired in real practice. A solution based on providing a range of methods for the company's selection was preferred. The discussion concluded in the development of the *methods catalogue*. The *methods catalogue* is a summary of methods which were identified during the literature review conducted along this thesis. The assignment of characteristics for each method was done based on the judgement of researches and therefore it is subjective. Other methods could have been applied for the development of the catalogue. A systematic literature review could have been conducted to create the list of methods and workshops or interviews with practitioners could have been conducted to consolidate the methods' characterisation. Those methods were not applied due to time constraints, but it is a methodological aspect that could be considered in future work.

Five case studies were conducted as part of the **Descriptive Study II** (DS II). Three case studies were part of the support evaluation and provided feedback to improve support. Two case studies were conducted for the application and success evaluation of the *k*-MORE methodology.

The case studies for support evaluation provided useful insight that influenced the form and methods suggested for the *k*-MORE methodology. Using workshops for knowledge acquisition in step 2 "Visualising" or the final configuration of the *questionnaire of influencing factors* proposed in step 3 "Analysing" – just to name a few examples – are decisions based on the iterative trial and error analysis conducted in the case studies. A challenge for the support evaluation in case studies with real companies was that companies wanted to establish their own requirements for application (usually restricting time and resources applied). Those requirements sometimes conflicted with the researchers' proposals but were considered anyway because the support was "under development". Some of those requirements caused failed applications that could have been avoided if the initially proposed support would not have been modified to fit companies' requirements.

The application and success evaluation of steps 1 to 7 of the *k*-MORE methodology took place in a case study in real setting. The application was realistic in time and resources and therefore, the case study was an adequate method to evaluate the applicability of the methodology. The procedure presented two limitations for the complete application of the proposed steps of the *k*-MORE methodology. One limitation was the anonymity of the employees answering the *questionnaire of influencing factors*. It was a requirement established by the company in order to preserve the employee's privacy. However, it caused that the individual consideration required in step 3 "Analysing" for cases showing high variety in the factor's perception could not be conducted because the target employees to continue the analysis were unknown. Therefore, this aspect of the methodology could not be applied until the end. The second limitation was the time restriction for the case study. The case study concluded with the first filling of the *planning sheets* but the iterative process for the actions implementation that is proposed in steps 4 to 7 "Planning the Reuse Cycle" could not be completed. Since steps 4 to 7 "Planning the Reuse Cycle" were not finalised, the application of step 8 "Maintaining" was not possible. The success evaluation was done with a survey conducted among employees. The survey was well understood and provided useful results to evaluate different aspects of the *k*-MORE methodology in practice.

The application and success evaluation of the *k*-MORE approach for knowledge package and reuse took place in an interdisciplinary collaboration project conducted at the university. The creation of a KB containing knowledge from the project served to evaluate the feasibility of creating a KB as it was proposed. The applicability and success evaluation of the *k*-MORE approach was done in an experimental set-up. This method was selected because there was no suitable project (using similar knowledge and accessible for researchers) to perform a real application. A major limitation for the experiment was the lack of a user-friendly user interface for the software implementation. As a result, the approach could not be evaluated as it was conceptualised and it might have influenced the results of the evaluation both in the application and in the participants' opinion. A fully user-friendly software implementation is required for future evaluations.

6.2 **Discussion of Results**

The following Subsections present the discussion of the thesis results. Subsection 6.2.1 reflects on the research contribution. The contribution to industrial practice is discussed in Subsection 6.2.2. Subsection 6.2.3 presents the reflection on the limitations of the proposed support.

6.2.1 Research Contribution

This thesis provides a double research contribution: 1) the **improved theoretical understanding** to increase knowledge reuse in engineering design companies gained during DS; and 2) a new approach to **plan the knowledge reuse cycle** in engineering design companies.

The interviews with practitioners conducted in DS I contribute to answer *RQ1: What are the reasons for the lack of knowledge reuse in industry?*. The conclusions of this study served to

establish requirements for the support to be developed within this thesis but the sample was too small to provide general conclusions for the research community. The same thing happened with the exploratory design experiments. The results of both the interview study and the exploratory design experiments can be used to narrow down the focus for further research. For example, the interview study revealed that knowledge management methods are already extensively implemented in engineering design companies and therefore, future studies could focus on analysing in detail the inefficiencies in their current implementation.

The major research contribution to improve understanding of the phenomenon of knowledge reuse is the **Worker-Centred Model**. The WCM describes the processes experienced during knowledge reuse from the point of view of individuals (knowledge workers). Factors influencing those processes were allocated to the model after a systematic literature review and analysis. The effort in synthesis and the allocation of the factors to one unique model, facilitates the intuitive understanding of a large amount of hardly comparable literature results. Thus, the WCM provides a concrete answer for *RQ2: What are the individual influencing factors for knowledge reuse?* from a point of view that had not been systematically considered in literature until now. The WCM can be used by researchers as a reference model for the development of new approaches to support knowledge reuse.

The major research contribution to provide support to plan the knowledge reuse cycle is the ***k*-MORE methodology**. The *k*-MORE methodology supports the systematic planning of the knowledge reuse cycle from scratch, combining both knowledge personalisation and codification, considering and addressing differences in individuals' behaviours and perceptions. Existing support addresses specific knowledge reuse cases, as it focuses either on knowledge codification or personalisation, and it does not consider differences in individuals' behaviour and perception within the same company.

The most innovative aspect of the *k*-MORE methodology is the individualised analysis that is performed in **step 3 "Analysing"**. The rules for the analysis of the knowledge map concentrate the analysis criteria to the minimum required for planning the phases of the knowledge reuse cycle. The *tables for rules reflection* describe the implications for each phase of the Reuse Cycle of the results of applying each rule. There is no current approach that provides such a systematic analysis of the company's knowledge to fulfil the goal of planning the knowledge reuse cycle. The process for analysis of individual perceptions offers a new view on the application of knowledge management in general. It is the first approach that not only supports but also fosters the differentiation of groups and concrete individuals in the company in order to address them individually for the selection of methods to perform the knowledge reuse cycle. The customised selection of methods increases the acceptance of methods by designers.

Furthermore, the *k*-MORE methodology provides numerous models and measures that could be applied to other approaches dealing with knowledge management. A significant contribution is the ***methods catalogue*** which provides a collection of methods to plan the knowledge reuse cycle. Other authors had created collections of knowledge management methods but this catalogue presents two main differences: 1) it focuses on methods for knowledge reuse in engineering design and therefore, it includes specific methods to manage design knowledge; and 2) it proposes an innovative structure for the methods characterisation.

The structure allows the consideration of methods under new points of view such as their ability to address factors influencing knowledge reuse for individuals.

The ***k*-MORE approach** for **knowledge package** and **reuse** offers a promising way of structuring the company's KB and combining knowledge search methods. A complete and user-friendly software implementation of the approach is required to evaluate its applicability. The defined characteristics of design situations can be used in other approaches.

The five **case studies** provided feedback to adapt the initial proposals for their practical application. Some findings were used in this thesis to design the *k*-MORE methodology and other findings can support further research.

6.2.2 Industrial Contribution

The industrial contribution of this thesis is the ***k*-MORE methodology**. The methodology constitutes a **practical guide** for knowledge management practitioners to plan the methods to perform the knowledge reuse cycle in engineering design companies from scratch. *k*-MORE is applicable without regard to the current implementation of knowledge management methods in the company, goals for knowledge reuse or understanding of what is "knowledge". Thus, the *k*-MORE methodology is widely applicable and adaptable to the company's situation. A feasible focus for the methodology application and the planning of the knowledge reuse cycle is defined in step 1 "Defining Goals". Furthermore, the methodology considers both knowledge personalisation and codification approaches at the same time, which is a realistic approach in practice. The processes, templates and support documentation that complement each step of the methodology facilitate its use in practice. The users of the methodology are managers or knowledge management practitioners. Designers and other employees are the users of the methods and actions selected after going through the methodology and they are also the input providers for the methodology.

Some building blocks of the *k*-MORE methodology deserve a special mention due to their practical-oriented design. The *reflection sheets* help practitioners to understand and reflect on the results of analysing the knowledge map in a user-friendly and direct way. The process for analysis of individual perceptions is directly applicable in form of a questionnaire that has been especially refined and designed for its application in industry. The presentation and analysis of results using boxplots and the *analysis flowchart* help practitioners to make conclusions systematically. The *methods catalogue* and *methods' descriptions* provide a fast and clear overview of existent methods contributing to knowledge reuse. Usually companies do not possess this information. The catalogue and descriptions present it in a structured and summarised way. The presentation of potential methods to plan the knowledge reuse cycle using the *methods' portfolios* offers a base for decision-making by company's experts.

Learnings from the case studies helped to establish the context and conditions required for the successful implementation of the *k*-MORE methodology in practice. The case studies showed the importance of investing resources in terms of availability of employees and time. The implication of company's managers during the whole application of the methodology is also key for its success.

6.2.3 Limitations of the Proposed Support

The proposed support was developed to be widely applicable and adaptable to the company's situation. However, the *k*-MORE methodology might not be applicable under certain conditions, it requires some prerequisites for its application and it leaves some aspects out of scope.

The feasibility of the methodology application is assured through focusing on a **reduced analysis area**. Managing large amounts of knowledge or considering numerous departments at the same time would complicate the individual analysis and the amount of actions and *planning sheets* generated could be too much to be handled properly. The application to large areas of the company could be done progressively starting from a detailed area and then extending the analysis. However, this case has not been considered or evaluated during this thesis.

The application of the methodology requires investing **time** and **resources** in terms of availability of employees for the steps proposed in the methodology. Investing time especially in the first steps of the methodology is necessary given the general initial situation and the need to achieve a common understanding of the meaning of "knowledge" for each company. The amount of time and discussion required in those first steps of *k*-MORE should not be underestimated. Company's managers should constantly support and communicate the goals of the methodology during its application.

Some corporate requirements such as **data secrecy** or preserving the **anonymity** of employees are shortcomings for the fully implementation of the *k*-MORE methodology. Access to company's knowledge is required to analyse it in detail. In order to perform the analysis of individual preferences, the employees participating in the *questionnaire of influencing factors* have to be identified so phases of the knowledge reuse cycle can be planned individual-specific.

The detailed **implementation** of the **methods** selected with the *k*-MORE methodology is **out of the scope** of this thesis. The *method description sheets* provide an introduction to understand the methods but each selected method should be further investigated and implemented according to the users and application context. Concrete knowledge representations and documentation forms have to be defined in order to assure the quality of the knowledge reused.

7. Summary and Outlook

This Chapter provides a thesis summary in Section 7.1 and the outlook suggesting points for future research in Section 7.2.

7.1 Summary

The objective of this thesis is **improving theoretical understanding** and **developing practical support** to increase **knowledge reuse** in engineering design companies. This objective is established in order to solve the problem which is identified at the beginning of this research work: despite the existence of the knowledge management discipline, reality is that knowledge reuse is not a common practice in engineering design companies. The Design Research Methodology (DRM) is used as research procedure for the research work.

Three methods are applied in the Descriptive Study I (DS I) to increase the understanding on the phenomenon of knowledge reuse in practice. An interview study with practitioners helps to understand the reasons for the lack of knowledge reuse in practice. A literature-based model (Worker Centred Model or WCM) is created to depict the factors influencing knowledge reuse for individuals. Two exploratory design experiments are conducted to observe individuals' needs and behaviours during the reuse of knowledge from knowledge bases. The results obtained during DS I are used to define the requirements for the support to be developed.

The approach of this thesis for increasing knowledge reuse in engineering design companies is to support the planning of the knowledge reuse cycle. Given the extensive scope of the aim and the need of guidance for practitioners, the type of support selected is a methodology. The proposed methodology is developed in the Prescriptive Study (PS) and it receives the name of ***k*-MORE**, which stands for **k**nowledge **M**anagement for **O**ptimised **RE**use. The steps of the *k*-MORE methodology support the following activities for the engineering design company: definition of company's goals for knowledge reuse, acquisition and visualisation of company's knowledge, analysis of company's knowledge map and individual perceptions of knowledge reuse, selection of methods to prepare the phases of the knowledge reuse cycle, and planning how to maintain the selected methods in daily work. Additionally to the *k*-MORE methodology, this thesis proposes an approach for knowledge package and reuse within a knowledge base, combining various visualisations and search methods. The goal of this approach is to fulfil the requirements for support concerning the "Reusing" phase of the knowledge reuse cycle that other methods are unable to fulfil. The integration of this approach is optional during the application of the *k*-MORE methodology.

The evaluation of support takes place in the Descriptive Study II (DS II). Three case studies are part of the support evaluation and provide feedback to improve support. Two case studies are conducted for the application and success evaluation of the *k*-MORE methodology. Steps 1 to 7 of the *k*-MORE methodology are applied in a real industrial case study. The *k*-MORE methodology turned out to be **applicable**, and the results of the methodology are considered **useful** by practitioners. Some aspects of the methodology could not be applied in real practice and their evaluation remains an open point for further research. A knowledge base is created

within a research collaboration project in order to evaluate the optional approach for knowledge package and reuse. The approach for knowledge package and reuse is evaluated in an experimental set-up. The experiment shows that the approach contributes to increase the reuse of documented knowledge compared to a traditional way of packaging and reusing. However, a fully **user-friendly software implementation** is **required** for a complete evaluation of the approach.

7.2 Outlook

The *k*-MORE methodology provides support to plan the knowledge reuse cycle in engineering design companies. The aspect of planning the **maintenance of the knowledge reuse cycle** is considered in Step 8 "Maintaining". This step is only initially addressed within this thesis. Future research can focus on developing and evaluating a systematic procedure for this step. Especial attention should be given to the integration of the maintain measures in daily work and the distribution of activities and responsibilities between knowledge managers and employees.

The initial **evaluation** of support conducted in this thesis can be extended with further case studies. Those case studies can show different application scenarios that could be generalised to design versions of the *k*-MORE methodology adapted to them. The aspects that differentiate the application scenarios should be investigated. The approach for knowledge package and reuse proposed within this thesis can also be evaluated in real case studies. A prerequisite for the evaluation is the implementation in a user-friendly software.

The ***methods catalogue*** provides a collection of methods to plan the phases of the knowledge reuse cycle. The proposed characterisation of methods from the catalogue was done based on the judgement of researchers. There is a need of investigating if the characterisation of methods can be generalised or if each company should create its own characterisation. In case the characterisation can be generalised, future research should focus on validating the proposed characterisation. If the characterisation of methods from the catalogue needs to be company-specific, future research should focus on developing a procedure for companies to perform this activity. Such procedure should be then integrated in the *k*-MORE methodology.

The automation of steps of the *k*-MORE methodology by means of **software** support could be considered in future research. The methodology has a continuous flow of input-output between steps and currently the knowledge manager is responsible of preparing the outputs of each step to be used as inputs in upcoming steps of the methodology. A software could do this automatically and reduce the effort for the knowledge manager. The *methods' portfolios* showing the potential methods for selection to plan the knowledge reuse cycle would be created automatically based on the results of previous steps of the methodology. A software implementation would also allow to conduct sensitivity analyses and create rapidly different scenarios of potential methods from the portfolios as basis to design the *planning sheets*.

All in all, the proposed support was designed for planning the knowledge reuse cycle of engineering design companies. Future research can investigate how to adapt the *k*-MORE methodology to plan the knowledge reuse cycle in **other types of companies**. The current methodology considers the company from a general point of view and therefore, it seems

applicable to other types of companies without major conceptual changes. The focus for the adaptation to other fields should be on identifying the different types of knowledge to deal with and the different methods to plan the knowledge reuse cycle that should be included in the *methods catalogue*.

8. References

Aasland, K. E. & Blankenburg, D. (2012). An analysis of the use and properties of the Obeya. In 18th International Conference on Engineering, Technology and Innovation. ICE 2012. Munich, Germany, 18-20 June. IEEE.

Ackoff, R. L. (1989). From data to wisdom. *Journal of Applied Systems Analysis* (16), pp. 3–6.

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), pp. 475–492. DOI: 10.1080/09544820841000170843O.

Ahmed-Kristensen, S. & Vianello, G. (2015). A model for reusing service knowledge based on an empirical case. *Res Eng Design* 26 (1), pp. 57–76. DOI: 10.1007/s00163-014-0184-6.

Aira Palomares, J. L. (2017). Development of a Knowledge Base for Knowledge Reuse in Design Projects - Design of the MVG eTrike. Master Thesis. Technical University of Munich, Munich, Germany.

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes* 50 (2), pp. 179–211. DOI: 10.1016/0749-5978(91)90020-T.

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

Amine, M. M. & Ahmed-Nacer, M. (2011). An Agile Methodology For Implementing Knowledge Management Systems: A Case Study In Component-Based Software Engineering. *International Journal of Software Engineering and Its Applications* 5 (4), pp. 159–170.

Argyris, C. (1992). On Organizational Learning. Cambridge, USA, Oxford, UK: Blackwell.

Baxter, D., Gao, J., Case, K., Harding, J., Young, B., Cochrane, S. & Dani, S. (2007). An engineering design knowledge reuse methodology using process modelling. *Research in Engineering Design* 18 (1), pp. 37–48. DOI: 10.1007/s00163-007-0028-8.

Baxter, D., Gao, J., Case, K., Harding, J., Young, B., Cochrane, S. & Dani, S. (2008). A framework to integrate design knowledge reuse and requirements management in engineering design. *Robotics and Computer-Integrated Manufacturing* 24 (4), pp. 585–593. DOI: 10.1016/j.rcim.2007.07.010.

Becerra-Fernandez, I. & Sabherwal, R. (2014). Knowledge Management: Systems and Processes. New York, USA: Routledge.

Beul, M. (2018). Analyse der Wissensverwendung im Rahmen des Entwicklungsprozesses von SCHÜCO. Semester Thesis. Technical University of Munich, Munich, Germany.

Binney, D. (2001). The knowledge management spectrum - understanding the KM landscape. *Journal of Knowledge Management* 5 (1), pp. 33–42. DOI: 10.1108/13673270110384383.

Blessing, L. T. M. & Chakrabarti, A. (2009). DRM, a Design Research Methodology. London: Springer London.

Blessing, L. T. M. & Wallace, K. (1998). Supporting the Knowledge Life-Cycle. In Kluwer Academic Publishers (Ed.) Knowledge Intensive Computer Aided Design. Third Workshop on Knowledge Intensive CAD. Tokyo, Japan, 1-4 December, pp. 21–38.

Bodrow, W. (2006). Knowledge management in small and medium-sized enterprises. In Kesheng Wang, George L. Kovacs, Michael Wozny, Minglun Fang (Eds.) Knowledge Enterprise: Intelligent Strategies in Product Design, Manufacturing, and Management. International Federation of Information Processing. Shanghai, China, pp. 41–53.

Buchanan, S. & Gibb, F. (2007). The information audit. Role and scope. *International Journal of Information Management* 27 (3), pp. 159–172. DOI: 10.1016/j.ijinfomgt.2007.01.002.

Burnett, S., Illingworth, L. & Webster, L. (2004). Knowledge auditing and mapping: a pragmatic approach. *Knowledge and Process Management* 11 (1), pp. 25–37. DOI: 10.1002/kpm.194.

Carey, E., Culley, S., McAlpine, H., Weber, F. & Xie, Y. (2012). Key issues in the take-up of knowledge management interventions in engineering design. In D. Marjanović, Mario Štorga, N. Pavković, N. Bojcetic (Eds.) 12th International Design Conference. DESIGN 2012. Dubrovnik, Croatia, 21-24 May, pp. 1405–1414.

Carro Saavedra, C., Fernandez Miguel, R. & Lindemann, U. (2015). A worker-centered model to understand the factors influencing knowledge application. In K. Seta, T. Watanabe (Eds.) Proceedings of the 11th International Conference on Knowledge Management (ICKM). Osaka, Japan, 04-06 November.

Carro Saavedra, C. & Lindemann, U. (2015). Increasing the Amount of Knowledge Reuse from Engineering Design Repositories. In 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management. Lisbon, Portugal, 12-14 November.

Carro Saavedra, C. & Lindemann, U. (2017). k-MORE - A Methodology to Manage Documented Knowledge for Reuse. In Anja Maier, Stanko Škec, Harrison Kim, Michael Kokkolaras, Josef Oehmen, Georges Fadel et al. (Eds.) 21st International Conference on Engineering Design (ICED17), pp. 151–160.

Carro Saavedra, C., Morales Quiles, J. & Lindemann, U. (2017a). Characteristics of Design Situations Influencing the Knowledge to Reuse. In R&D Management Conference 2017. Leuven, Belgium, 1-5 July.

Carro Saavedra, C., Serrano Villodres, T. & Lindemann, U. (2017b). Review and Classification of Knowledge in Engineering Design. In Amaresh Chakrabarti, Debkumar Chakrabarti (Eds.) Proceedings of the 6th International Conference on Research into Design (ICoRD'17). Research into Design for Communities, vol. 2. 2 volumes: Springer, pp. 617–627.

Chandrasegaran, S. K., Ramani, K., Sriram, R. D., Horváth, I., Bernard, A., Harik, R. F. & Gao, W. (2013). The evolution, challenges, and future of knowledge representation in product design systems. *Computer-Aided Design* 45 (2), pp. 204–228. DOI: 10.1016/j.cad.2012.08.006.

Chirumalla, K. (2013). Development of a Methodology for Lessons Learned Practice. From post-project learning to continuous process-based learning. Doctoral Dissertation. Lulea University of Technology, Lulea, Sweden. Innovation and Design.

Choi, S. Y., Lee, H. & Yoo, Y. (2010). The Impact of Information Technology and Transactive Memory Systems on Knowledge Sharing, Application, and Team Performance: a Field Study. *MIS Quarterly* 34 (4), pp. 855–870.

Choy, S. Y., Lee, W. B. & Cheung, C. F. (2004). A Systematic Approach for Knowledge Audit Analysis: Integration of Knowledge Inventory, Mapping and Knowledge Flow Analysis 10 (6), pp. 674–682.

Chua, A. Y. K., Lam, W. & Majid, S. (2006). Knowledge reuse in action: the case of CALL. *Journal of Information Science* 32 (3), pp. 251–260. DOI: 10.1177/0165551506064384.

Coffey, J. W. & Hoffman, R. R. (2003). Knowledge modeling for the preservation of institutional memory. *Journal of Knowledge Management* 7 (3), pp. 38–52. DOI: 10.1108/13673270310485613.

Collins. Collins English Dictionary.

COVEO (2014). The Knowledge Rework Report. COVEO. Available online at https://www.coveo.com/en/company/news-releases/2014/new-study-reveals-knowledge-workers-mostly-do-rework, checked on 11/11/2016.

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* 2007 (8), pp. 1285–1298. DOI: 10.1243/09544054JEM580.

d'Albert, H., Carro Saavedra, C. & Maurer, M. (2015). Business Knowledge Development using Knowledge Maps. In International Conference on Business and Internet - Fall Session (ICBI 2015-Fall), 10-12 November. Nagoya, Japan.

Dalkir, K. (2005). Knowledge Management in Theory and Practice: Elsevier.

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. DOI: 10.1243/09544054JEM651.

Davenport, T. H. & Prusak, L. (2000). Working Knowledge: How Organizations Manage what They Know: Harvard Business School Press.

Dehghani, R. & Ramsin, R. (2015). Methodologies for developing knowledge management systems: an evaluation framework. *Journal of Knowledge Management* 19 (4), pp. 682–710. DOI: 10.1108/JKM-10-2014-0438.

Demian, P. & Fruchter, R. (2009). Effective visualisation of design versions: visual storytelling for design reuse. *Research in Engineering Design* 19 (4), pp. 193–204.

Dick, M., Nebauer-Herzig, K. & Termath, W. (2016). Triad conversation. In M. Dick, W. Marotzki, H. Mieg (Eds.) Handbuch Professionsentwicklung. Bad Heilbrunn, Germany: Julius Klinkhardt, pp. 331–341.

Diebold, T. E. (2016). Wissensmanagement: Wissensdokumentation, –nutzung und konzeptionelle Gestaltung der Wissensbasis bei ARRI. Master Thesis. Technical University of Munich, Munich, Germany.

Dittmer, G. (1995). Managen mit Methode. Instrumente für individuelle Lösungen: Gabler.

Duffy, S. M., Duffy, A. H. B. & MacCallum, K. J. (1995). A Design Reuse Model. In 10th International Conference on Engineering Design. ICED 95. Praha, Check Republic, 22-24 August, pp. 490–495.

Earl, M. (2000). Every business in an information business. In Donald A. Marchand, Thomas H. Davenport, Tim Dickson (Eds.) Mastering Information Management, pp. 16–22.

Earl, M. (2001). Knowledge Management Strategies: Toward a Taxonomy. *Journal of Management Information Systems* 18 (1), pp. 215–233. DOI: 10.1080/07421222.2001.11045670.

Eppler, M. J. (2004). Making Knowledge Visible through Knowledge Maps: Concepts, Elements, Cases. In Clyde W. Holsapple (Ed.) Handbook on Knowledge Management 1. Knowledge Matters. Heidelberg Berlin: Springer, pp. 189–205.

Eppler, M. J. & Burkhard, R. A. (2007). Visual representations in knowledge management: framework and cases. *Journal of Knowledge Management* 11 (4), pp. 112–122. DOI: 10.1108/13673270710762756.

Fernandez Miguel, R. (2015). Knowledge Management in New Product Development - Analysis of the Factors Influencing the Success in Real Praxis. Master Thesis. Technical University of Munich, Munich, Germany.

Fernandez Miguel, R., Carro Saavedra, C. & Lindemann, U. (2016). Factors Influencing Knowledge Application. A Review from the Knowledge Management Field. In D. Marjanović, M. Storga, N. Pavković, N. Bojcetic, Stanko Škec (Eds.) 14th International Design Conference. DESIGN 2016, 16-19 May. Glasgow: Design Society, pp. 985–996.

Firdaus, M., Wang, H., Qin, H. & Liu, Y. (2015). Digital repository for design knowledge reuse. In C. Weber, S. Husung, M. Cantamessa, G. Cascini, D. Marjanovic, F. Montagna (Eds.) 20th International Conference on Engineering Design. ICED 2015. Milan, Italy, 27-30 July.

Frappaolo, C. (2008). Implicit Knowledge. *Knowledge Management Research & Practice* 6 (1), pp. 23–25.

Frey-Luxemburger, M. (2014). Wissensmanagement Grundlagen und praktische Anwendung. Wiesbaden, Germany: Springer Vieweg.

Fruchter, R. & Demian, P. (2002). CoMem: Designing an interaction experience for reuse of rich contextual knowledge from a corporate memory. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 16 (Issue 3), pp. 127–147.

Fruchter, R., Reiner, K., Leifer, L. & Toye, G. (1998). VisionManager: A Computer Environment for Design Evolution Capture. *Concurrent Engineering* 6 (1), pp. 71–84.

Gericke, K. & Blessing, L. T. M. (2012). An analysis of design process models across disciplines. In D. Marjanović, Mario Štorga, N. Pavković, N. Bojcetic (Eds.) 12th International Design Conference. DESIGN 2012. Dubrovnik, Croatia, 21-24 May.

Ghose, M. & Jambhekar, A. (2003). Networks, Digital Libraries and Knowledge Management: Trends & Developments. *DESIDOC Bulletin of Information Technology* 23 (5), pp. 3–12. DOI: 10.14429/dbit.23.5.3607.

Gold, A. H., Malhotra, A. & Segars, A. H. (2001). Knowledge Management: An Organizational Capabilities Perspective. *Journal of Management Information Systems* 18 (1), pp. 185–214.

Goncalves, M. (2012). Learning Organizations: Turning Knowledge Into Actions. New York: Business Expert Press.

Grant, R. M. (1996). Toward a Knowledge-based Theory of the Firm. *Strategic Management Journal* 17 (Special Issue), pp. 109–122. DOI: 10.1002/smj.4250171110.

Gressgård, L. J. (2014). Knowledge exchange systems usage. The importance of content contribution and application in distributed environments. *Journal of Knowledge Management* 18 (2), pp. 329–341. DOI: 10.1108/JKM-09-2013-0339.

Gretsch, S., Mandl, H. & Schätz, R. (2012). Implementation Process of a Knowledge Management Initiative: Yellow Pages. In H. Tse Hou (Ed.) New Research on Knowledge Management Models and Methods. Taiwan: IntechOpen, pp. 311–332.

Heisig, P., Caldwell, N. H. M., Grebici, K. & Clarkson, P. J. (2010). Exploring knowledge and information needs in engineering from the past and for the future - results from a survey. *Design Studies* 31, pp. 499–532.

Hicks, B. J., Culley, S. J., Allen, R. D. & Mullineux, G. (2002). A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design. *International Journal of Information Management* 22 (4), pp. 263–280. DOI: 10.1016/S0268-4012(02)00012-9.

Hill, C. W. L., Jones, G. R. & Schilling, M. A. (2015). Strategic Management Theory. Stamford, USA: Cengage Learning.

Howard, T. J., Culley, S. & Dekoninck, E. A. (2011). Reuse of ideas and concepts for creative stimuli in engineering design. *Journal of Engineering Design* 22 (8), pp. 565–581. DOI: 10.1080/09544821003598573.

Jänsch, J. & Birkhofer, H. (2006). The development of the guideline VDI 2221 - The change of direction. In D. Marjanović (Ed.) 9th International Design Conference. DESIGN 2006. Dubrovnik, Croatia, 15-18 May, pp. 45–52.

Jiang, Y., Yan, Y., Dong, Y., Wang, G. & Hao, J. (2015). A method of multidimensional knowledge push for product designers. In Proceedings of the 2015 International Conference

on Education Technology, Management and Humanities Science. ETMHS 2015. Shaanxi, China, 21-22 March, pp. 869–872.

Kamara, J. M., Anumba, C. J. & Carrillo, P. M. (2002). A CLEVER approach to selecting a knowledge management strategy. *International Journal of Project Management* 20 (3), pp. 205–211.

Kaufman, R., Rojas, A. M. & Mayer, H. (1993). Needs assessment: a user's guide. New Jersey: Englewood Cliffs.

King, W. R. (2009). Knowledge Management and Organisational Learning. In William R. King (Ed.) Knowledge Management and Organizational Learning. Annals of Information Systems. New York, USA: Springer (4), pp. 3–13.

Kohn, A. (2014). Entwicklung einer Wissensbasis für die Arbeit mit Produktmodellen. Doctoral Dissertation. Technical University of Munich, Munich, Germany.

Langenhan, A. (2012). Wissensmanagement: Leitfaden für die Einführung von Wissensmanagement in Unternehmen. Hamburg, Germany: Diplomica.

Lauer, W. M. (2010). Integrative Dokumenten- und Prozessbeschreibung in dynamischen Produktentwicklungsprozessen. Doctoral Dissertation. Technical University of Munich, Munich, Germany.

Lehner, F. (2012). Wissensmanagement – Grundlagen, Methoden und technische Unterstützung. Munich, Germany: Hanser.

Li, L., Qin, F., Gao, S. & Liu, Y. (2014). An approach for design rationale retrieval using ontology-aided indexing. *Journal of Engineering Design* 25 (7-9), pp. 259–279. DOI: 10.1080/09544828.2014.969690.

Li, M. & Gao, F. (2003). Why Nonaka highlights tacit knowledge. A critical review. *Journal of Knowledge Management* 7 (4), pp. 6–14. DOI: 10.1108/13673270310492903.

Liebowitz, J., Rubenstein-Montano, B., McCaw, D., Buchwalter, J., Browning, C., Newman, B. & Rebeck, K. (2000). The Knowledge Audit. *Knowledge and Process Management* 7 (1), pp. 3–10.

Lindemann, U. (2009). Methodische Entwicklung technischer Produkte. Methoden flexibel und situationsgerecht anwenden. Berlin, Germany: Springer.

Lindemann, U. & Maurer, M. (2007). Facing Multi-Domain Complexity in Product Development. In Frank-Lothar Krause (Ed.) The Future of Product Development. Proceedings of the 17th CIRP Design Conference. Berlin Heidelberg: Springer, pp. 351–361.

Liu, S., McMahon, C. & Bracewell, R. H. (2007). A web-based semantic information retrieval system to support decision-making in collaborative design. In J.-C. Bocquet (Ed.) 16th International Conference on Engineering Design. ICED 2007. Paris, France, 28-31 July.

Long, D. W. de & Fahley, L. (2000). Diagnosing Cultural Barriers to Knowledge Management. *Academy of Management Executive* 14 (4), pp. 113–127.

Lotti Oliva, F. (2014). Knowledge management barriers, practices and maturity model. *Journal of Knowledge Management* 18 (6), pp. 1053–1074. DOI: 10.1108/JKM-03-2014-0080.

Lucas, L. (2018). Wissenserfassung, -darstellung und -analyse im Rahmen des Entwicklungsprozesses von SCHÜCO. Master Thesis. Technical University of Munich, Munich, Germany.

Maier, R. (2007). Knowledge Management Systems. Information and Communication Technologies for Knowledge Management. Berlin Heidelberg: Springer.

Maier, R. & Remus, U. (2002). Defining process-oriented knowledge management strategies. *Knowledge and Process Management* 9 (2), pp. 103–118. DOI: 10.1002/kpm.136.

Majchrzak, A., Wagner, C. & Yates, D. (2013). The Impact of Shaping on Knowledge Reuse for Organizational Improvement with Wikis. *MISQ* 37 (2), pp. 455–469. DOI: 10.25300/MISQ/2013/37.2.07.

Manchester Metropolitan University (2019). Job Shadowing Guidelines. Available online at https://www2.mmu.ac.uk/media/mmuacuk/content/documents/human-resources/a-z/guidance-procedures-and-handbooks/Job_Shadowing_Guidelines.pdf, checked on 3/7/2019.

Mänken, E. W. (2009). Mitarbeiterzeitschriften noch besser machen: VS Verlag für Sozialwissenschaften.

Manohar Singh, R. & Gupta, M. (2014). Knowledge management in teams. Empirical integration and development of a scale. *Journal of Knowledge Management* 18 (4), pp. 777–794. DOI: 10.1108/JKM-11-2013-0450.

Markides, C. (1998). Strategic Innovation in Established Companies. *Sloan Management Review* 30 (3), pp. 31–42.

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.

Martin Cruz, N., Martin Perez, V. & Trevilla Cantero, C. (2009). The influence of employee motivation on knowledge transfer. *Journal of Knowledge Management* 13 (6).

Maurer, M. (2011). Systematic knowledge transfer based on knowledge correlations. In A. Chakrabarti (Ed.) Proceedings of the 3rd International Conference on Research into Design (ICoRD'11). ICoRD'11. Bangalore, India, 10-12 January, pp. 320–328.

Maurer, M. (2014). Unternehmenswissen systematisch entwickeln. Edited by bayme vbm. Technical University of Munich. Munich, Germany.

McMahon, C., Lowe, A. & Culley, S. (2004). Knowledge management in engineering design: personalization and codification. *Journal of Engineering Design* 15 (4), pp. 307–325. DOI: 10.1080/09544820410001697154.

Merriam-Webster. Merriam-Webster's Dictionary of English Usage.

Milton, N. (2010). The Lessons Learned Handbook: Practical Approaches to Learning from Experience. Oxford, UK: Chandos Publishing.

Modoni, G. E., Caldarola, E. G. & Walter Terkaj, M. S. (2015). The Knowledge Reuse in an Industrial Scenario: A Case Study. In The Seventh International Conference on Information, Process, and Knowledge Management. eKNOW 2015. Lisbon, Portugal, 22-27 February, pp. 66–71.

Montesa Rausell, P. (2016). Development of a knowledge base for knowledge reuse in design projects – innovative ideas for the MINI interior. Master Thesis. Technical University of Munich, Munich, Germany.

Newell, A. (1982). The knowledge level. *Artificial Intelligence* 18 (1), pp. 87–127. DOI: 10.1016/0004-3702(82)90012-1.

Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science* 5 (1), pp. 14–37. DOI: 10.1287/orsc.5.1.14.

Nonaka, I. & Takeuchi, H. (1995). The Knowledge-Creating Company: Oxford University Press.

Nonaka, I. & von Krogh, G. (2009). Tacit Knowledge and Knowledge Conversion: Controversy and Advancement in Organizational Knowledge Creation Theory. *Organization Science* 20 (3), pp. 635–652. DOI: 10.1287/orsc.1080.0412.

North, K. & Kumta, G. (2014). Knowledge Management: Value Creation Through Organizational Learning: Springer International Publishing.

O'Dell, C. & Grayson, C. J. (1998). If only we knew what we know. The transfer of internal knowledge and best practice. New York, USA: Simon & Schuster.

Orth, R., Voigt, S. & Kohl, I. (2011). Praxisleitfaden Wissensmanagement. Prozessorientiertes Wissensmanagement nach dem ProWis-Ansatz einführen. Edited by Fraunhofer Verlag. Fraunhofer-Institut. Stuttgart.

Oshri, I. (2006). Knowledge Reuse. In David G. Schwartz (Ed.) Encyclopedia of knowledge management. Hershey PA: Idea Group Reference, pp. 487–492.

Pahl, G., Beitz, W., Feldhusen, J. & Grote, K. H. (2007). Engineering Design. A Systematic Approach. London, UK: Springer.

Paramasivan, T. (2003). Knowledge Audit. *The Chartered Accountant* 52 (5), pp. 498–506.

Park, J. (2011). Developing a knowledge management system for storing and using the design knowledge acquired in the process of a user-centered design of the next generation information appliances. *Design Studies* 32 (5), pp. 482–513.

Perez Soltero, A., Barcelo Valenzuela, M., Sanchez Schmitz, G., Martin Rubio, F., Palma Mendez, J. T. & Alberto Vanti, A. (2007). A Model and Methodology to Knowledge Auditing Considering Core Processes. *The Icfai Journal of Knowledge Management* 5 (1), pp. 7–23.

Pflieger, L. (2017). Evaluation of the *k*-MORE proposals for Knowledge Reuse in Design Projects - Design of the MVG eTrike. Semester Thesis. Technical University of Munich, Munich, Germany.

Polanyi, M. (1966). The tacit dimension. New York: Doubleday & Company.

Probst, G., Raub, S. & Romhardt, K. (2012). Wissen managen. Wie Unternehmen ihre wertvollste Ressource optimal nutzen. Wiesbaden: Gabler.

Ranjbarfard, M., Aghdasi, M., López-Sáez, P. & Navas López, J. E. (2014). The barriers of knowledge generation, storage, distribution and application that impede learning in gas and petroleum companies. *Journal of Knowledge Management* 18 (3), pp. 494–522. DOI: 10.1108/JKM-08-2013-0324.

Rego, A., Pinho, I., Pedrosa, J. & Pina e Cunha, M. (2009). Barriers and Facilitators to Knowledge Management in University Research Centers: An Exploratory Study. *Management Research: Journal of the Iberoamerican Academy of Management* 7 (1), pp. 33–47.

Reinmann, G. (2009). Studientext Wissensmanagement. Philosophisch-Sozialwissenschaftliche Fakultät. Universtät Augsburg. Augsburg.

Reinmann-Rothmeier, G. (2001). Wissen managen: Das Münchener Modell. Open Access LMU. Available online at https://doi.org/10.5282/ubm/epub.239.

Reinmann-Rothmeier, G. & Mandl, H. (1998). Multiple Wege zur Förderung von Wissensmanagement in Unternehmen. Ludwig-Maximilians-Universität, checked on 10/8/2018.

Rubenstein-Montano, B., Liebowitz, J., Buchwalter, J., McCaw, D., Newman, B. & Rebeck, K. (2001). SMARTVision: a knowledge-management methodology. *Journal of Knowledge Management* 5 (4), pp. 300–310. DOI: 10.1108/13673270110411724.

Salas de Arribas, G. (2015). Development of a Knowledge Base to Support Junior Product Developers. Master Thesis. Technical University of Munich, Munich, Germany.

Schaal, S. (1991). Integrierte Wissensverarbeitung mit CAD - Am Beispiel der konstruktionsbegleitenden Kalkulation. Doctoral Dissertation. Technical University of Munich, Munich, Germany.

Schacht, S. & Maedche, A. (2016). A Methodology for Systematic Project Knowledge Reuse. In Liana Razmerita, Gloria Phillips-Wren, Lakhmi C. Jain (Eds.) Innovations in Knowledge Management. The Impact of Social Media, Semantic Web and Cloud Computing: Springer.

Schenkl, S. A. (2015). Wissensorientierte Entwicklung von Produkt-Service-Systemen. Doctoral Dissertation. Technical University of Munich, Munich, Germany.

Serrano Villodres, T. (2016). Review and Classification of Types of Knowledge in Engineering Design. Master Thesis. Technical University of Munich, Munich, Germany.

Sharma, R. & Chowdhury, N. (2007). On The Use of A Diagnostic Tool for Knowledge Audits. *Journal of Knowledge Management Practice* 8 (4).

Sim, S. K. & Duffy, A. H. B. (2003). Towards an ontology of generic engineering design activities. *Research in Engineering Design* 14 (4), pp. 200–223. DOI: 10.1007/s00163-003-0037-1.

Sivaloganathan, S. & Shahin, T. M. M. (1999). Design reuse: an overview. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, pp. 641–654.

Štorga, M., Andreasen, M. M. & Marjanović, D. (2010). The design ontology: foundation for the design knowledge exchange and management. *Journal of Engineering Design* 21 (4), pp. 427–454. DOI: 10.1080/09544820802322557.

Sung, R., Ritchie, J. M., Rea, H. J. & Corney, J. (2011). Automated design knowledge capture and representation in single-user CAD environments. *Journal of Engineering Design* 22 (7), pp. 487–503. DOI: 10.1080/09544820903527187.

Szulanski, G. (1996). Exploring internal stickiness: impediments to the transfer of best practice within the firm. *Strategic Management Journal* 17, pp. 27–43.

Ulrich, K. D. & Eppinger, S. D. (2003). Product Design and Development. New York, USA: McGraw Hill.

van Aken, J. E. (2005). Valid knowledge for the professional design of large and complex design processes. *Design Studies* 26 (4), pp. 379–404.

van Eck, D. (2011). Supporting design knowledge exchange by converting models of functional decomposition. *Journal of Engineering Design* 22 (11-12), pp. 839–858. DOI: 10.1080/09544828.2011.603692.

van Eck, D. (2015). Dissolving the 'problem of the absent artifact': Design representations as means for counterfactual understanding and knowledge generalisation. *Design Studies* 39, pp. 1–18.

VDI (1993). Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte. VDI 2221.

VDI (2004). Entwicklungsmethodik für mechatronische Systeme. VDI 2206.

Vianello, G. (2011). Transfer and Reuse of Knowledge from the Service Phase of Complex Products. Doctoral Dissertation. Technical University of Denmark. Department of Management Engineering. Available online at ISBN 978-87-92706-24-9.

Vijaykumar, G. & Chakrabarti, A. (2008). Understanding the Knowledge Needs of Designers During Design Process in Industry. *Journal of Computing and Information Science in Engineering* 8 (1), pp. 1–9. DOI: 10.1115/1.2840776.

Vijaykumar, G. & Chakrabarti, A. (2010). Assessment of Design Tools for Knowledge Capture and Reuse. In Peter Heisig, P. J. Clarkson, Sandor Vajna (Eds.) Modelling and Management of Engineering Processes. London, UK: Springer, pp. 141–150.

Vijaykumar, G. & Chakrabarti, A. (2013). Designers' Perception on Information Processes. In Amaresh Chakrabarti, Raghu V. Prakash (Eds.) Proceedings of the 4th International Conference on Research into Design (ICoRD'13). Global Product Development: Springer, pp. 785–796.

von Krogh, G. (1998). Care in Knowledge Creation. *California Management Review* 40 (3), pp. 133–153. DOI: 10.2307/41165947.

Webster, J. & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly* 16 (2), pp. 13–23.

Wickel, M. C., Schenkl, S. A., Schmidt, D. M., Hense, J., Mandl, H. & Maurer, M. (2013). Knowledge structure maps based on Multiple Domain Matrices. *The Journal of Innovation Impact* 5 (1), pp. 5–16.

Wiig, K. M. (1995). Knowledge Management Methods. Practical Approaches to Managing Knowledge. Arlington, Texas: Schema Press.

Wildner, S. (2011). Problemorientiertes Wissensmanagement. Eine Neukonzeption des Wissensmanagements aus konstruktivistischer Sicht. Doctoral Dissertation. University of Passau, Passau, Germany.

Williams, T. (2008). How Do Organizations Learn Lessons From Projects - And Do They? *IEEE Transactions on Engineering Management* 55 (2), pp. 248–266. DOI: 10.1109/TEM.2007.912920.

Winkler, K. & Mandl, H. (2007). Implementation of knowledge management in organizations. *Learn Inq* 1 (1), pp. 71–81. DOI: 10.1007/s11519-007-0006-0.

Yu, J., Cha, J. & Lu, Y. (2012). Design synthesis approach based on process decomposition to design reuse. *Journal of Engineering Design* 23 (7), pp. 526–543. DOI: 10.1080/09544828.2011.629316.

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

Zack, M. H. (1999b). Managing Codified Knowledge. *MIT Sloan Management Review*, pp. 45–58.

9. Appendix

9.1 List of Abbreviations

CAD	Computer Aided Design
CDS	Characterisation of Design Situation
DRM	Design Research Methodology
DS	Descriptive Study
DeSiDe	Design Situation Definition
EDE	Explorative Design Experiment
FSV	Free Search in Visualisations
H	Hypothesis
ICT	Information and Communication Technology
IT	Information Technology
KB	Knowledge Base
KBE	Knowledge Base Engineering
KMS	Knowledge Management Systems
k-MORE	*knowledge* Management for Optimised Reuse
MDM	Multiple Domain Matrix
MPM	Munich Procedural Model
P	Participant
PDP	Product Development Process
PS	Prescriptive Study
PSS	Product Service Systems
RC	Research Clarification
RQ	Research Question
SD	Support Documentation
SECI	Socialisation, Externalisation, Combination and Internalisation
SWOT	Strengths, Weaknesses, Opportunities and Threats
T	Template
WCM	Worker-Centred Model

9.2 Definitions of Data, Information and Knowledge

The following table presents the definitions of the terms data, information and knowledge provided by the main authors in the field of knowledge management. The table provides additional content to the discussion presented in Subsection 2.1.1 about the definitions of such terms.

	Definition	**Source**
Data	"Data are defined as symbols that represent properties of objects, events and their environment. They are the products of observation"	(Ackoff 1989)
	"Data represent observations or facts out of context that are, therefore, not directly meaningful"	(Zack 1999b)
	"Set of discrete objective facts about events"	(Davenport and Prusak 2000)
	"Content that is directly observable or verifiable, a fact"	(Dalkir 2005)
Information	"Information is contained in descriptions, answers to questions that begin with such words as who, what, when and how many"	(Ackoff 1989)
	"Information results from placing data within some meaningful context, often in the form of a message"	(Zack 1999b)
	"Unlike data, information has meaning. Data becomes information when its creator adds meaning"	(Davenport and Prusak 2000)
	"Content that represents analysed data"	(Dalkir 2005)
Knowledge	"Knowledge is know-how, and is what makes possible the transformation of information into instructions"	(Ackoff 1989)
	"dynamic human process of justifying personal belief toward the "truth""	(Nonaka and Takeuchi 1995)
	"Knowledge is that which we come to believe and value on the basis of the meaningfully organized accumulation of information (messages) through experience, communication, or inference"	(Zack 1999b)
	"Knowledge is a fluid mix of framed experiences, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organisations, it often becomes embedded not only in documents or repositories but also in organisational routines, processes, practices, and norms"	(Davenport and Prusak 2000)

	"Knowledge is information possessed in the mind of individuals. It is personalized information (which may or may not be new, unique, useful, or accurate) related to facts, procedures, concepts, interpretations, ideas, observations, and judgments"	(Alavi and Leidner 2001)
	"Knowledge is a more subjective way of knowing and it is typically based on experiential or individual values, perceptions, and experience"	(Dalkir 2005)
	"Knowledge is the totality of knowledge and skills that individuals use to solve problems"	(Probst et al. 2012)

9.3 Systematic Review of Knowledge Reuse Approaches in Engineering Design

The following tables present the results of the systematic literature review of current approaches for knowledge reuse in engineering design which was conducted for Subsection 2.3.3.

Search in the Journal "Research in Engineering Design"

Search words: (knowledge OR design OR idea) AND (retrieval OR reuse OR use OR sharing OR transfer OR representation OR capture OR exchange)

Review: from Volume 21 (2010) to Volume 26 (2015)

Authors	Title	Year	Comments	Consider?
Kristensen & Vianello	A model for **reusing** service **knowledge** based on an empirical case	2015	Model for reusing service knowledge	Yes
Ahmad, Wynn & Clarkson	Change impact on a product and its redesign process: a tool for **knowledge** capture and **reuse**	2013	Pdf not available	No
Deken, Kleinsmann, Aurisicchio, Lauche & Bracewell	Tapping into past design experiences: **knowledge sharing** and creation during novice–expert design consultations	2012	Observational field study. No model or method is presented	No
Vianello & Ahmed	**Transfer** of **knowledge** from the service phase: a case study from the oil industry	2012	Observational field study. No model or method is presented	No

Search in the "Journal of Engineering Design"

Search words: (knowledge OR design OR idea) AND (retrieval OR reuse OR use OR sharing OR transfer OR representation OR capture OR exchange)

Review: from Volume 21 (2010) to Volume 26 (2015)

Authors	**Title**	**Year**	**Comments**	**Consider?**
Li, Quin, Gao & Liu	An approach for **design** rationale **retrieval** using ontology-aided indexing	2014	Focus on computer-based retrieval of codified knowledge	Yes
Yu, Cha & Lu	Design synthesis approach based on process decomposition to **design reuse**	2012	Focus on computer-based design reuse applying KBE to CAD	Yes
van Eck	Supporting design **knowledge exchange** by converting models of functional decomposition	2011	Focus on computer-based transfer of functional information	Yes
Howard, Culley & Dekoninck	**Reuse** of **ideas** and concepts for creative stimuli in engineering design	2011	Four types of creative stimuli computer tools	Yes
Sung, Ritchie & Rea	Automated design **knowledge capture** and **representation** in single-user CAD environments	2011	Focus on computer-based design reuse applying KBE to CAD	Yes
Storga, Andreasen & Marjanovic	The design ontology: foundation for the design **knowledge exchange** and management	2010	Focus on computer-based transfer of codified design knowledge	Yes

Search in the Journal "Design Studies"

Search words: (knowledge OR design OR idea) AND (retrieval OR reuse OR use OR sharing OR transfer OR representation OR capture OR exchange)

Review: from Volume 31 (2010) to Volume 40 (2015)

Authors	Title	Year	Comments	Consider?
van Eck	Dissolving the 'problem of the absent artifact': Design **representations** as means for counterfactual understanding and **knowledge** generalisation	2015	Focus on computer-based design reuse applying KBE to CAD	Yes
Park	Developing a **knowledge** management system for storing and **using** the design knowledge acquired in the process of a user-centered design of the next generation information appliances	2011	Focus on computer-based transfer of codified user-centered design process knowledge	Yes
Reed, Scanlan, Wills, Halliday	**Knowledge use** in an advanced manufacturing environment	2011	It is a study. It does not present models, methods or tools for reuse	No

9.4 Interviews on Knowledge Management in DS I

This Section presents the details in the preparation and results of the seven interviews conducted to junior engineers as part of the DS I (see Section 3.2).

9.4.1 Questions for the Interviews

The questions were formulated to cover 10 relevant topics, which are named from A) to J): A) general information; B) job position and experience; C) understanding of knowledge management; D) company's knowledge management; E) tasks' knowledge requirements, F) knowledge acquisition/transfer in interviewee's company; G) knowledge networks or repositories in interviewee's company; H) conflicts in interviewee's company; I) knowledge documentation in interviewee's company; and J) efficiency perception and further information (Fernandez Miguel 2015).

Topic	Question Code	Question	Purpose of the question
A. General information	A1	Name:	Personal information
	A2	Company:	
	A3	Department:	
B. Job position and experience	B1	What is your job position in the company? *(e.g.: project manager, product developer, designer, etc.)*	To set the framework of the interview
	B2	How long have you been in this position?	To check the deepness of interviewee's opinion
	B3	Have you had a similar job position in another company? Which company? For how long? *Point differences between companies in further questions.*	To further check bias in interviewee's opinions.
C. Understanding of knowledge management	C1	What do you understand as knowledge in the context of your work?	To know interviewee's personal framework
	C2	What do you understand as knowledge management?	To know interviewee's personal framework
	C3	What reasons are there to carry out activities related to knowledge management?	To check the importance the interviewee gives to knowledge management
	C4	Is knowledge management important for you?	To check the importance the interviewee gives to knowledge management
	C5	What do you understand as a routine, a periodic and a sporadic task?	To know interviewee's personal framework
D. Company's knowledge management	D1	Is your company concerned with the importance of the knowledge management? In which ways?	To check the importance interviewee's company gives to knowledge management
	D2	Which techniques for knowledge sharing and reuse are available in your company? *(e.g.:* *Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other* *IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software,*	To check the framework the interviewee works with

		question-based reasoning software, document managers, roject management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).	
	D3	Are there any incentives in your company for sharing or reusing knowledge?	To check the importance interviewee's company give to knowledge reuse
	D4	Are there any other issues regarding to the knowledge management in your company that you would like to mention?	To know further information
E. Tasks knowledge requirements	E1	Which are your and your teamwork's daily routine, periodic and sporadic tasks?	To check the framework the interviewee works with
	E2	What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*	To check the types of knowledge the interviewee uses
	E3	Do you or your teamwork always possess the knowledge or information you need?	To check interviewee's possession of explicit knowledge.
	E4	If not, which knowledge or information you miss do you usually search for or request?	To check the types of explicit knowledge the interviewee usually request.
F. Knowledge acquisition/ transfer in interviewee's company	F1	From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?	To check the sources of explicit knowledge the interviewee usually uses and their quality.
	F2	Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?	To check the problems the interviewee has while requesting for explicit knowledge
	F3	If you need someone's help while performing a task, where do you go or what systems do you use?	To check interviewee's possession of tacit knowledge.

		Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)	
	F4	Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?	To check the problems the interviewee has while requesting for tacit knowledge
	F5	If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*	To check intensive tacit knowledge transfer in interviewee's company
	F6	How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?	To check interviewee's perception about the efficiency of the knowledge transfer in interviewee's company
G. Knowledge networks or repositories in interviewee's company	G1	Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?	To check interviewee's opinion about which tacit knowledge should be transformed into explicit
	G2	Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? *(e.g.: number of ratings, "other people used", etc.)*	To check the techniques the interviewee uses to check the quality of the explicit or tacit knowledge
	G3	When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?	To check interviewee's contribution to improve the quality of the existing explicit knowledge
H. Conflicts in interviewee's company	H1	Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? *(e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)*	To check possible conflicts between interviewee's teamwork way of performing tasks and company guidelines
	H2	Do you sometimes find barriers while accessing for knowledge or information? Where are the	To check possible interviewee's bias about

		barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*	KMS performance
	H3	When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*	To know interviewee's perception about useless knowledge
	H4	Do you think that getting other knowledge could improve the efficiency of your work?	To measure the width of the KMS the interviewee uses.
	H5	Do you miss any feature in the techniques related to knowledge management your company have implemented?	To know if the KMS of interviewee's company could cover more areas.
I. Knowledge documentation in interviewee's company	I1	Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*	To check interviewee's contribution to KMS
	I2	How do you document the knowledge or information? Do you use any kind of template or guidelines?	To check interviewee's way of documenting the knowledge
	I3	Does your teamwork document best practices? How?	To check the documentation of best practices by Interviewee's teamwork.
J. Efficiency perception and further information	J1	Do you consider that you or your teamwork could be more efficient? In which ways?	To know interviewee's perception of the relation between the KMS implemented in his company and his efficiency.
	J2	Are there any other issues regarding knowledge management affecting your or your team's task performance that you would like to mention?	To know further information

9.4.2 Minutes of the Interviews

This Subsection presents the minutes of the interviews. The interviewer is abbreviated as **I** and the participants are abbreviated as **P1**, **P2**, **P3**, **P4**, **P5**, **P6** and **P7**.

Interview 1

A) General information

(A1) Participant 1 or P1

(A2) Company: A

(A3) Department: Total Vehicle Development

B) Job position and experience

I: (B1) What is your job position in the company? (*e.g.: project manager, product developer, designer, etc.)*

P1: Trainee for interior and trunk development.

I: (B2) How long have you been in this position?

P1: 6 weeks

I: (B3) Have you had a similar job position in another company? Which company? For how long? *Point differences between companies in further questions*

P1: No

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P1: Way of processing data in the daily job and the ability to interpret them to obtain results. Knowledge is necessary in order to establish conclusions from data.

I: (C2) What do you understand as knowledge management?

P2: Managing the knowledge of many people at the same time in order to make it productive. Each person contributes a little bit to the whole with his/her knowledge.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P1: Knowledge provides a competitive advantage which leads the company to success. Knowledge management increases productivity, it avoids knowledge loss, and it allows knowledge transfer from people who leave the company to people who come into the company.

I: (C4) Is knowledge management important for you?

P1: Yes, I want to know what is going on in the company.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P1: A routine is what I do every day. A periodic task is calculating the volume of the trunk. A sporadic task is something which I've done once and I don't know if I will have to do it again.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P1: Yes. The first month they transfer you knowledge.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? (*e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software, question-based reasoning software, document managers, roject management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).*

P1: Non IT-based: mentoring, training and education, cross-functional teams. IT-based: internal chat to connect people and ask for fast help.

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P1: Not really, but it is either done like this or it is impossible to work.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P1: No.

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P1: A routine is to measure to trunk's volume, sometimes physically and sometimes in CATIA. A periodic task is to measure already manufactured parts, their sections in CATIA and to prepare presentations for meetings to reach conclusions. A sporadic task is to move a car to take physical measures.

I: (E2) What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*

P1: Knowledge about CATIA, soft skills to deal with people (e.g. languages). Knowledge about my objectives and requirements. There is no know-why.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P1: No.

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P1: Knowledge about how to repair CATIA when it crashes. If this happens, we have to call the informatics so they can fix it.

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P1: In the digital repositories of the company.

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P1: You need a document, you tried to open it but you are not allowed to open it. It takes around two day to receive a permit.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? *Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)*

P1: Mobile phone, check competences and department. Chat.

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P1: (Question not discussed)

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*

P1: (Question not discussed)

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P1: (Question not discussed)

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P1: (Question not discussed)

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? *(e.g.: number of ratings, "other people used", etc.)*

P1: If there are, I have not seen them yet.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P1: Feedback is given during meetings.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? *(e.g.: imposition of procedures that do not match with yours, too rigid protocols, etc.)*

P1: No, the reports are quite simple. Filling reports causes a bit of rejection due to its repetition but it is important.

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*

P1: The main barrier are the licences to access data. They are good to protect the knowledge from people leaving the company but it goes very slow and it slows down the speed of working. They limit especially between departments and also inside departments. It should be more agile (hours or minutes but not weeks). Inside the same department it is unclear who can get a licence for what. If I need pictures to prepare reports, I need to call another person. Each time I had a problem with a licence, I had to call someone, but it was actually all documented. Documenting is good, but also documenting the responsible persons.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*

P1: I have not experienced this yet.

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P1: No.

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P1: (Question not discussed)

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*

P1: We create a protocol after each meeting and we do use it later. It is also useful for other departments. Also CAD files.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P1: Yes, there are standard colours for the CAD models and we have templates for presentations and reports.

I: (I3) Does your teamwork document best practices? How?

P1: Yes, in presentations. We distinguish between red, yellow and green.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P1: A more efficient and flexible data protection system.

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P1: No.

Interview 2

A) General information

(A1) Participant 2 or P2

(A2) Company: A

(A3) Department: Development of electronic control units

B) Job position and experience

I: (B1) What is your job position in the company? (*e.g.: project manager, product developer, designer, etc.)*

P2: Trainee

I: (B2) How long have you been in this position?

P2: 5 months.

I: (B3) Have you had a similar job position in another company? Which company? For how long? *Point differences between companies in further questions*

P2: No.

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P2: Ability to use CATIA, ability to synthesise ideas in a real part.

I: (C2) What do you understand as knowledge management?

P2: The management of documented knowledge obtained by the employees, documenting the progress done by each employee in order to avoid the loss of knowledge in case someone leaves the company.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P2: Avoid the loss of knowledge and avoid repetitions.

I: (C4) Is knowledge management important for you?

P2: Not at an individual level, but yes the level of the company and its resources. Personally, knowledge management forces you to be organised but it also requires time for it.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P2: Routine is what I do every day, periodic what I do every other time but not every day, and sporadic only sometimes.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P2: Yes. People's work is stored in databases in such a way that only some people have access due to security issues.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? (*e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software, question-based reasoning software, document managers, project management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).*

P2: Non IT-based: mentoring, training and education, cross-functional teams. IT-based: collaborative software, video conference, document managers, project management software, blogs and databases.

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P2: No.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P2: No.

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P2: Routinely: check email, check new on "A", 3D simulation of a motorcycle acceleration, obtain signals for the models and design CATIA parts. Periodic: talk to my supervisor to comment the weekly progress. Sporadic: go to other department to ask for something to perform a concrete task, e.g. go to the factory to talk to the employees of the production line and obtain feedback for my work.

I: (E2) What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*

P2: CATIA, Matlab, geometry, materials, electronics, signal treatment and languages.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P2: No.

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P2: Sensors or parts characteristics.

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P2: Ask my boss, Wikipedia and internet.

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P2: I usually find everything.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? *Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)*

P2: Just in person.

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P2: There are no problems.

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*

P2: Mentoring, manuals and tutorials in Wikipedia or internet.

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P2: I would be glad if we had trainings for the employees although they were not exactly about the software you are using at that time for your work. A teacher who can correct you.

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P2: Basic knowledge is not necessary to be documented.

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? *(e.g.: number of ratings, "other people used", etc.)*

P2: I do not recall.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P2: I am just knowledge user. I just contact the person or you can create a new version of a document, depending of your credentials.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? *(e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)*

P2: (Question not discussed)

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*

P2: You need permits to access to all documents. They depend of the department. It takes around 3 to 5 days to get access. Sometimes when you get access, you don't need the document anymore.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*

P2: (Question not discussed)

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P2: No.

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P2: (Question not discussed)

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*

P2: Yes, and some other persons can use it to check if the process was optimal.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P2: Standard references for assemblies. Standard templates but not for everything.

I: (I3) Does your teamwork document best practices? How?

P2: Yes, sometimes in the protocol, sometimes freely.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P2: Faster credentials management and less bureaucracy.

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P2: No.

Interview 3

A) General information

(A1) Participant 3 or P3

(A2) Company: B

(A3) Department: Seat design

B) Job position and experience

I: (B1) What is your job position in the company? *(e.g.: project manager, product developer, designer, etc.)*

P3: Design engineer.

I: (B2) How long have you been in this position?

P3: 10 months.

I: (B3) Have you had a similar job position in another company? Which company? For how long? *Point differences between companies in further question,*

P3: Yes, 6 months of CAD modelling for a different type of products.

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P3: Theoretical knowledge to design a product (ergonomic, manufacturing, general car structure, materials), language, and use of CAD software.

I: (C2) What do you understand as knowledge management?

P3: At a company level, how are the knowledge resources used and how is knowledge transfer to new employees.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P3: To save time and do not start from cero to go further.

I: (C4) Is knowledge management important for you?

P3: It is important to transfer my knowledge to other people who may need it and therefor do not repeat the same tasks which I have already done, and vice versa.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P3: A routine is done without thinking, it is done very often and it does not require much attention. A periodic task is done every now and then and a sporadic task is done 1 or 2 times.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P3: It does not exist a specific department for knowledge management. The technical manager tells you where to start.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? *(e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software, question-based reasoning software, document managers, roject management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).*

P3: IT-based: collaborative software (WebEx), document managers, project management software, screen sharing, phone, and outlook. There is a chat but it is not used. I think it is necessary to avoid to expose reasoning and avoid misunderstandings.

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P3: No, but I think they are completely necessary.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P3: That documenting is necessary to be prepared for people leaving the company.

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P3: Routines: modelling and modifying CAD models of seats. Periodic: meeting experts from our client company (a big automotive developer) in order to decide changes, see what is possible and what not, and define the work to do. Sporadic: attend to car fairs.

I: (E2) What kind of knowledge do you need to perform your tasks? (Distinguish between tasks if applicable. *(e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.))*

P3: Seat surrounding features, CAD software knowledge, languages, theoretical knowledge to design a product (ergonomic, manufacturing, general car structure, materials). Soft skills are also important because I need to communicate to the client which information they have to send me.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P3: No.

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P3: Knowledge about informatics. We contact IT support but they are not very efficient.

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P3: From WebEX or internal from the client (in this case only a colleague of mine is allowed to do it).

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P3: The fact that I am not allowed to do it personally and I always have to contact someone else.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? *Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)*

P3: Email or WhatsApp.

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P3: If someone is not reacting to your emails, then you have to waste time until they react. There are setbacks (from 5 minutes to 3 hours) when using screen and data sharing because licenses expire.

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? (e.g.: normal classroom training, mentoring, manuals, etc.)

P3: Based on similar examples or mentoring. General manuals. For example, there is one German guideline on how to proceed with measurement processes.

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P3: The manuals are efficient for the company but not for your knowledge. You learn the process but you don't understand it. Although I find this is normal because it increases the productivity.

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P3: (Question not discussed)

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? (e.g.: number of ratings, "other people used", etc.)

P3: No.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P3: There is no extra documentation. The client company does not give you any document to start with.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? (e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)

P3: (Question not discussed)

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? (e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)

P3: Yes, getting credentials from the client company takes a lot of time and it is unclear which credential you need. There is too much bureaucracy. It should be more dynamic. The client company is responsible of their documents and they cannot access their own documents. They tell you that there is nothing to search but in the end it turns out there usually is. We have to keep working with old version just to be able to continue the work. Then, the requested documents arrive and we have to make changes. This is a waste of time.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? (e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)

P3: Handbooks which are too vague to be helpful. Generally, I avoid handbooks.

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P3: Yes.

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P3: (Question not discussed)

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? (e.g.: your conviction about a more efficient way of working, you are obligated, etc.)

P3: Yes, documents of the processes, the pdf established including date, name and index. We have to document all changes in an excel file with all personal data, date, index, type of change and version control. Everybody uses it.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P3: The is a standard coding for the files and a suggested template.

I: (I3) Does your teamwork document best practices? How?

P3: Mostly informal in small annotations and recommendations about new findings.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P3: Yes. (Already commented)

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P3: (Already commented)

Interview 4

A) General information

(A1) Participant 4 or P4

(A2) Company: currently in C (previously in D and E)

(A3) Department: Engineering Research and Development

B) Job position and experience

I: (B1) What is your job position in the company? *(e.g.: project manager, product developer, designer, etc.)*

P4: Working student writing the master thesis.

I: (B2) How long have you been in this position?

P4: 1 year.

I: (B3) Have you had a similar job position in another company? Which company? For how long? *(Point differences between companies in further questions)*

P4: D (10 months), company E (2 years)

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P4: Theoretical knowledge: general concepts to perform my work (physic, montage), and practical knowledge (know-how): who has used them and for what.

I: (C2) What do you understand as knowledge management?

P4: In a company it is how to manage the company's knowledge (trainings, documentation, administration), the knowledge of the employees. Personally it is where you acquire your knowledge.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P4: Because if it is not well-managed, you can lose it and you may have to reinvent the wheel. The more structured your knowledge is, the better and faster your employees can work in their designs.

I: (C4) Is knowledge management important for you?

P4: Yes. If there is not a good knowledge management, all engineers have to do the same researches.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P4: Sporadic: something you almost never do. Routine: something you do every day, always in the same way. Periodic: something you do every now and then but not always in the same way.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P4: Company C is well organized (by departments and projects) repositories (intranet). Unlimited access to the knowledge documented in your department. Access to other departments' repositories with credentials (agile and fast). All previous developments, scientific articles, and projects from service providers companies. In Company

D the knowledge was badly managed, there was not even consistency naming the files. The company had just started and it had 15 employees. In Company E No there was no concern about knowledge management, no coordinated developments.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? *(e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software, question-based reasoning software, document managers, project management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).*

P4: Non IT based: mentoring, communities of practice, training and education. Communities of practice are used often and they are quite useful. IT based: collaborative software, document managers, project management software, wikis (per department and managed by an expert), social networks (Facebook group for professional and private topics).

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P4: No that I know, but I guess the three persons who organised the communities of practice (send the invitations, prepare presentations) and offer help received something.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P4: In Company E, there was no coordination between the developments inside a project and we were constantly reinventing the wheel. Sometimes we could avoid it through personal communication because we were around 30 employees.

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P4: Routines: build in CAD, analysis of FEM. Periodic: search information about how some concrete part works, manufacturing methods (at the beginning of a development). Sporadic: when you don't know how to do something, you do something for the first time, search for patents.

I: (E2) What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*

P4: Software and technical knowledge (academic background). Know-when in Company C is not so important because I work in the early design phases, but in Company E it was very important. Knowledge about the work shop to design the montage. Language.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P4: No.

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P4: Parts requirements, parts environment, how to use softwares.

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P4: How to use softwares in internet. For requirements we search in data from old projects, they are well organised and it does not take long, less than one hour. For manuals each department has the ones which are more used.

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P4: There is no index of non-digital material. In some project which was performed by someone who had left the company and you had to ask for something concrete, some things could be better documented but generally is ok.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? (Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.))

P4: Direct contact with team members (email, telephone, meetings). There is an intra-firm transport system (one intern drives a car and it is useful to make contacts).

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P4: (Already commented)

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*

P4: Mentor, internet and internal manuals. If it is a very new task, then in a training.

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P4: (Already commented)

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P4: Not to the second question. Documenting is necessary, especially in my case about manufacturing, limitations in the manufacturing processes are very important for the design.

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? (e.g.: number of ratings, "other people used", etc.)

P4: No.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P4: No.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? (e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)

P4: No, but it depends on the own department.

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*

P4: No.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*

P4: No difficulties.

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P4: Yes, but not technical knowledge, soft skills would be nice.

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P4: (Question not discussed)

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*

P4: In company C yes. There is a report per project, the CAD files are organised and we can create new versions. There are also protocols of the meetings. New projects can base on previous ones.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P4: There is a naming code for the files and a version manager for CATIA (LCA).

I: (I3) Does your teamwork document best practices? How?

P4: Yes. In the meetings reports.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P4: Faster access to the information and intelligent search.

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P4: No, I just want to point out the difference between company E and company C.

Interview 5

A) General information

(A1) Participant 5 or P5

(A2) Company: F

(A3) Department: Cooling Systems Design

B) Job position and experience

I: (B1) What is your job position in the company? *(e.g.: project manager, product developer, designer, etc.)*

P5: Design engineer.

I: (B2) How long have you been in this position?

P5: 1 year.

I: (B3) Have you had a similar job position in another company? Which company? For how long? *(Point differences between companies in further questions)*

P5: No.

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P5: Engineering theoretical background, company structure and operation, procedural knowledge (how to prioritise, time management).

I: (C2) What do you understand as knowledge management?

P5: The way of documenting and transferring the required knowledge to carry out a project.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P5: To make employees work more effective and avoid future errors: the less knowledge background of the employee, the more errors he make.

I: (C4) Is knowledge management important for you?

P5: Yes, to transfer knowledge to new employees and to know what others make so we can better coordinate efforts.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P5: Routine: basic task, done every day. Periodic: task performed regularly and connected to the routines. Sporadic: some exceptional task.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P5: Yes. But our client company is not concerned of a coordinated knowledge management with the services providers.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? *(e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software, question-based reasoning software, document managers, project management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).*

P5: Non IT-based: mentoring, communities of practices, training courses, cross-functional teams. There was an attempt to establish a "Weißwurstrunde" so the team from the client company and the service providers would have breakfast together on Friday. IT-based: collaborative software, outlook, video conference, scree sharing, telephone, document managers, wikis.

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P5: Not specifically for knowledge management. The incentive is be better than other companies and obtain more projects.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P5: (Question not disussed)

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P5: Routine: design of parts in CAD. Periodic: meeting with some other department to agree on geometric specifications. Sporadic: meetings to see if the objectives are being fulfilled on time.

I: (E2) What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*

P5: Engineering theoretical background, IT basics, procedural knowledge, company structure and operation.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P5: Definitely no.

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P5: CAD models, requirements, and not only the requirements but also the reasons for those.

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P5: Internet and intranet. It is difficult to find it, you have to ask someone.

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P5: There is no access to documents from previous designs. This leads to reinventing the wheel. The knowledge is badly organised in the intranet, so you have to ask someone.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? *Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)*

P5: Contact per email, telephone or meetings.

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P5: Accessing employees from high positions is difficult and it takes time. Some people do not answer emails, phone or do not attend to meetings.

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*

P5: There is no manual. You attend to a workshop or you review presentations from old workshops.

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P5: You attend to the workshop and then you forget what they told you. In the presentation is not everything. I think there should be more documentation and it should be in English because there are many international employees.

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P5: Basic knowledge should be documented.

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? *(e.g.: number of ratings, "other people used", etc.)*

P5: No.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P5: One can create new versions from previous documents so as to correct errors or to update them with new designs.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? *(e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)*

P5: Senior employees are less open to changes.

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*

P5: The client company does not want to provide you with know-why. If the request is not properly justified, they do not provide it to you. But this could avoid mistakes.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*

P5: (Question not discussed)

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P5: Knowing why of the designs are this way. This information arrives when it is too late.

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P5: (Question not discussed)

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*

P5: In meetings an assistant takes notes that are later corroborated and structured.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P5: Yes, there are templates and cross-department templates.

I: (I3) Does your teamwork document best practices? How?

P5: We document lessons learned (a typical problem, how we solved it and how it could be avoided), but the client company either does not use them or they do it wrong.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P5: (Already commented)

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P5: No.

Interview 6

A) General information

(A1) Participant 6 or P6

(A2) Company: G

(A3) Department: Power electronics units test and validation

B) Job position and experience

I: (B1) What is your job position in the company? *(e.g.: project manager, product developer, designer, etc.)*

P6: Problem manager.

I: (B2) How long have you been in this position?

P6: 5 months.

I: (B3) Have you had a similar job position in another company? Which company? For how long? *Point differences between companies in further questions.*

P6: No.

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P6: How other departments work, how to manage new arriving information and results, how to manage all the information.

I: (C2) What do you understand as knowledge management?

P6: Faster management of the available information and better management and coordination of resources.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P6: Employees work more effectively and knowledge is transferred to employees.

I: (C4) Is knowledge management important for you?

P6: Yes. It is important to know who knows what. In my company everything is new and it is essential to properly manage knowledge and information in order to use it in next designs, to know how to proceed if there are problems.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P6: Routine: do something every day. Periodic: a task which is regularly done (once a week). Sporadic: it occurs just in some exceptional occasions, no fix times.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P6: The company makes many efforts in this direction.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? *(e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference software, question-based reasoning software, document managers, roject management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).*

P6: Mostly IT-based: collaborative software (email, chat), scree sharing, telephone, document managers, wikis, meetings.

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P6: No.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P6: No.

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P6: Routine: update data. Periodic: write reports and attend to meetings. Sporadic: clean unit to create place for new data.

I: (E2) What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*

P6: Requirements, theoretical background, declarative knowledge, conditional knowledge.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P6: No.

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P6: Know-why.

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P6: Internet, intranet and colleagues.

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P6: The intranet is not well organised.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? *Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)*

P6: Contact colleagues, request per email and phone.

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P6: It is difficult to find a room to meet someone.

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*

P6: Word of mouth. Trainings.

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P6: Word of mouth is efficient for immediate issues.

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P6: All basic routines and systems should be documented.

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? *(e.g.: number of ratings, "other people used", etc.)*

P6: No.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P6: Yes, I create new versions if I see an error or in order to include new things.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? *(e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)*

P6: Lack of time when fulfilling the template.

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*

P6: Credentials are a problem.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*

P6: The software manuals were too general so they were not helpful. In the end I had to check internet.

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P6: I would need knowledge about the development in other stages, which is not available right now. Lack of coordination.

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P6: I would like to know what is going on before and after my work in the design process.

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*

P6: We save all emails.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P6: There are templates available.

I: (I3) Does your teamwork document best practices? How?

P6: Not really.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P6: (Already commented)

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P6: No.

Interview 7

A) General information

(A1) Participant 7 or P7

(A2) Company: A

(A3) Department: Driving dynamics development

B) Job position and experience

I: (B1) What is your job position in the company? *(e.g.: project manager, product developer, designer, etc.)*

P7: Development engineer.

I: (B2) How long have you been in this position?

P7: 1 year.

I: (B3) Have you had a similar job position in another company? Which company? For how long? *Point differences between companies in further questions.*

P7: No.

C) Understanding of knowledge management

I: (C1) What do you understand as knowledge in the context of your work?

P7: Capturing, organising and managing knowledge from previous experiences.

I: (C2) What do you understand as knowledge management?

P7: Managing experiences and lessons learnt.

I: (C3) What reasons are there to carry out activities related to knowledge management?

P7: Difficult but important to locate the required information.

I: (C4) Is knowledge management important for you?

P7: Yes, and I made a user manual to help others use what I made.

I: (C5) What do you understand as a routine, a periodic and a sporadic task?

P7: Routine: it doesn't require much thinking. Periodic: it is repeated every now and then. Sporadic: spontaneously.

D) Company's knowledge management

I: (D1) Is your company concerned with the importance of the knowledge management? In which ways?

P7: Yes, document everything so as to later others can use it.

I: (D2) Which techniques for knowledge sharing and reuse are available in your company? *(e.g.: Non IT based: interviews/videotaping, mentoring, storytelling, communities of practice, training and education, cross-functional teams, other / IT based: collaborative software (e.g.: email, chat, surveys, etc.), video conference*

software, question-based reasoning software, document managers, roject management software (e.g.: calendar, project management, etc.), forums, wikis, blogs, social networks, microblogs, other).

P7: Mentoring, communities of practice, cross-functional teams, collaborative software, document managers, project management software, wikis and social networks.

I: (D3) Are there any incentives in your company for sharing or reusing knowledge?

P7: No.

I: (D4) Are there any other issues regarding to the knowledge management in your company that you would like to mention?

P7: No.

E) Tasks knowledge requirements

I: (E1) Which are your and your teamwork's daily routine, periodic and sporadic tasks?

P7: Routine: check email and work in the project. Periodic: small presentations to see the advances of the project. Sporadic: guided visits around departments or to explain something to someone.

I: (E2) What kind of knowledge do you need to perform your tasks? *Distinguish between tasks if applicable. (e.g.: requirements, CAD data, diagrams, working models, geometry data, interface information, know-about, know-how, know-why, know-when, know-with or knowledge from other disciplines, etc.)*

P7: IT basics, theoretical background, language, previous models, previous tools, skills from a test driver.

I: (E3) Do you or your teamwork always possess the knowledge or information you need?

P7: (Question not discussed)

I: (E4) If not, which knowledge or information you miss do you usually search for or request?

P7: (Question not discussed)

F) Knowledge acquisition/ transfer in interviewee's company

I: (F1) From where do you usually get the knowledge or information you miss? *(e.g.: your department, outside your department, outside your company, etc.)* Do you usually find it? How long does it usually takes you to get it? Do you usually find it helpful?

P7: Intranet. Sometimes directly from the person.

I: (F2) Which problems do you usually find while requesting for knowledge or information? In your opinion, how could be them solved?

P7: Limitations of the IT systems. People don't answer or it takes time.

I: (F3) If you need someone's help while performing a task, where do you go or what systems do you use? *Distinguish between tasks if applicable. (e.g.: forums, video conference, etc.)*

P7: Direct contact with people, chat or meetings.

I: (F4) Which problems do you usually find while requesting for someone's help? In your opinion, how could be them solved?

P7: Availability of meetings rooms.

I: (F5) If you perform a new task for the first time, how do you learn what do you need to do? *(e.g.: normal classroom training, mentoring, manuals, etc.)*

P7: From a mentor or manual.

I: (F6) How efficient are these ways of accessing or transferring knowledge? How could they be improved in your opinion?

P7: There were training before, but they were not more useful.

G) Knowledge networks or repositories in interviewee's company

I: (G1) Do you think that sometimes is better to document someone's knowledge that is not already documented? Do you think someone's documented knowledge should be better not documented?

P7: Better not documenting if the task is too complex. But models for example, should be documented.

I: (G2) Are there in your company available ratings or credibility indicators in order to check the quality of the knowledge or information available? Do you rely on them? Do you contribute to them? *(e.g.: number of ratings, "other people used", etc.)*

P7: No.

I: (G3) When using the knowledge or information, do you also contribute to it in order to improve the quality of already existing knowledge and information by means of, for example, improving consistency, avoiding redundancy or correcting mistakes?

P7: Yes, I modify reports to correct errors.

H) Conflicts in interviewee's company

I: (H1) Is your or your teamwork's way of performing tasks in conflict with the knowledge or information sharing and reuse protocols your company have implemented? *(e.g.: imposition of procedures that do not match with yours, to rigid protocols, etc.)*

P7: There are too many bureaucratic steps which slow down the work.

I: (H2) Do you sometimes find barriers while accessing for knowledge or information? Where are the barriers? *(e.g.: ideological conflicts, lack of integration between departments/units, struggles for control of specific resources, etc.)*

P7: Credentials.

I: (H3) When you have knowledge or information available, what could be the reason or reasons of not using it? *(e.g.: difficulties trying to find the right knowledge or information because of to much or unstructured knowledge or information, lack of trust from other's knowledge or information, incomplete knowledge or information, etc.)*

P7: (Question not discussed)

I: (H4) Do you think that getting other knowledge could improve the efficiency of your work?

P7: (Question not discussed)

I: (H5) Do you miss any feature in the techniques related to knowledge management your company have implemented?

P7: More cross-department connections (some departments making twice the same things).

I) Knowledge documentation in interviewee's company

I: (I1) Do you or your teamwork document any kind of new knowledge or information while performing your tasks? Why? Will anyone use it? For which purposes? *(e.g.: your conviction about a more efficient way of working, you are obligated, etc.)*

P7: Everything is documented. We create a presentation with a summary for the managers.

I: (I2) How do you document the knowledge or information? Do you use any kind of template or guidelines?

P7: There are templates for the naming and the content of the files, at the level of the client company and for our department in particular.

I: (I3) Does your teamwork document best practices? How?

P7: Yes, about how to program correctly.

J) Efficiency perception and further information

I: (J1) Do you consider that you or your teamwork could be more efficient? In which ways?

P7: (Already commented)

I: (J2) Are there any other issues regarding to knowledge management affecting your or your team's task performance that you would like to mention?

P7: People are not concerned with documenting knowledge and it should be given more importance to that.

9.5 Systematic Literature Review in DS I

This Section presents details of the systematic review and analysis of influencing factors for knowledge reuse that was conducted as part of the DS I (see Subsection 3.3.2).

9.5.1 Methodology for Review and Analysis of Influencing Factors

	Step	Conditions	Results
1	Selection of the leading journals	• Location: Web of Science • Keywords: Knowledge Management AND (Barrier OR Factor) in all text fields • Time window: 2005 to 2015 • Selection criteria: The 3 non-proceeding journals with greatest number of citations	• Journal of Knowledge Management • Knowledge Management Research & Practice • Information & Management
2	Selection of relevant papers	• Location: The three selected research journals • Keywords: Barrier OR Factor in the title • Time window: 2005 to 2015	• Journal of Knowledge Management: 30 papers • Knowledge Management Research & Practice: 9 (not available) • Information & Management: 4
3	Collection of all factors	• Collection all factors in an Excel sheet	• 364 factors from 31 papers • 3 papers had no factors
4	Filtering of out of scope factors	• Out of scope criteria: - The factor is too abstractly defined - The factor impact crosses firm's boundaries - The factor is a process or strategy itself - The factor is a variable of individuals' behaviours	• 254 factors considered • 110 out of scope factors
5	Filtering of duplicated factors	• Duplicates Criteria: - Exact duplicates - The factor is written as barrier or vice versa - Synonyms and antonyms - The meaning of a factor is contained into another	• 142 non-duplicated factors • 112 duplicates
6	Classification into the four	• Classify the factors into the four categories of the WCM	• Infrastructure factors: 26 • Knowledge factors: 16

	WCM categories		• Psycho-social factors: 77 • Strategic factors: 23
7	Grouping into similar factors	• Grouping of similar factors into more widely described ones	• Infrastructure factors: 3 • Knowledge factors: 4 • Psycho-social factors: 12 • Strategic factors: 2

9.5.2 DOI of Selected Papers

Papers from the Journal of Knowledge Management

doi:10.1108/13673271011015633; doi:10.1108/13673270710738898; doi:10.1108/13673271211218861; doi:10.1108/13673271211276155; doi:10.1108/13673271111179271; doi:10.1108/JKM-02-2015-0052; doi:10.1108/13673271211198963; doi:10.1108/JKM-08-2013-0300; doi:10.1108/JKM-08-2013-0316; doi:10.1108/JKM-06-2013-0233; doi:10.1108/13673271011050139; doi:10.1108/13673270810852377; doi:10.1108/13673271011015606; doi:10.1108/13673271111108693; doi:10.1108/JKM-03-2014-0080; doi:10.1108/13673270810852368; doi:10.1108/13673271211198954; doi:10.1108/13673270810859550; doi:10.1108/13673270910962860; doi:10.1108/13673270510610341; doi:10.1108/JKM-08-2013-0324; doi:10.1108/13673270810875886; doi:10.1108/13673270510602746; doi:10.1108/13673270710728231; doi:10.1108/13673270910988097; doi:10.1108/13673270910997105; doi:10.1108/13673271211246167; doi:10.1108/13673270610679408; doi:10.1108/13673270510602773; doi:10.1108/13673270510590236

Papers from Knowledge Management Research & Practice

doi: 10.1057/kmrp.2011.2; doi: 10.1057/kmrp.2012.24; doi: 10.1057/kmrp.2010.13; doi: 10.1057/kmrp.2013.30; doi: 10.1057/kmrp.2013.37; doi: 10.1057/kmrp.2013.45; doi: 10.1057/palgrave.kmrp.8500153; doi: 10.1057/kmrp.2012.9; doi: 10.1057/kmrp.2013.54

Papers from Information & Management

doi: 10.1016/j.im.2010.03.001; doi: 10.1016/j.im.2010.08.003; doi: 10.1016/j.im.2008.03.003; doi: 10.1016/j.im.2011.11.001

9.5.3 Reviewed Factors Grouped to Each Influencing Factor of the WCM

This Subsection presents the factors grouped to each one of the final influencing factors included in the WCM. This grouping took place in step 7 of the methodology to analyse the results of the literature review.

Infrastructure Factors

- **Organisational structure**: Simple versus complex knowledge; No set process to facilitate the knowledge transfer; Decentralisation (silo structure, turfism, with powerful departmental structures); Coordination among employees and departments; Relationship network; Structure (Vertical - horizontal); Trash information; Distance between the echelons of knowledge source and receiver; Lack of intangible mechanisms: unscheduled meetings, informal seminars, or conversations; Communication and knowledge flows are restricted into certain directions; Size of business units often is not small enough and

unmanageable to enhance contact and facilitate ease of sharing; Flexible structure and design; Relationship with the existing structure; Roles of members and supporting functions; Too much administration, too much involvement to bureaucracy; Failure to develop a transactive memory system

- **IT structure**: Legacy systems; Useless technology; Available technology (Does IT support knowledge requirement?); Knowledge system modification; Information systems; Lack of technical support (internal or external) and immediate maintenance of integrated IT systems; Lack of compatibility between diverse IT systems and processes; User-friendliness
- **Physical structure**: Office design to increase interaction; Physical proximity among colleagues

Knowledge Factors

- **Knowledge affinity**: Language; Knowledge distance; Relatedness of transferred knowledge with existing knowledge; Cultural distance; Cultural awareness; Primary knowledge and shared identity; Complex nature; Knowledge gaps between members; Lack of awareness; Low awareness and realisation of the value and benefit of possessed knowledge to others; Low awareness and realization of knowledge sharing
- **Learning aptitude**: Learning aptitude of individual; Learning aptitude of team; Lack of retentive capacity
- **Knowledge breadth**: Causal ambiguity
- **Knowledge depth**: Overall technical terminology

Psycho-social Factors

- **Perceived risk**: Perceived risk; Worried about reward, recognition, criticism, and punishment; Fear of reducing job security
- **Perceived benefit**: Perceived relative advantage; Perceived expectation; Making every-day work easier and faster; Rewards; Lack of performance appraisal; Formal acknowledgement
- **Knowledge as power**: There is fear of ‘‘losing the edge’’. The perceived power base; Suspicion of whether other teams are sharing the knowledge in the same open way as we are doing. Competition with others; Knowledge may be perceived as a threat; Fear of loss of ownership and control of knowledge property and individual competitive edges/professional identity; Internal resistance (protect interests of organisation/business unit); Fear of undermining position; Power; Afraid that knowledge may be inadequate or unimpressive; Need to gain acceptance into the team; Acceptance of the team by the organisation; Norm of reciprocity
- **Past experiences**: Past experiences of conflicts that arose due to learning transfer; Perceived irrelevance of the knowledge for future purposes; Ambiguity; Prior relationships; Not evidence-based; Non-validated knowledge; Abstence of negative past experiences linked to unit responsible for knowledge management; Differences in experience levels
- **Commitment**: Organisational commitment; Membership; Divergent objectives and/or hidden agenda; Team has other aspirations than knowledge transfer; Team benefit

maximization vs organisational benefit maximization; Divergent aspirations of teams: innovation as a threat; Manager commitment

- **Trust**: Team confidence in the individual/acceptance of the individual; Individual's values are in variance with team values (e.g. trust, honesty, and integrity etc.); Can the individual be trusted?; Team value system (e.g. can the team be trusted?); Unprovenness; Info not perceived as reliable; Fear of contamination; Credibility; Accepting willingness; Trust; Mutual trust; Doubt about whether the knowledge is updated; NIH syndrome; Lack of trust in system (security); Trust culture
- **Workload**: Individual management of time; Lack of slack times and heavy workload; High level of stress and fear of disadvantage/risk; Knowledge cost; Lack of contact time and interaction between knowledge sources and recipients
- **Culture**: Knowledge-centred culture; Organisational context; Learning culture and teamwork; Lack of sharing culture; Culture and cultural characteristics
- **Personal relationships**: Relationship, Tie strength, Poor relationship between knowledge source and receiver, Lack of contact time and interaction
- **Social skills**: Skills of communication and persuasion; Articulability; Transfer capacity; Difficulty of concrete expression; Lack of competence of staff; Emotional Intelligence
- **Personality**: Personality differences (lack of rapport within individual members); Different individual characteristics; Age differences; Gender differences; Differences in education levels
- **Mind openness**: Openness; Favourable environment for questioning

Strategic Factors

- **Strategic alignment**: Inconsistent organisational strategy, systems, policies, practices and knowledge management processes; Culture (knowledge strategy); K Strategy implementation; Lack of fitness between knowledge and important organisational goals; Poor targeting of knowledge; Knowledge-centred HR practices; Lack of fit between innovation and organisational assumptions and beliefs; Unrealistic expectations of technology; Objectives and focus; Unclear job description ("not my job" phenomenon) and/or strict job description; Strict rules and regulations; Difficulty of standardization; knowledge management-centred training actions within overall training planning; Formal inclusions of knowledge management duties in job design; Lack of integration of IT systems and processes
- **Leadership**: Lack of top management support; Leadership styles; Knowledge-oriented leadership; Organisational support; Authority to perform knowledge activities; Cultural support; Consolidation of team members' perceptions to one message; Lack of communication and demonstration of all advantages of any new systems over existing ones

9.6 Exploratory Design Experiment II (EDE II)

This Section presents details of the EDE II which was conducted as part of the DS I of this thesis.

9.6.1 Design Cases

Case I

You have been working as engineer in BMW for the last **10 years** in the design department. Since then you have been **taking part in almost all projects** and therefore you got to know every team member. Moreover, as BMW promotes a **strong sharing culture** and active communication between team members, you feel comfortable talking about the problems and solutions that you face during the design.

BMW is concerned because the Asia market is innovating much more quickly that they are, so they decided to relieve you from your current tasks, so you can **find an innovation** that boosts the market.

Fields to be completed to characterise the design situation:

- Familiarity with the product (required)
- Type of group work (required)
- Design phase (optional)
- Type of activity (optional)
- Product complexity (optional)
- Design purpose (required)
- Restriction on time (required)

Case II

BMW has **just employed** you as designer. They are concerned about the last design of the middle tunnel their "Modular team" created for their MINI Cooper. Some customers are having problems and they want you to **investigate the design** and see if there were some mistakes made, so they can be repaired.

9.6.2 Rules to Match Design Parameters and Metadata

Characteristic of design situation	**Status**	**Correspondent documents' metadata**
Familiarity with the product	Familiar	Status = End Type = Video / Audio / Photo
	Not familiar	Status = In progress / End Type = Text / PDF
Type of group work	Independent	Type = Text / PDF / Excel
	Collaborative	Type = PowerPoint / CAD
Design phase	Research	Phase = Research
	First iteration	Phase = First iteration

	Second iteration	Phase = Second iteration
Type of activity	Beginning	Category = "select" Number phases and subphases in which the document is used > 3
	Middle-End	Category = "select" Number phases and subphases in which the document is used < 3
Product complexity	General	Number phases and subphases in which the document is used > 3
	Specific	Number phases and subphases in which the document is used < 3
Design purpose	Innovate	Phase = Research
	Improve	Phase = Second iteration
Restriction on time	Time available	*explore KB
	No time available	Status = End Type = Video / Audio / CAD / Photo

9.7 *k*-MORE User Kit

Each of the steps of the *k*-MORE methodology consists of various activities in which several techniques are applied. This Section presents the procedure and additional material for their practical application by knowledge managers.

9.7.1 Additional Material to Conduct Step 1 "Defining Goals"

Procedure

Activity	**Method**	**Input**	**Output**	**Output form**
Defining normative goal and is-situation	Needs assessment in discussion between company's managers	• *Types of goals* (SD) • Empty *needs assessment* (T)	• Normative goal • Is-situation	Documented in *needs assessment* (T)
Defining strategic goal	Needs assessment in discussion between company's managers	• *Types of goals* (SD) • *Needs assessment* (T) filled with normative goal and is-situation • *Knowledge audit framework* (SD)	• Strategic goal	Documented in *needs assessment* (T)

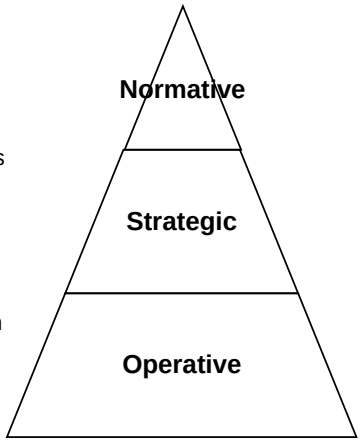
Defining process phase to target	Needs assessment in discussion between company's managers	• Filled *needs assessment* (T) • Company PDP (if available) • *Standard PDP* (if company's PDP not available) (SD)	• Focus PDP phase/s	Indicated on the used PDP
Defining target knowledge	Needs assessment in discussion between company's managers	• Filled *needs assessment* (T) • Focus PDP phase/s • *Knowledge pyramid* (SD) • *Taxonomy of knowledge dimensions* (SD) • Empty *definition of knowledge target* (T)	• Definition of know-ledge target	Documented in *definition of knowledge target* (T)
Identifying stakeholder	Discussion between company's managers	• Filled *needs assessment* (T) • Filled *definition of knowledge target* (T) • List of companies departments • Empty *stakeholders' portfolio* (T)	• Stakeholders to involve in next steps of *k*-MORE	Filled *stakeholders' portfolio* (T)
Identifying representative projects	Discussion between company's managers	• Filled *definition of knowledge target* (T) • Filled *stakeholders' portfolio* (T) • Empty *definition of representative projects* (T)	• Representative projects	Documented in *definition of representative projects* (T)

Note: the terms in cursive font are part of the Support Documentation (SD) or Templates (T)

Support Documentation (SD)

Types of goals

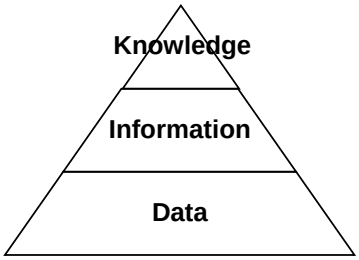
- **Normative goal**: vision of corporate policy and company's culture
  - Example: leader in innovation, culture of knowledge sharing
  - Define when? *k*-MORE step 1 "Defining goals"
- **Strategic goal**: long-term measures necessary to achieve the normative goals
  - Example: development of new competences, achieve knowledge transparency
  - Define when? *k*-MORE step 1 "Defining goals"
- **Operative goal**: daily activities which will be conducted for the implementation of the strategic goals
  - Example: training programs, expert database
  - Define when? end results of *k*-MORE



More information: Probst et al. (2012)

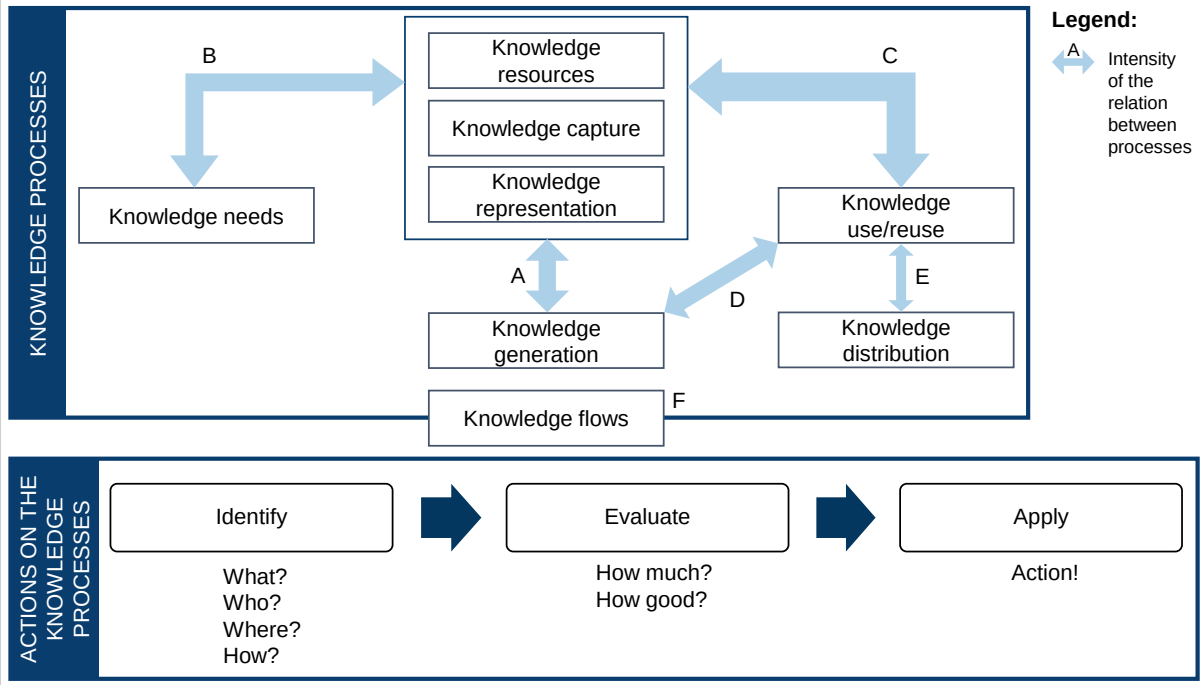
Knowledge pyramid

- **Knowledge**: information combined with experience, context, interpretation, and reflection
  - Example: 2°C is warm, because the temperature in Munich in January is usually lower
- **Information**: placing data within some meaningful context
  - Example: 2°C in Munich in January
- **Data**: raw observations and facts
  - Example: 2



More information: Dalkir (2005)

Knowledge audit framework



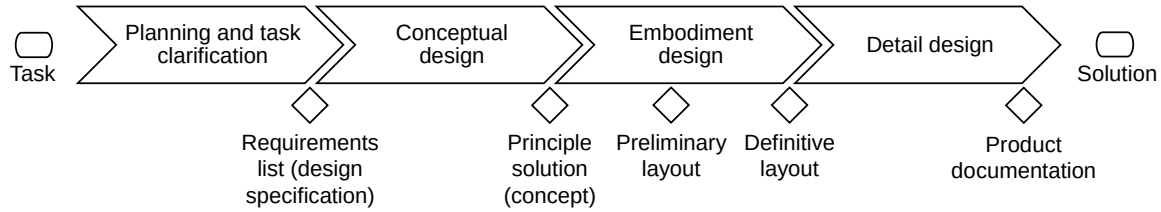
Taxonomy of knowledge dimensions

Dimension	Category			
Origin	Internal	External		
Nature	Explicit	Implicit	Tacit	
Concretization level	General	Specific		
Situation of knowledge acquisition	Experience	Contact	Human ability	
Subject	Product	Process	Contacts	Environment
	Constraints and specifications Conceptual Structural Functional Behavioral Technical Calculations	Manufacturing process Design process	Supplier Customer Competitor Other stakeholders	Legislation Country/market Environmental entity Product lifecycle

Note: the categories of the dimension “subject” are further subdivided due to the relevance of their concretization for different purposes on engineering design.

More information: Carro Saavedra, Serrano Villodres and Lindemann (2017)

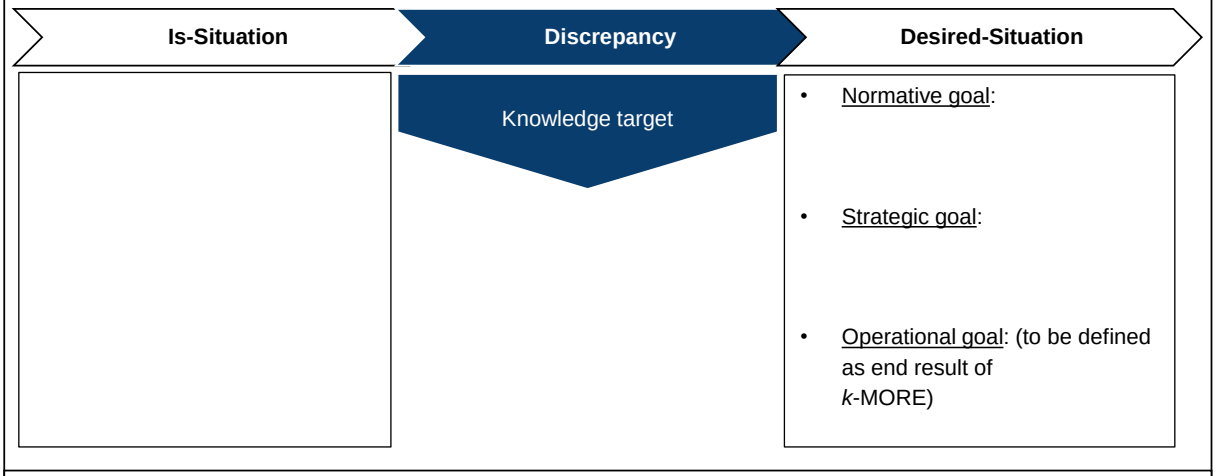
Standard PDP



More information: Pahl & Beitz (2007)

Templates (T)

Needs assessment



More information: Kaufman et al. (1993)

Definition of knowledge target

Which **knowledge** (knowledge target) should be considered for **systematic reuse**?

Concept name: **knowledge**		
Key attributes	Examples	Nonexamples

Definitions:

- **Attribute**: characteristic of the knowledge target, such as tacit, explicit, internal, external, documented, not documented, etc. The knowledge pyramid and the taxonomy of knowledge categories serve as inspiration to define the attributes of the knowledge target.
- **Example**: real example from the company of knowledge which has the defined attributes.
- **Nonexample**: real example from the company of knowledge which does not have the defined attributes.

More information: Dalkir (2005), Buchanan and Gibb (2007)

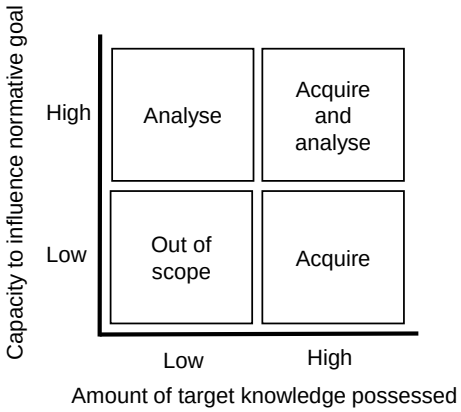
Stakeholders' portfolio

Questions to fill the portfolio

- Which is the capacity of each stakeholder/department to **influence** on the company's **normative goal** (defined in the needs assessment)?
- Which is the **amount** of **target knowledge** (defined in the definition of knowledge target) of each stakeholder/department?

Interpretation of results:

- **Analyse**: the influencing factors for knowledge reuse of the stakeholder/department in this field of the portfolio will be analysed in the step "Analysis" of *k*-MORE
- **Acquire:** the knowledge of the stakeholder/department in this field of the portfolio will be acquired and visualised in a knowledge map in the step "Visualising" of *k*-MORE



Definition of representative projects

Representative projects will be the focus of the knowledge acquisition

Helpful questions

- Which are the **products** developed in the company?
- Which products have a **representative development process**?

Product developed	Departments involved	Characteristics	Similar to…

9.7.2 Additional Material to Conduct Step 2 "Visualising"

Procedure

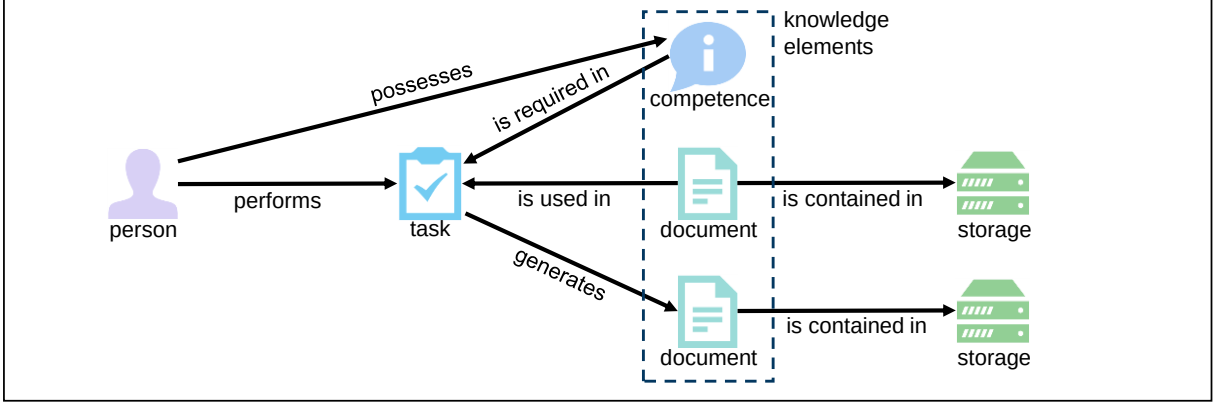
Activity	Method	Input	Output	Output form
Select participants	Discussion between company's managers	• Stakeholders to involve in next steps of *k*-MORE • Representative projects • Target knowledge	• List of participants	Free choice
Prepare examples	Discussion with participants	• List of participants • *Metamodel of knowledge map* (SD)	• Company-specific examples	Documented in knowledge map form
Conduct acquisition workshops	Workshop	• Company-specific examples • *Process for the acquisition workshop*	• Roles, tasks and knowledge elements	Filled digital *Mapping Matrix* (T)

		(SD) • Empty *Mapping Matrix* (T)		
Refine results	Iterative questionnaire or interview	• Filled digital *Mapping Matrix* (T)	• Roles, tasks and knowledge elements	Filled digital *Mapping Matrix* (T)
Consolidate results	Questionnaire, interview or workshop	• Filled digital *Mapping Matrix* (T) • *Process for the consolidation workshop* (SD)	• Final roles, tasks and knowledge elements • Should-be knowledge flows	Filled digital *Mapping Matrix* (T) including should-be knowledge flows
Create knowledge maps	Graph modelling software	• Filled digital *Mapping Matrix* (T) including should-be knowledge flows	• As-is knowledge map • Should-be knowledge map	Digital graphs

Note: the terms in cursive font are part of the Support Documentation (SD) or Templates (T)

Support Documentation (SD)

Metamodel of knowledge map

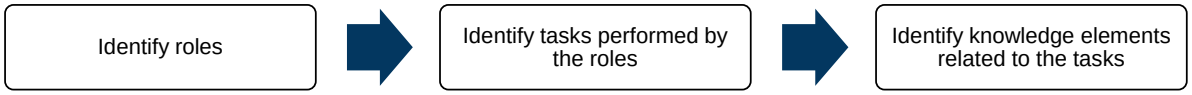


Process for the acquisition workshop

Participants: max. 6 participants with good overview of processes and knowledge in the department/area

Duration: max. 4 h (around 1 h per phase with breaks in between)

Material
- Department-specific examples of roles, tasks and knowledge elements
- Representative projects and list of storages
- Workshop cards in 3 colours (Roles: yellow, tasks: green, knowledge elements: blue), two pin boards, flipchart, pens.



Identify roles
- Each participant writes his/her own role/s on a card and pins it/them on the pin board with a short explanation
- The group identifies other roles of the department/area which are not performed by the workshop participants
- Roles clustering, so in the end no more than 15 roles remain
- Assign roles of non-participants to workshop participants

Identify tasks performed by the roles
- Each participant writes the tasks performed by the roles he/she has assigned
- Tasks clustering so in the end no more than 30 different tasks remain
- Order task according to the product development process
- In a break (organiser): create the mapping matrix in a pin board and fill it with the collected tasks

Identify knowledge elements related to the tasks
- Each participant writes the knowledge elements for the correspondent tasks of their assigned roles and pins them in the mapping matrix of the pin board. Competences are marked with “C” and documents with “D”. In the case of the documents, include storage in the back side of the card.
- The group identifies repeated documents so names are consolidated and duplicities eliminated
- Identify links in the matrix (documents used are indicated with “u”, documents generated are indicated with “g”, and competences required are indicated with “c”)

Hint: the main objective is to collect all knowledge elements. The links with “u”, “g” and “r” can be collected after the workshop using the digital mapping matrix

Process for the consolidation workshop

Participants: max. 6 participants (1/2 participants of each department/area who participated in the acquisition workshops)

Duration: max. 4 h (around 1 h for the first phase and around 2 h for the second phase with breaks in between)

Material
- Printed digital mapping matrix of each of the departments/areas collected in the acquisition workshops
- One poster with the generated knowledge elements of each department/area
- Two posters of the tasks of each department/area
- Two pin boards, pens.

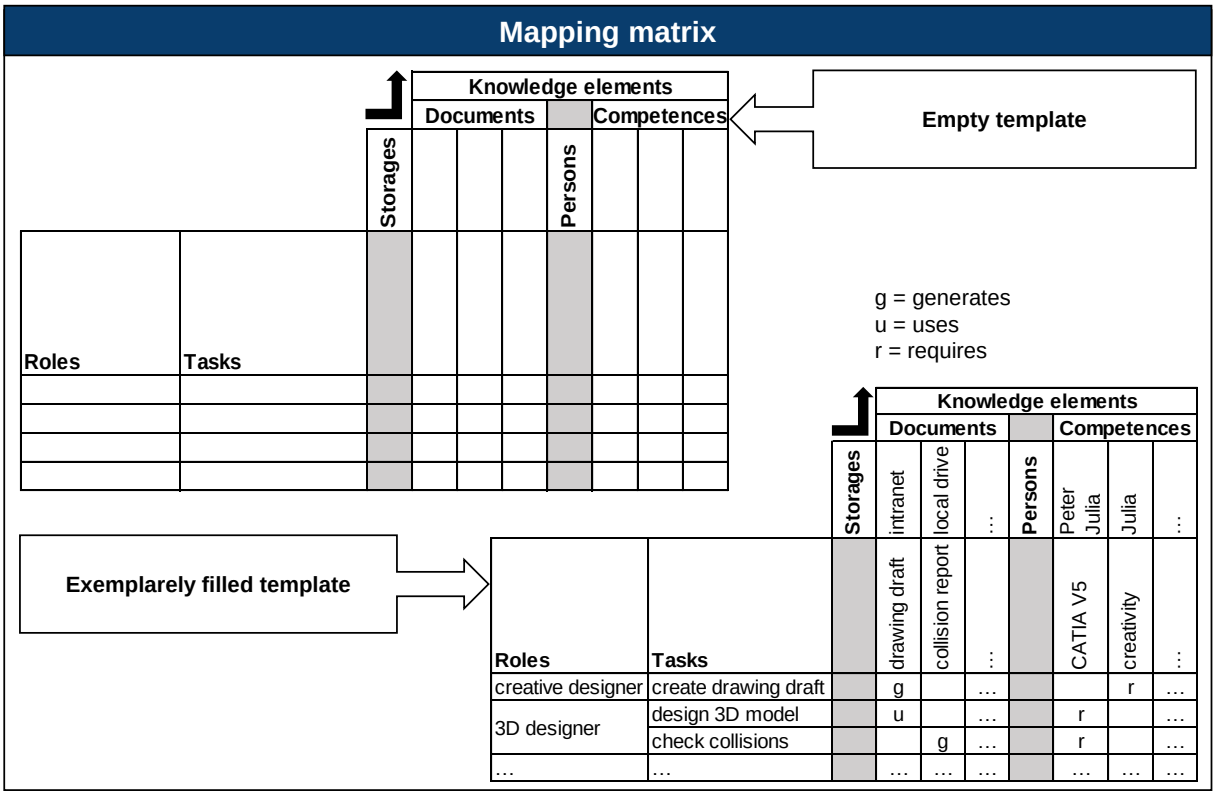
Identify current knowledge exchange between departments
- Each participant receives the printed digital mapping matrix of its department/area
- Working in groups of people from different departments, the participants go through the matrices and they identify exchanged knowledge elements, consolidate naming of the knowledge elements, review and complete the assigned links. Knowledge elements can be added.

Hint: this part considers only the is situation

Identify should-be knowledge exchange between departments
- Put together the poster of generated knowledge elements of each department and the posters indicating the tasks of the other departments.
- Identify which knowledge elements from other departments should-be exchanged drawing directly the links on the posters.

Hint: the most relevant combination of departments should be considered first (in case there is no time to complete all)

Templates (T)


Mapping matrix
Knowledge elements
Documents
Competences
Storages
Persons
Roles
Tasks
Empty template
g = generates
u = uses
r = requires
Exemplarely filled template
intranet
local drive
Peter
Julia
drawing draft
collision report
CATIA V5
creativity
creative designer
create drawing draft
3D designer
design 3D model
check collisions

9.7.3 Additional Material to Conduct Step 3 “Analysing”

Procedure

Analysis of the knowledge map				
Activity	**Method**	**Input**	**Output**	**Output form**
Apply analysing rules	Graph analysis	• As-is knowledge map • Should-be knowledge map • *Table for rules reflection* (SD)	• Results of the analysis	Documented in *reflection sheets* (T)
Reflect the results	Discussion between company’s managers	• *Table for rules reflection* (SD) • *Reflection sheets* (T) filled with the results of the analysis	• Critical elements and initial actions	Documented in *reflection sheets* (T)

Analysis of individual perceptions				
Activity	**Method**	**Input**	**Output**	**Output form**
Prepare questionnaire	Discussion with participants	• *Worker-Centred Model* (SD) • Empty *questionnaire of influencing factors* (T)	• Company-specific examples of current consideration of each influencing factor	Documented in *questionnaire of influencing factors* (T)
Conduct questionnaire	Online questionnaire	• Filled *questionnaire of influencing factors (company)* (T) • *Questionnaire of influencing factors (relevance)* (SD)	• Questionnaire results	Free choice
Visualise and analyse the results	Boxplots and gap analysis	• Questionnaire results • *Boxplot definition* (SD) • *Analysis flowchart* (SD)	• Needs for consideration of each factor (global and individual)	Free choice

Note: the terms in cursive font are part of the Support Documentation (SD) or Templates (T)

Support Documentation (SD)

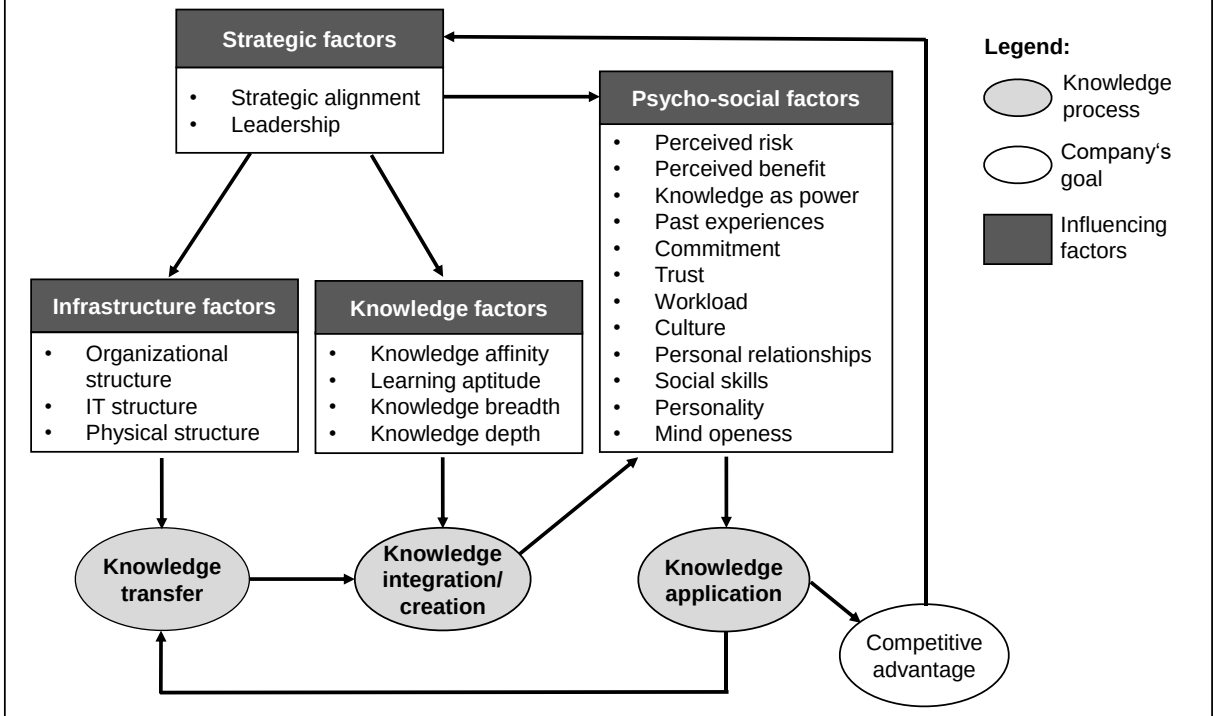
Phase to consider	Rule	Measure in the knowledge map	Implication for the Reuse Cycle	Reflection
 **Packaging**	Storages containing low number of documents	Storage number of "is contained in" edges	These storages are candidates to be eliminated	• Are the storages really necessary? • Is it possible to use more the storages?
	Storages containing high number of documents	Storage number of "is contained in" edges	These storages are the candidates to centralise storages and they should be the focus for improvements	• Are the storages updated and maintained? • Are the storages easily accessible and used? • Is it possible to improve the structure?
	Documents stored in many storages	Document number of "is contained in" edges	The storage of these documents should be unified	• Is it possible to reduce the number of storages?
	Most common terms in documents' names	Words included in documents' names	Most common terms serve as basis to define categories of a structured KB	• Are categories recognisable? • How can categories for other knowledge element be defined? Who could be a contact person for that?
	Most common terms in competences' names	Words included in competences' names	Most common terms serve as basis to define categories of a structured KB	• Are categories recognisable? • How can categories for other knowledge element be defined? Who could be a contact person for that?

Phase to consider	Rule	Measure in the knowledge map	Implication for the Reuse Cycle	Reflection
 **Capturing & documenting**	Frequently generated documents	Document number of "generates" edges	These documents require clear standards and agreement about versions, updates and templates	• Are there clear documentation processes (template, automation) • Are the processes well integrated in daily work? • How are updates communicated? Is it clear?
	Documents not frequently generated or used	Number of "is used in" and "generates" edges in documents	These documents tend to be documented for own purposes. They can be unusable with time due to lack of understandable structures and terminology	• Are the documents understandable? • Are the generators of the documents well known and available?
	Roles which generate many documents	Document number of "generates" edges (link to roles through "performs" edges)	These roles are the focus group for documentation and they should be involved in its planning	• Are responsible for documentation clearly defined?

Phase to consider	Rule	Measure in the knowledge map	Implication for the Reuse Cycle	Reflection
 **Reusing**	Frequently used documents	Document number of "is used in" edges	These documents require clear access and understandability	• Are the documents clear and understandable? • How is it assured that always the new version is the one retrieved?
	Roles which use many documents	Document number of "is used in" edges (link to roles through "performs")	These roles are the focus group for reusing and they should be involved in its planning	• Can the roles access the documents efficiently?

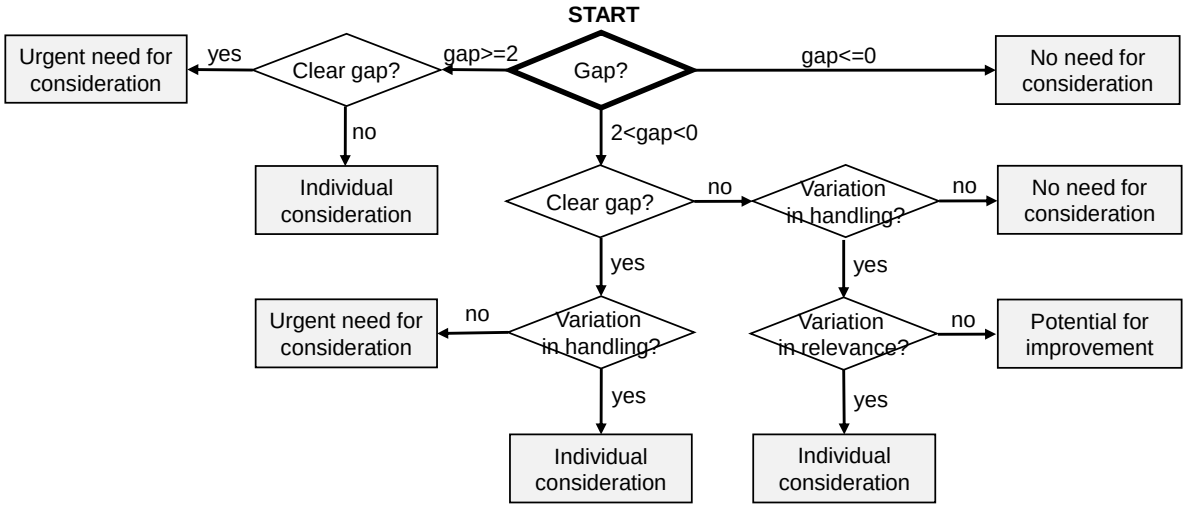
Phase to consider	Rule	Measure in the knowledge map	Implication for the Reuse Cycle	Reflection
 **Distributing**	Frequently required competences	Competence number of "is required in" edges	There should be enough roles possessing these competences, and they should be quickly identified and available	• Are competence owners well known and available? • Are enough of these competences available?
	Competence possessed by few roles	Competence number of "possesses" edges	Competences possessed by few roles may get lost. Their distribution to roles must be considered	• Is the number of owners enough? • Are the competences' owners well known and available?
	Documents transferred between many roles	Number of roles connected to a document (link through "performs" plus "is used in" / "generates" edges)	These documents require clear access under consideration of credentials. Active exchange should be promoted	• Have the correspondent roles the credentials needed? • Is sensitive knowledge protected? • How are updates communicated? • How could the roles increase their informal exchange?
	Visible clusters in the knowledge map	-	Clusters are groups of people that intensively exchange knowledge. Credentials in the cluster and from outside should be considered, as well as how to promote the exchange in and between clusters	• Is there any desired/relevant knowledge not accessible between clusters? • Should clusters exchange more to each other? How? • Should more exchange/ new credentials inside the cluster be promoted? How?

Worker-Centred Model

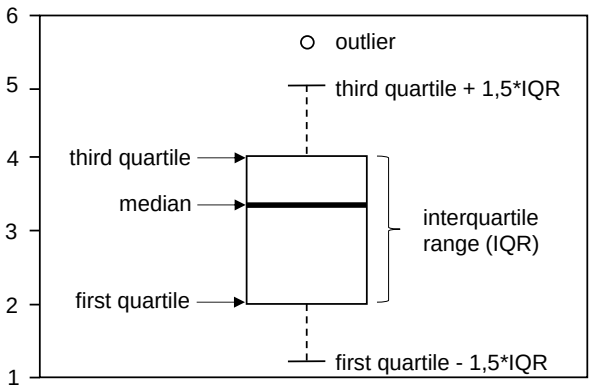


More information: Carro Saavedra, Fernandez Miguel and Lindemann (2015); Fernandez Miguel, Carro Saavedra and Lindemann (2016)

Analysis flowchart



Boxplot definition



First quartile: 25% of the answers are below this value

Third quartile: 75% of the answers are below this value

Interquartile range (IQR): rectangle between the first and third quartile. It contains 50% of the answers

Upper limit: third quartile + 1,5*IQR

Lower limit: first quartile - 1,5*IQR

Media: value separating the higher half from the lower half of a data sample

Outlier: data point that is located outside the fences of the boxplot

More information: Eid et al. (2017)

Definitions of WCM influencing factors

INFRASTRUCTURE FACTORS

- **Organisational structure**: it is the distribution of the company's human resources (hierarchies, departments, teams, etc.) and the company's processes that to carry out the employees' work.
- **IT structure**: it is the implementation of IT systems such as intranets, email, chat-clients, and/or videoconferencing systems that your company provides for KM and coordination.
- **Physical structure**: it is the arrangement of people (and other resources such as meeting rooms, meeting places, etc.) within buildings. This also includes the positioning of departments in the same or different buildings or in different cities or countries.

KNOWLEDGE FACTORS

- **Knowledge affinity**: it describes how easy it is for one or various individuals to understand the knowledge received based on what they already know.
- **Learning aptitude**: it is the ability to learn new things and understand how they can be used.
- **Knowledge breadth**: it indicates to which degree knowledge can be generalised and applied to different situations.
- **Knowledge depth**: it indicates to which degree knowledge is detailed and specific to restricted situations.

PSYCHO-SOCIAL FACTORS

- **Perceived risk**: it describes the personal perception of negative effects that can occur due to an act of knowledge reuse.
- **Perceived benefit**: it describes the personal perception of positive effects that can occur due to an act of knowledge reuse.
- **Knowledge as power**: it is the perception that knowledge can be used to maintain a competitive position in the company (uniqueness, reputation, etc.) or to lose it (criticism, exposure, etc.).
- **Past experiences**: they can be positive or negative. These experiences allow to establish analogies for new situations from memories.
- **Commitment**: it indicates the degree to which employees are ready to work for the success of the company.
- **Trust**: it is the belief in the reliability, truth or ability of a person or thing.
- **Workload**: it describes the relationship between the time it takes to complete a task and the length of that time window to perform it.
- **Culture**: it describes the behavioural characteristics of a particular social group (company, country, etc.).
- **Personal relationships:** they describe the interaction between two or more people.
- **Social skills**: they are the ability to communicate, persuade, and interact with others without causing inappropriate conflicts or disagreements.
- **Personality**: it represents the different mental attitudes of a person.
- **Mind openness**: it means being open to others' views, ideas and knowledge.

STRATEGIC FACTORS

- **Strategic alignment**: it is the degree to which the different resources (IT, buildings, daily meetings, available knowledge, etc.) are coordinated to meet common goals.
- **Leadership**: it is the ability of company's leaders to create an environment in which employees seek and share the knowledge they need:

Templates (T)

Reflection sheet

Rule	Implication for the Reuse Cycle	Phase to consider
(from table for rules reflection)	*(from table for rules reflection)*	*(from table for rules reflection)*

Results	Reflection
	(from table for rules reflection)

Critical elements and initial actions

Questionnaire of influencing factors (company)

Influencing factor

"Company's *influencing factor* influences *knowledge process*"

Definitions:

- [Definition of influencing factor]
- [Definition of knowledge process]

Example of current *influencing factor* in your company:

- [Company-specific example]

Please rate the next statement

The current handling of *influencing factor* in my company supports the *knowledge process* in the company

Completely disagree	Disagree	Rather disagree	Rather agree	Agree	Completely agree
☐	☐	☐	☐	☐	☐

Please justify your answer (optional)

Questionnaire of influencing factors (relevance)

If your reached this point of the questionnaire, you have evaluated how your company handles the 21 influencing factors. Now, we ask you to evaluate the **general relevance** of the factors. Please forget the specific case of your company and reflect which factors are most influencing for any company to achieve successful knowledge reuse.

In case you need to remind the definition of the influencing factor, just position your mouse pointer on top.

Please rate the next statement

The influencing factor is generally relevant to achieve knowledge transfer, knowledge generation/creation and knowledge application in engineering design companies.

	Completely disagree	Disagree	Rather disagree	Rather agree	Agree	Completely agree
IT-structure	☐	☐	☐	☐	☐	☐
Organisational structure	☐	☐	☐	☐	☐	☐
Physical structure	☐	☐	☐	☐	☐	☐
Knowledge affinity	☐	☐	☐	☐	☐	☐
Learning aptitude	☐	☐	☐	☐	☐	☐
Knowledge breath	☐	☐	☐	☐	☐	☐
Knowledge depth	☐	☐	☐	☐	☐	☐
Perceived risk	☐	☐	☐	☐	☐	☐
Perceived benefit	☐	☐	☐	☐	☐	☐
Knowledge as power	☐	☐	☐	☐	☐	☐
Past experiences	☐	☐	☐	☐	☐	☐
Commitment	☐	☐	☐	☐	☐	☐
Trust	☐	☐	☐	☐	☐	☐
Workload	☐	☐	☐	☐	☐	☐
Culture	☐	☐	☐	☐	☐	☐
Personal relationships	☐	☐	☐	☐	☐	☐
Social skills	☐	☐	☐	☐	☐	☐
Personality	☐	☐	☐	☐	☐	☐
Mind openess	☐	☐	☐	☐	☐	☐
Strategic alignment	☐	☐	☐	☐	☐	☐
Strategic leadership	☐	☐	☐	☐	☐	☐

9.7.4 Additional Material to Conduct Steps 4 to 7 “Planning the Reuse Cycle”

Procedure

Activity	Method	Input	Output	Output form
Prepare methods’ portfolio	Work of knowledge manager	• Needs for consideration of each factor • Empty *methods’ portfolio* (T) • *Methods catalogue* (SD)	• Suitable methods per phase of the knowledge reuse cycle	Documented in *methods’ portfolio* (T)
Define actions	Work of knowledge manager	• Filled *reflection sheets* (T)	• Actions	Documented in *planning sheets* (T)
Define next steps	Work of knowledge manager	• *Planning sheets* (T) filled with actions • As-is knowledge map • Should-be knowledge map	• Next steps	Documented in *planning sheets* (T)
Propose methods	Work of knowledge manager / Discussion between company’s managers	• *Planning sheets* (T) filled with actions and next steps • Filled *methods’ portfolio* (T)	• Selected methods for discussion • Selected methods for implementation	Documented in *planning sheets* (T)
Carry out next steps	Work of knowledge manager / Discussion with stakeholders	• Filled *planning sheets* (T)	• New actions and next steps (iteration) • Final actions for implementation of the knowledge reuse cycle (end of planning)	Documented in new *planning sheets* (T)

Note: the terms in cursive font are part of the Support Documentation (SD) or Templates (T)

Support Documentation (SD)

METHODS CATALOGUE (Part 1)

Method	Addressed influencing factors																										Supported phase KRC					Specially supported knowledge type															Imp. time			Imp. effort		
	IT structure	Organisational structure	Physical structure	Knowledge affinity	Learning aptitude	Knowledge breath	Knowledge depth	Perceived risk	Perceived benefit	Knowledge as power	Past experiences	Commitment	Trust	Workload	Culture	Personal relationships	Social skills	Personality	Mind openess	Strategic alignment	Strategic leadership	Cap. & doc.	Packaging	Distributing	Reusing	Maintaining	Origin: External	Origin: Internal	Nature: Explicit	Nature: Implicit	Nature: Tacit	Concret. level: General	Concret. level: Specific	Situation of knowledge: Experience	Situation of knowledge: Contact	Human ability acquistion	Subject: Product	Subject: Process	Subject: Contacts	Subject: Environment	Short-term	Mid-term	Long-term	Low	Medium	High
Advanced trainings knowledge					X	X	X					X								X	X			X		X	X					X								X				X	
Advanced trainings social skills					X							X					X	X	X	X	X			X		X	X					X								X				X	
Balanced scorecard																				X	X				X																	X			X	
Benchmarking (of KM methods)								X												X	X				X	X															X				X	
Benchmarking (of technical products)						X	X																		X	X										X					X				X	
Best practice sharing (of design methods)						X	X																	X		X	X										X						X	X			
Best practice sharing (of KM methods)								X												X	X			X		X	X															X	X			
Blended Learning						X	X																	X		X	X		X												X				X	
Blue Pages (external experts register)									X					X									X				X		X												X			X		
CoMem	X					X	X							X									X		X			X	X	X												X				X
Communities of Practice (CoP)		X		X	X	X	X	X		X	X		X		X	X			X	X	X			X			X								X						X				X
Computer with Rhinoceros CAD package	X																					X			X			X	X				X								X			X	
Corporate University				X								X			X				X					X																		X				X
C-QuARK				X				X	X		X			X											X			X	X												X			X		
Creation of new positions responsible for KM		X													X					X	X	X	X	X	X																X				X	
Creativity techniques																			X							X																X			X		
Digital Knowlegde Repository	X																						X		X		X	X	X														X				X
Economic rewards									X									X				X			X																X				X	
Employee information, newspaper				X								X			X						X			X				X															X		X			
Employees teach employees				X		X	X			X		X	X		X	X				X				X			X								X						X					X
External contact fairs																	X		X	X					X	X		X										X			X		X		X		
Feedback orientated knowledge dialogue between experts and „employees with basic knowledge“				X		X	X						X		X	X								X				X	X					X						X			X		
Firm intern transportation service			X											X		X								X																X				X	
Form a constructive and open atmosphere		X			X					X			X		X	X			X		X			X	X		X															X			X	
Forming knowledge promoting organisation forms		X								X			X		X	X				X				X			X								X							X			X
Found an affiliated company		X	X	X						X		X							X	X	X			X																		X			X
Frequently-Asked-Questions catalogue (FAQ)				X					X		X		X	X	X					X	X		X			X	X	X													X			X	
Get together				X								X	X		X	X								X			X							X							X			X	
Glossary, corporate directory		X		X										X	X					X					X				X								X					X			X	
Hiring of external experts																				X					X	X			X	X			X		X							X			X	
Info-Center				X					X					X						X	X			X			X															X			X	
Installing an owner and a manager of each database	X																			X			X													X						X			X	
Internal contact fairs				X									X		X	X			X					X			X	X						X							X			X		
Intranet	X																						X																				X				X

METHODS CATALOGUE (Part 2)

Method	Addressed influencing factors																													Supported phase KRC				Specially supported knowledge type															Imp. time			Imp. effort		
	IT structure	Organisational structure	Physical structure	Knowledge affinity	Learning aptitude	Knowledge breath	Knowledge depth	Perceived risk	Perceived benefit	Knowledge as power	Past experiences	Commitment	Trust	Workload	Culture	Personal relationships	Social skills	Personality	Mind openess	Strategic alignment	Strategic leadership	Cap. & doc.	Packaging	Distributing	Reusing	Maintaining	Origin		Nature		Concret. level		Situation of knowledge		Human ability acquistion	Subject				Short-term	Mid-term	Long-term	Low	Medium	High
																											External	Internal	Explicit	Impliit	Tacit	General	Specific	Experience	Contact		Product	Process	Contacts	Environment						
Job shadowing				X	X	X	X			X						X								X			X			X				X							X			X		
Job enlargement		X										X						X	X		X			X																		X		
Job enrichment		X							X	X								X						X			X														X	X		
Job rotation		X		X	X	X	X			X	X				X	X			X					X			X														X			X
Knowledge maps	X			X						X				X	X	X				X			X		X		X														X			X	
Launch innovation processes																				X						X				X												X			X	
Lessons Learned							X	X		X	X	X				X					X	X			X			X	X	X												X			X	
Lunch and learn				X									X	X		X	X								X			X								X							X			X	
Media library	X								X		X			X											X	X				X							X					X			X	
Mentoring / coaching				X		X	X					X	X		X	X								X			X								X						X				X
Mind mapping				X		X	X															X							X												X			X		
Mobile e-notes taker	X						X															X			X		X	X	X												X			X	
Multidimensional knowledge push	X			X				X						X											X				X													X			X	
Obeya		X		X	X	X	X	X		X		X	X		X				X					X			X														X			X	
Ontology				X				X						X									X		X			X													X			X	
Open-space-technology		X		X	X	X	X	X		X		X	X			X			X					X		X		X													X			X	
Pinboard / ideas market												X			X				X	X	X	X						X	X	X												X			X	
PreSERVe						X	X															X						X					X									X			X	
Process modeling						X	X															X						X	X													X			X	
Project documentation						X	X															X						X	X													X	X			
ProMem	X					X	X																X		X		X		X												X			X	
PROSUS	X								X					X									X				X	X			X				X	X					X			X	
Roleplaying				X	X								X		X	X	X	X	X					X						X											X			X		
Semantic information retrieval system	X													X											X		X	X	X												X			X	
Team events outside of the organisation				X								X	X		X	X								X			X							X							X			X	
Trainee program for employees		X		X	X										X	X								X			X														X			X	
Triad conversation				X	X					X	X		X			X								X						X			X							X			X	
Video-based Lessons learned	X					X	X				X				X							X			X		X		X	X			X								X			X	
Visual storytelling	X					X	X															X			X		X	X	X			X				X					X			X	
Wacom tablet with viewing facility	X						X															X			X		X	X	X												X			X	
Webinars / e-learning						X	X																			X	X		X												X			X		
Weblogs						X	X				X				X									X	X			X	X												X			X		
Wiki	X			X		X	X		X		X			X	X							X			X			X	X												X			X		
Yellow pages (internal expert register)									X					X									X					X	X									X			X			X		

Advanced trainings knowledge

Goal Preservation (internal training) and increasing (external training) of employees' knowledge	**Advantages** "Win-Win" situation for employee and employer	**Disadvantages** It requires employees' self-discipline and organisational skills
Tools/Procedure Trainer, room for trainings		
Hints It can be in any direction and with any focus		
Source for further information Probst et al. (2012, pp. 152–154)		

Advanced trainings social skills

Goal Preservation (internal training) and increasing (external training) of employees' social skills	**Advantages** "Win-Win" situation for employee and employer	**Disadvantages** It requires employees' self-discipline and organisational skills
Tools/Procedure Trainer, room for trainings		
Hints It can be in any direction and with any focus		
Source for further information Probst et al. (2012, pp. 152–154)		

Balance scorecard

Goal Analysis of company's vision and strategy in order to identify new knowledge management needs	**Advantages** Controlling of alignment of knowledge management and company's strategy	**Disadvantages** Time consuming and company-specific
Tools/Procedure Analysis from four perspectives: 1) Financial 2) Customer 3) Internal processes 4) Learn and growing		
Hints -		
Source for further information Probst et al. (2012, p. 230)		

Benchmarking (of knowledge management methods)

Goal	**Advantages**	**Disadvantages**
Continuous analysis and comparison of methods applied in different companies	Increasing companies' knowledge about knowledge management methods	It requires access to other companies data
Tools/Procedure 1) Select subject 2) Select the company to be compared with 3) Acquire data 4) Determined performance gaps and causes 5) Perform improvement actions		
Hints -		
Source for further information http://wirtschaftslexikon.gabler.de/Definition/benchmarking.html		

Benchmarking (of technical products)

Goal	**Advantages**	**Disadvantages**
Continuous analysis and comparison of methods applied in different companies	Increasing companies' knowledge about technical products	It requires access to other companies data
Tools/Procedure 1) Select subject 2) Select the company to be compared with 3) Acquire data 4) Determined performance gaps and causes 5) Perform improvement actions		
Hints -		
Source for further information http://wirtschaftslexikon.gabler.de/Definition/benchmarking.html		

Best practice sharing (of design methods)

Goal	**Advantages**	**Disadvantages**
Discussing the applied design methods with other companies	Increasing companies' knowledge about design methods	Participants must be open for sharing their knowledge
Tools/Procedure 1) Identify practices that fit your needs 2) Adopt them to you		
Hints It can also take place inside the company		
Source for further information Reinmann (2009, pp. 77–79)		

Best practice sharing (of knowledge management methods)

Goal Discussing the applied knowledge management methods with other companies	**Advantages** Increasing companies' knowledge about knowledge management methods	**Disadvantages** Participants must be open for sharing their knowledge
Tools/Procedure 1) Identify practices that fit your needs 2) Adopt them to you		
Hints It can also take place inside the company		
Source for further information Reinmann (2009, pp. 77–79)		

Blending learning

Goal Combining online educational material with traditional classroom methods in order to distribute knowledge fast, understand it deeply and apply it independently	**Advantages** High flexibility and personalisation for teachers and students	**Disadvantages** Unreliable or not user friendly tools can deliver a bad learning experience
Tools/Procedure Different models: face-to-face driver, rotation, labs, self-blend, online driver		
Hints -		
Source for further information Frey-Luxemburger (2014, pp. 146–165)		

Blue pages (external experts register)

Goal Register of external experts to obtain certain knowledge when needed	**Advantages** Expert can be asked when it is needed	**Disadvantages** Experts might not be accessible when needed
Tools/Procedure Software, computer, server		
Hints It must be maintained by a responsible person		
Source for further information Lehner (2012, p. 200)		

CoMem

Goal Corporate memory to adopt the process of internal knowledge reuse to the process of external knowledge reuse	**Advantages** Overview of the captured knowledge, zoom and filter	**Disadvantages** It implies a full change on the way of working during product design
Tools/Procedure CoMem-Software, ProMem-Software, computer		
Hints Time and effort relatively high Extension of ProMem		
Source for further information Fruchter and Demian (2002)		

Communities of Practice (CoP)

Goal Knowledge transfer and learning without support of a teacher or lecturer	**Advantages** Synergies through exchange of experiences of heterogeneity of participants Acquiring different perspectives	**Disadvantages** A reason to create a CoP is required Possible disagreements
Tools/Procedure -		
Hints Open discussions and knowledge exchange can be online or offline		
Source for further information Lehner (2012, pp. 221–224)		

Computer with Rhinoceros CAD package

Goal Capture sketches and curves to ideate 3D models of designs	**Advantages** It supports the natural generation of 3D models	**Disadvantages** It requires computer licenses that can be expensive It only supports 3D modelling information
Tools Rhinoceros (software), computer		
Hints -		
Source for further information https://www.rhino3d.com/sales/europe/Germany Vijaykumar and Chakrabarti (2010)		

Corporate university

Goal Create a common culture, loyalty and feeling of belonging to a company	**Advantages** Highly company related	**Disadvantages** Very costly
Tools/Procedure Facilities, materials, teachers		
Hints Time and effort are very high		
Source for further information http://www.managerseminare.de/Datenbanken_Lexikon/Corporate-Universities,153125		

C-QuARK

Goal Guide novice designers to be aware of what they need to know	**Advantages** Very easy implementation (low time and resources)	**Disadvantages** No software implementation
Tools/Procedure Paper sheet presenting the method		
Hints The method can be used to structure information within the Intranet		
Source for further information Ahmed and Wallace (2004)		

Creation of new positions responsible for knowledge management

Goal Assign new responsibilities to implement knowledge management in the company like Chief Knowledge Officer (CKO)	**Advantages** Improvement of knowledge management	**Disadvantages** One person might not be enough Costly
Tools/Procedure Tasks of Chief Knowledge Officer (CKO): • Create successful knowledge management infrastructure • Distribute knowledge • Identify high priorities • Understand knowledge management users • Ensure knowledge architecture		
Hints -		
Source for further information Ghose and Jambhekar (2003, p. 8)		

Creativity techniques

Goal Promote creativity in order to develop new knowledge and ideas	**Advantages** No boundaries and no criticism while collecting ideas	**Disadvantages** Openness of participants is required Lack of methods' competence can generate participants' rejection
Tools/Procedure Numerous techniques: brainstorming, synectics, etc.		
Hints -		
Source for further information Probst et al. (2012, p. 120)		

Digital knowledge repository

Goal Archive documentation in a structured digital format	**Advantages** Getting rid of asynchronicity	**Disadvantages** Lose of overview
Tools/Procedure Software, computer		
Hints It must be maintained by a responsible person		
Source for further information Firdaus et al. (2015)		

Economic rewards

Goal Providing employee's motivation to perform valuable tasks for the organisation	**Advantages** Fast implementation	**Disadvantages** It might not work for everybody
Tools/Procedure Direct rewards: wages, incentives, bonus Indirect rewards: time not worked, training, contributions to employees' benefit plans such as medical dental and life insurance, fringe benefits, expense account, and other allowances		
Hints It attracts individuals who value economic wealth		
Source for further information Martin Cruz et al. (2009)		

Employee information, newspaper

Goal Serve as source of information for (former) employees with company- and industry-relevant topics	**Advantages** Easy to create	**Disadvantages** Responsible person is required
Tools/Procedure -		
Hints It can be printed or in digital form		
Source for further information Mänken (2009)		

Employees teach employees

Goal Increasing the bond between employees and detecting faster the knowledge gaps	**Advantages** Communication between employees is increased	**Disadvantages** Lack of employees qualification for teaching others
Tools/Procedure -		
Hints "Teachers" should possess the required teaching skills		
Source for further information Probst et al. (2012, p. 240)		

External contact fairs

Goal Bringing together different parties and people to promote knowledge exchange	**Advantages** Acquiring new knowledge contacts Personal contact without appointments	**Disadvantages** Time consuming
Tools/Procedure 1) Plan the event regarding time, place and people 2) Invite all people who should meet 3) Maybe provide a moderator		
Hints -		
Source for further information -		

Feedback orientated knowledge dialogue between experts and „employees with basic knowledge“

Goal Facilitate transfer of specialists and managers knowledge to employees with basic knowledge	**Advantages** Adapted to the knowledge and needs of participants	**Disadvantages** Openness of participants is required
Tools/Procedure 1) Acquisition of a mentor's (expert) knowledge: objects and dependencies 2) Acquisition of a mentee's (employee with basic knowledge) knowledge gaps 3) Creation of knowledge bundles 4) Prioritizing enablers for detailed consideration 5) Visual support of transfer workshops		
Hints Specially recommended in cases of high employees fluctuation		
Source for further information Maurer (2011)		

Firm intern transportation service

Goal Provide fast transportation between different physical parts of the company	**Advantages** Increase communication in person between employees	**Disadvantages** It can be costly
Tools Transportation means, drivers		
Hints -		
Source for further information -		

Form a constructive and open atmosphere

Goal Discussing new aspects of topics, see from a different angles and foster exchange among employees	**Advantages** Increased knowledge transfer Potential innovations	**Disadvantages** Loss of overview Lack of tangible goal
Tools/Procedure -		
Hints It must be applied to all work-areas		
Source for further information Probst et al. (2012, p. 131)		

Forming knowledge promoting organisation forms

Goal Promoting exchange and discussion; strengthening of innovational an communicational processes	**Advantages** Exchange of opinion between employees Increased mind openness	**Disadvantages** Neglecting other organisation forms
Tools/Procedure -		
Hints It can either be to start a new organisation or to change the existing one		
Source for further information Lehner (2012, p. 220)		

Found an affiliated company

Goal Establish leadership qualities from the start from employees of the old company	**Advantages** Consistent company culture	**Disadvantages** Limited scope High effort
Tools/Procedure -		
Hints -		
Source for further information Probst et al. (2012, p. 121)		

Frequently-Asked-Questions catalogue (FAQ)

Goal It provides an overview to help you find a quickly answer to predefined questions	**Advantages** Documenting frequently asked questions	**Disadvantages** The question or answer someone is looking for might not be in the list
Tools/Procedure 1) Conduct a survey or collect all questions the shareholders and stakeholders have 2) Sort them by quantity 3) Make a cut at a pre-defined counter 4) Present them to the shareholders and stakeholders with the corresponding answers		
Hints It can be made for different divisions or groups of employees		
Source for further information Lehner (2012, p. 317)		

Get together

Goal Increasing self-corporate feeling and social skills	**Advantages** Increasing bond between employees	**Disadvantages** Private/organisational time consumption
Tools/Procedure 1) Plan the event regarding time, place and people 2) Invite all people who should meet 3) Maybe provide a moderator		
Hints -		
Source for further information Lehner (2012, p. 165)		

Glossary, corporate directory

Goal Defining and explaining technical terms	**Advantages** Easy to access and understand	**Disadvantages** It requires regular and careful maintenance
Tools/Procedure Software, hosting platform		
Hints It must be maintained by a responsible person		
Source for further information Lehner (2012, p. 200)		

Hiring of external experts

Goal Capturing external knowledge	**Advantages** Acquiring new knowledge	**Disadvantages** Costly
Tools/Procedure -		
Hints -		
Source for further information Probst et al. (2012, p. 99)		

Info-Center

Goal Creating a centralised contact point to answer questions	**Advantages** Fast access to information	**Disadvantages** Responsible person is required
Tools/Procedure -		
Hints -		
Source for further information http://wirtschaftslexikon.gabler.de/Definition/information-center.html		

Installing an owner and a manager of each database

Goal Ensure that the content is up-to-date and to keep the database professionally to the highest level	**Advantages** The database can be relied on at any time without hesitation	**Disadvantages** The specialist body must constantly draw the database manager's attention to its duties
Tools/Procedure -		
Hints It should be done for every database		
Source for further information Probst et al. (2012, p. 205)		

Internal contact fairs

Goal Bringing together different parties and people and promoting the exchange of knowledge	**Advantages** Communication within the organisation Personal contact without appointments	**Disadvantages** High organisational effort
Tools/Procedure 1) Plan the event regarding time, place and people 2) Invite all people who should meet 3) Maybe provide a moderator		
Hints -		
Source for further information -		

Intranet

Goal Connecting employees and distributing company's information within an internal and therefore non-public computer network	**Advantages** It assures the access of only authorised people	**Disadvantages** It requires regular and careful maintenance
Tools/Procedure Software, computer, server		
Hints -		
Source for further information http://wirtschaftslexikon.gabler.de/Definition/intranet.html		

Job shadowing

Goal One person observes another at work to get to know the job in question	**Advantages** Observed person can work almost undisturbed	**Disadvantages** Observant is not "working"
Tools/Procedure Job shadowing can take a day or longer The observer does not work on his or her own, but rather watches others in their work		
Hints -		
Source for further information Manchester Metropolitan University (2019)		

Job enlargement

Goal Extending the activities originally carried out by an employee to include further work elements	**Advantages** Employees want to extend their competences can be motivated in this way	**Disadvantages** Employees can be stressed by additional tasks
Tools/Procedure Combining various activities at the same level in the organisation and adding them to the existing job		
Hints -		
Source for further information Langenhan (2012)		

Job enrichment

Goal Increasing individual responsibility, decision-making and control powers and thus the employee's room for maneuver	**Advantages** Employees who strive for more responsibility can be motivated in this way	**Disadvantages** Challenging implementation in strong hierarchical structures
Tools/Procedure Assign employees additional responsibilities (normally reserved for higher positions)		
Hints -		
Source for further information Langenhan (2012)		

Job rotation

Goal Scheduled change of tasks or activities, including the exchange of tasks to extend the specialist knowledge of the employees	**Advantages** Knowledge distribution amongst employees and therefore secured in the company	**Disadvantages** Employees can be stressed by new tasks It can be inefficient for the company
Tools/Procedure Rotate the employees' assigned jobs throughout their employment		
Hints -		
Source for further information Langenhan (2012)		

Knowledge maps

Goal Providing a comprehensible overview of which knowledge is at which place of the company	**Advantages** Easy access to the knowledge storage/experts It can be limited to the important assignments	**Disadvantages** High effort to be created It requires regular and careful maintenance
Tools/Procedure Workshops, software for visualisation		
Hints -		
Source for further information Lehner (2012, p. 46)		

Launch innovation processes

Goal Successful implementation of ideas and inventions	**Advantages** It can reduce effort and production time	**Disadvantages** Psychological issues may occur in different steps for the different participants
Tools/Procedure -		
Hints Creativity must be supported		
Source for further information Probst et al. (2012, p. 122)		

Lessons learned

Goal Discuss and document positive and negative practical experiences to define actions for future tasks	**Advantages** Avoid repetition of mistakes and knowledge loss	**Disadvantages** Time consuming
Tools/Procedure Workshop sessions and documentation		
Hints -		
Source for further information Reinmann (2009, p. 79); Schacht and Maedche (2016)		

Lunch and learn

Goal Discussing new aspects of topics, see from a different angles and foster exchange among employees	**Advantages** Chances of open exchange (no predefined topics) with different partners	**Disadvantages** Openness of participants is required
Tools/Procedure It can be at the lunch-break or after work time		
Hints -		
Source for further information Dalkir (2005, p. 195)		

Media library

Goal Organised collection of learning materials in digital form	**Advantages** Different types of media can be used, borrowed or purchased in the library	**Disadvantages** It requires regular and careful maintenance
Tools/Procedure Computer, server, hosting platform, software		
Hints -		
Source for further information https://knowledgebase.poppulo.com/articles/Best_Practice_Guide/Tips-for-managing-your-Media-Library		

Mentoring / coaching

Goal Supporting knowledge transfer between experts and inexperienced employees	**Advantages** Training of social and communicational skills Mentors get fresh ideas from juniors	**Disadvantages** Time consuming for the mentors
Tools/Procedure 1) Identify experts and employees with basic knowledge 2) Try to match them regarding their knowledge advance and knowledge lack 3) Create an atmosphere for pleasant exchange		
Hints Required time and effort are relatively high		
Source for further information Probst et al. (2012, p. 240)		

Mind mapping

Goal Documentation of short notes in the form of a linked graph	**Advantages** Central aspects are easy recognizable	**Disadvantages** The map is a schema that is not providing all information
Tools/Procedure 1) Create a central idea 2) Add branches to your map 3) Add keywords 4) Colour code the branches (optional) 5) Include images (optional)		
Hints -		
Source for further information http://methodenpool.uni-koeln.de/download/mindmapping.pdf		

Mobile e-notes taker

Goal Capture natural handwriting to store drawings, sketches, notes, etc.	**Advantages** Combining the metaphors of both paper and computer	**Disadvantages** Risk of information overload No quality control of captured notes
Tools/Procedure Provide each employee with device		
Hints -		
Source for further information https://www.indiamart.com/proddetail/mobile-e-notes-taker-2295584191.html Vijaykumar and Chakrabarti (2010)		

Multidimensional knowledge push

Goal Shortening the time required for completing a task by pushing the "right" knowledge through intelligent computer knowledge algorithms	**Advantages** Highly task specific	**Disadvantages** Very high time and effort for its development
Tools/Procedure 1) Collecting user behavior 2) Collecting task and contextual information 3) User role mapping 4) Implement the knowledge push		
Hints -		
Source for further information Jiang et al. (2015)		

Obeya

Goal Achieving rapid communication and decision-making during product and process development by instituting a "large room" as an arena for discussions	**Advantages** Enable fast communication and decision making	**Disadvantages** Agreement on dates to use the room
Tools/Procedure Different types of rooms with different types of purposes can be installed: war room, work room, meeting room, discovery room, sharing room, workflow room, management room		
Hints -		
Source for further information Aasland and Blankenburg (2012)		

Ontology

Goal Providing a comprehensible visualisation of knowledge structures	**Advantages** It can be limited to the important assignments	**Disadvantages** It requires a consensus in terminology, hierarchies and relations for the ontology
Tools/Procedure Software for visualisation		
Hints There are predetermined languages for ontology creation: RDF, DAML+OIL, F-Logic, OWL, etc.		
Source for further information Lehner (2012, p. 203)		

Open-space technology

Goal Working with a large number of people on an open topic in a short period of time in a solution-oriented manner	**Advantages** Complex topics can be dealt with efficiently in a short period of time	**Disadvantages** Openness of participants is required
Tools/Procedure 1) All participants sitting in a circle and no items on the agenda 2) Agenda-setting exercise 3) Self-organisation in smaller discussion groups 4) Discussion groups report the result of discussions to the big group 5) Results are gathered in a book of proceedings that is given to participants		
Hints -		
Source for further information Dalkir (2005, p. 194)		

Pinboard / ideas market

Goal Collecting knowledge, opinions or solutions on questions raised	**Advantages** Fast knowledge acquisition	**Disadvantages** The results can be very heterogeneous and require long processing time
Tools/Procedure Space (physical) Software, computer and hosting platform (virtual)		
Hints -		
Source for further information -		

PreSERVe

Goal Iterative knowledge elicitation in order to obtain semantic and material representation of expert knowledge	**Advantages** Applicable to any field and type of company	**Disadvantages** It requires computer support and the implication of experts
Tools/Procedure 1) Preparing for knowledge elicitation 2) Defining elicitation scope 3) Knowledge elicitation 4) Rendering 5) Verification		
Hints -		
Source for further information Coffey and Hoffman (2003)		

Process modelling

Goal Understanding of activities, functions, roles and processes within and outside an organisation	**Advantages** Overview of activities supports the location and application of knowledge	**Disadvantages** Agreement on the followed/desired process can be challenging
Tools/Procedure Process modelling software		
Hints -		
Source for further information Lehner (2012, p. 204)		

Project documentation

Goal Recording project events as Lessons learned	**Advantages** Avoid repetition of mistakes and knowledge loss	**Disadvantages** Time consuming Risk of information overload
Tools/Procedure Software, computer		
Hints -		
Source for further information Probst et al. (2012, p. 150)		

ProMem

Goal Capture and reuse of project-linked knowledge	**Advantages** Capturing and indexing in real time	**Disadvantages** It implies a full change on the way of working during product design
Tools/Procedure ProMem software, computer		
Hints It works together with CoMem		
Source for further information Fruchter et al. (1998); Fruchter and Demian (2002)		

PROSUS

Goal Continuous capture and retrieve of issues and activities during the design process	**Advantages** Clear structure thanks to a design matrix	**Disadvantages** It implies a full change on the way of working during product design
Tools/Procedure Software, computer		
Hints -		
Source for further information Blessing and Wallace (1998)		

Roleplaying

Goal Developing a better understanding of each other taking the roles of others	**Advantages** Supporting creative	**Disadvantages** Openness of participants is required
Tools/Procedure 1) Warm up the group 2) Select participants' roles 3) Set the stage 4) Prepare the observers 5) Enact 6) Discuss and evaluate 7) Reenact 8) Discuss and evaluate		
Hints -		
Source for further information http://de.wikipedia.org/wiki/Rollenspiel_%28Spiel%29		

Semantic information retrieval system

Goal Access network computers and seek the provision of the required information fragments to facilitate shared understanding across team members	**Advantages** Fast information acquisition	**Disadvantages** The results can require long processing time
Tools/Procedure Software, computer		
Hints -		
Source for further information Liu et al. (2007)		

Team events outside of the organisation

Goal Improvement of team building in everyday working life, intrinsic motivation, team-oriented conflict resolution, reorientation of encrusted company structures	**Advantages** Employees get to know each other better	**Disadvantages** Openness of participants is required
Tools/Procedure 1) Plan the event regarding time, place and people 2) Invite all people who should meet 3) Maybe provide a moderator		
Hints -		
Source for further information Dalkir (2005, p. 54)		

Trainee program for employees

Goal Quick learning of corporate philosophy, workflows and colleagues from various departments	**Advantages** Organisational oriented	**Disadvantages** The trainee can be overwhelmed
Tools/Procedure -		
Hints -		
Source for further information -		

Triad conversation

Goal Transfer of experience knowledge from experienced persons to inexperienced persons	**Advantages** Avoid misunderstandings between interlocutors thanks to the moderators' guidance	**Disadvantages** A third person (moderator) is required
Tools/Procedure 1) Bringing the two interlocutors together 2) Moderator ensures that the narrator's flow of words is not interrupted and that the novice has the opportunity to ask questions of understanding 3) Moderator asks questions about the content in order to uncover implicit knowledge and ensure the transfer of this knowledge from expert to novice 4) Securing the results with concluding agreements on the implementation or application of knowledge		
Hints Third person must remain neutral		
Source for further information Dick et al. (2016)		

Video-based Lessons learned

Goal Record positive and negative practical experiences to define actions for future tasks	**Advantages** Very intuitive way of capturing knowledge It supports the reuse of tacit knowledge	**Disadvantages** Time consuming knowledge capture Time required to visualise the videos
Tools/Procedure Camera, microphone, digital storage format		
Hints -		
Source for further information Chirumalla (2013)		

Visual storytelling

Goal Identify, capture, and document knowledge in form of visual story	**Advantages** It supports the documentation of implicit and tacit knowledge	**Disadvantages** Time consuming knowledge capture
Tools/Procedure Software, computer		
Hints -		
Source for further information Demian and Fruchter (2009)		

Wacom tablet with viewing facility

Goal Capture handwriting to store drawings, sketches, notes, etc.	**Advantages** No paper required	**Disadvantages** Risk of information overload No quality control of captured notes
Tools/Procedure Provide each employee with device		
Hints -		
Source for further information https://www.wacom.com/en-us Vijaykumar and Chakrabarti (2010)		

Webinars / e-learning

Goal Distributing learning content with electronic devices	**Advantages** High flexibility No local limitation	**Disadvantages** Limited interaction with teachers Unreliable or not user friendly tools can deliver a bad learning experience
Tools/Procedure Software, computer		
Hints Quality of the learning material is very important		
Source for further information Frey-Luxemburger (2014, pp. 146–165)		

Weblogs

Goal Formulate thoughts and facts to provide readers or listeners with knowledge and skills acquired in the past	**Advantages** Chronological order	**Disadvantages** It can be too heterogeneous
Tools/Procedure Software, computer, internet, hosting platform		
Hints It can be formal or informal		
Source for further information -		

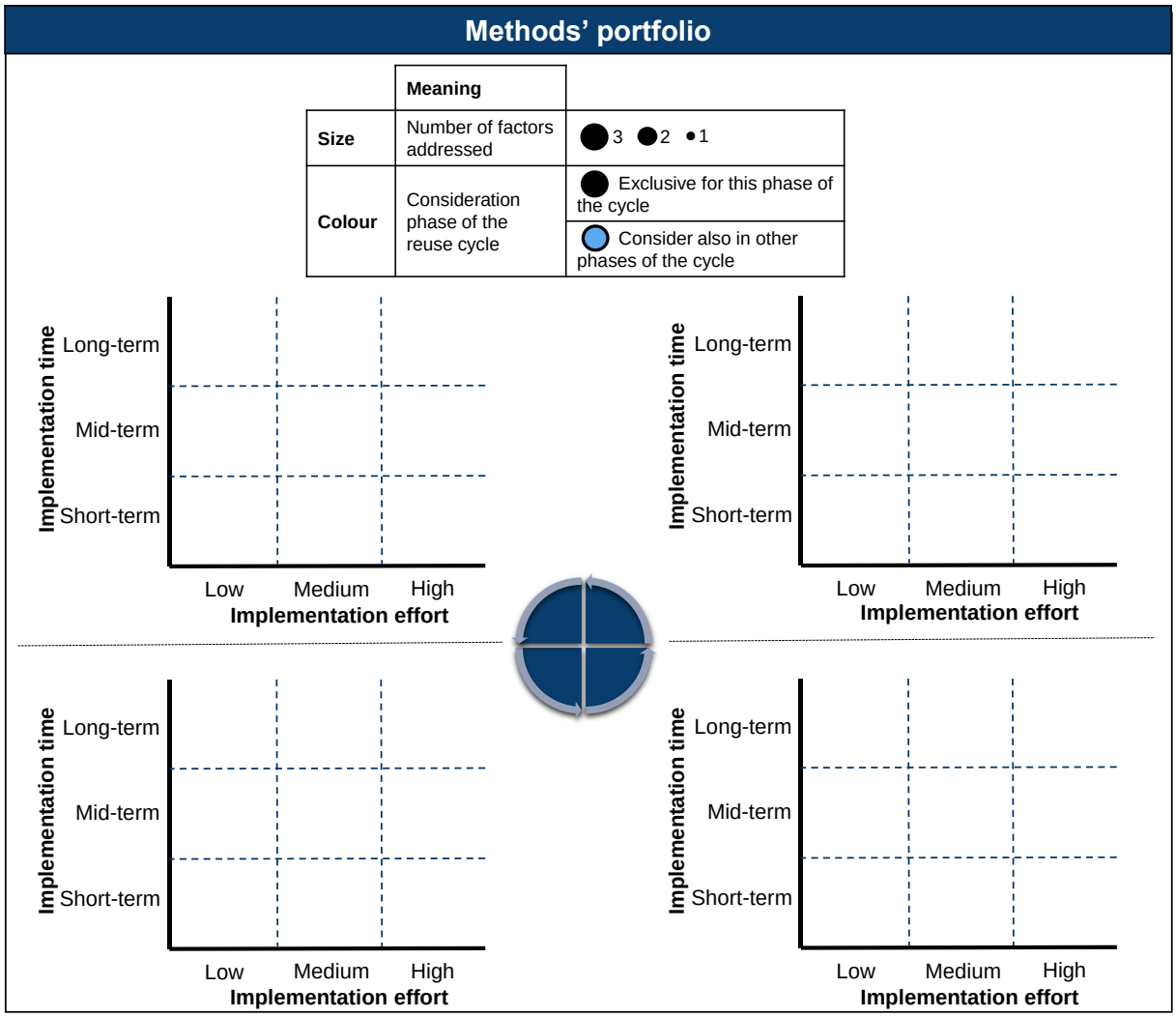
Wiki

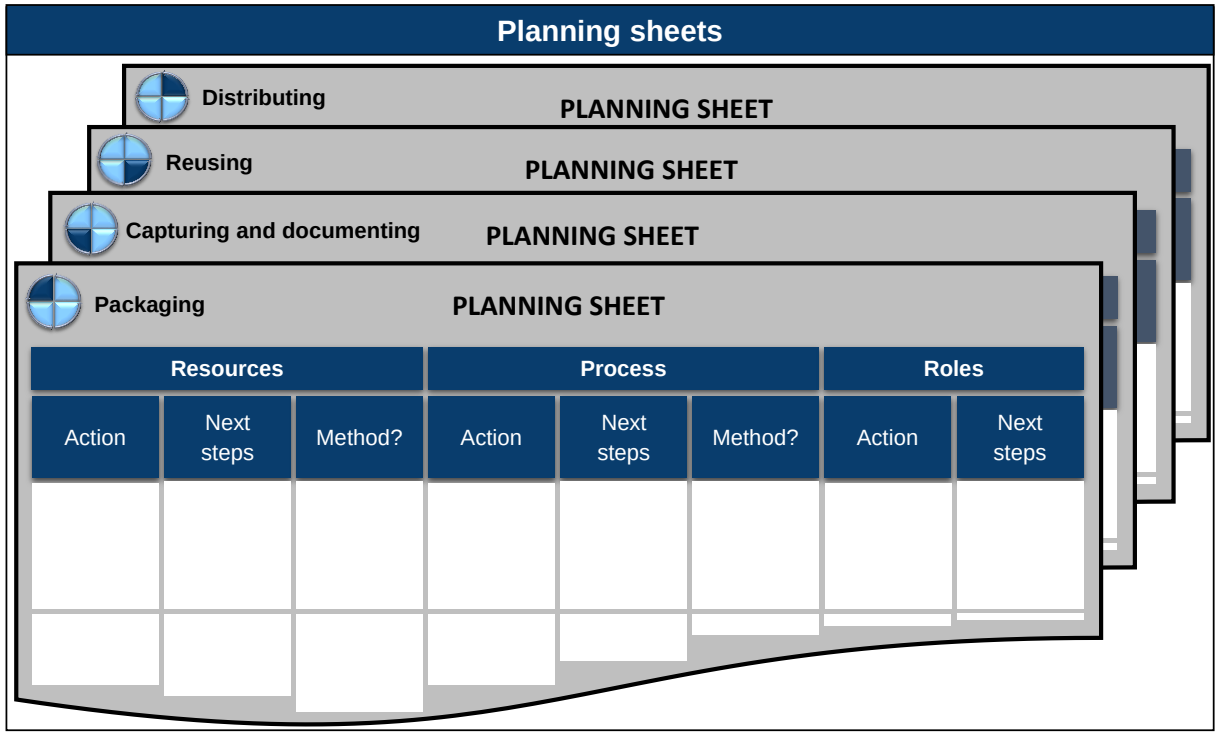
Goal Providing the strategic ability to continuously and repeatedly acquire, create and use company's knowledge in a cyclical process	**Advantages** Centralised knowledge storage	**Disadvantages** It requires regular and careful maintenance
Tools/Procedure Software, computer, hosting platform, server		
Hints -		
Source for further information Lehner (2012, p. 310)		

Yellow pages (internal expert register)

Goal Provide a directory of experts within the company to obtain certain knowledge when needed	**Advantages** Expert can be asked when it is needed	**Disadvantages** Experts might not be accessible when needed
Tools/Procedure Software, computer, server		
Hints It must be maintained by a responsible person		
Source for further information Lehner (2012, p. 199); Gretsch et al. (2012)		

Templates (T)


Methods' portfolio
Meaning
Size
Number of factors addressed
3 2 1
Colour
Consideration phase of the reuse cycle
Exclusive for this phase of the cycle
Consider also in other phases of the cycle
Implementation time
Long-term
Mid-term
Short-term
Low
Medium
High
Implementation effort


Planning sheets
Distributing
PLANNING SHEET
Reusing
PLANNING SHEET
Capturing and documenting
PLANNING SHEET
Packaging
PLANNING SHEET
Resources
Process
Roles
Action
Next steps
Method?
Action
Next steps
Method?
Action
Next steps

9.7.5 Additional Material to Conduct the *k*-MORE Approach for Knowledge Package and Reuse

Procedure for the Lessons Learned Sessions

Activity	Method	Input	Output	Output form
Establish project environment and context	Questionnaire	• *Preparation questionnaire* for lessons learned session	• Questionnaire results	Free choice
Identification of key events	Workshop	• Project environment and context as summary of questionnaire results	• Key events	List of key events
Definition of Lessons learned	Workshop with 5-why method	• List of key events	• Intermediate Lessons learned	Filled *lessons learned documentation* template
Review with topic expert	Discussion with experts	• Intermediate Lessons learned	• Final Lessons learned	Filled *lessons learned documentation* template

Lessons Learned Documentation Template

Lessons learned documentation

Topic	Key event	Best Practice (BP) or Problem (P)	Lesson Learned	Description	Action	Topic Expert Feedback

9.8 Conceptual Evaluation

On the 23rd of May 2017 the *k*-MORE approach for knowledge package (phase 5 of *k*-MORE) and reuse (phase 7 of *k*-MORE) were presented and evaluated by five students who participated in Phase I of the MVG eTrike project. The evaluation was part of a student thesis (Aira Palomares 2017). Details of this evaluation are presented in this Section of the Appendix.

Evaluation Questionnaire

The 5 participants answered 9 questions related to the characteristics of the presented approach. The questionnaire was implemented in the SurveyMonkey service for online questionnaires (https://de.surveymonkey.com/).

Question number	Question	Possible answers			
Q1	Do you think that the representation of knowledge in several visualisations facilitates the knowledge search?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q2	The main goal of visualization A (knowledge map) is to provide an overview of the relations between persons, tasks, documents, storages and persons' competences. Do you consider this information useful for your design work?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q3	The main goal of visualization B (knowledge categories) is to structure the documents and competences of the company in categories. Do you consider this information useful for your design work?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q4	The main goal of visualization C (workflow) is to show the project timeline, with the performed tasks and used/generated documents. Do you consider this information useful for your design work?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q5	Do you think that the free search in the visualizations contributes to increase knowledge reuse?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q6	Do you think that the search using the Search Scenarios contributes to increase knowledge reuse?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q7	Do you think that the search using DeSiDe contributes to increase knowledge reuse?	Fully disagree*	Rather disagree*	Rather agree	Fully agree
Q8	Do you have any suggestion to improve the knowledge base and the way of using it, which you have not mentioned yet? Please write them down	Free answer			
Q9	Do you find any aspect of the knowledge base and the way of using it particularly positive? Please write them down	Free answer			

*in case of providing this answer, a new question with free answer option was asked: "Could you please explain why?".

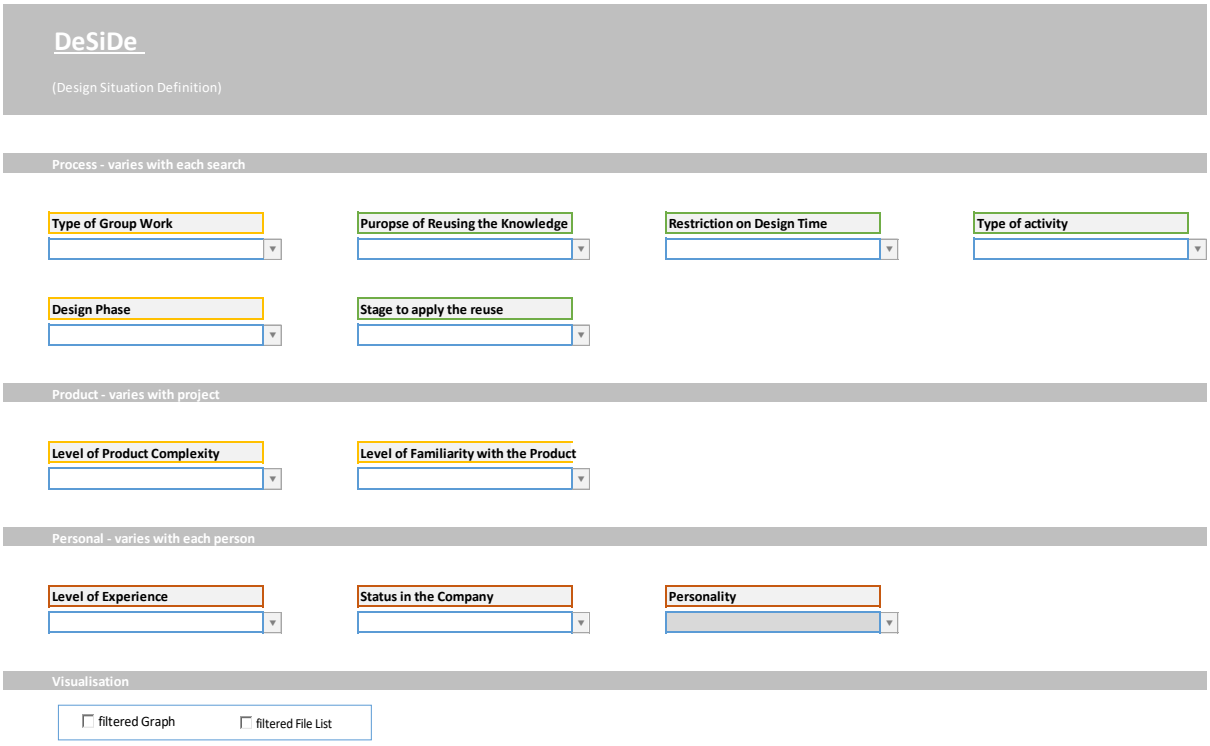
9.9 **Practical Evaluation**

On the 15th and 19th of September 2017 the *k*-MORE approach for knowledge package (phase 5 of *k*-MORE) and reuse (phase 7 of *k*-MORE) was applied and evaluated by two groups of three students who participated in Phase II of the MVG eTrike project. The evaluation was part of a student thesis (Pflieger 2017). Details of this evaluation are presented in this Section of the Appendix.

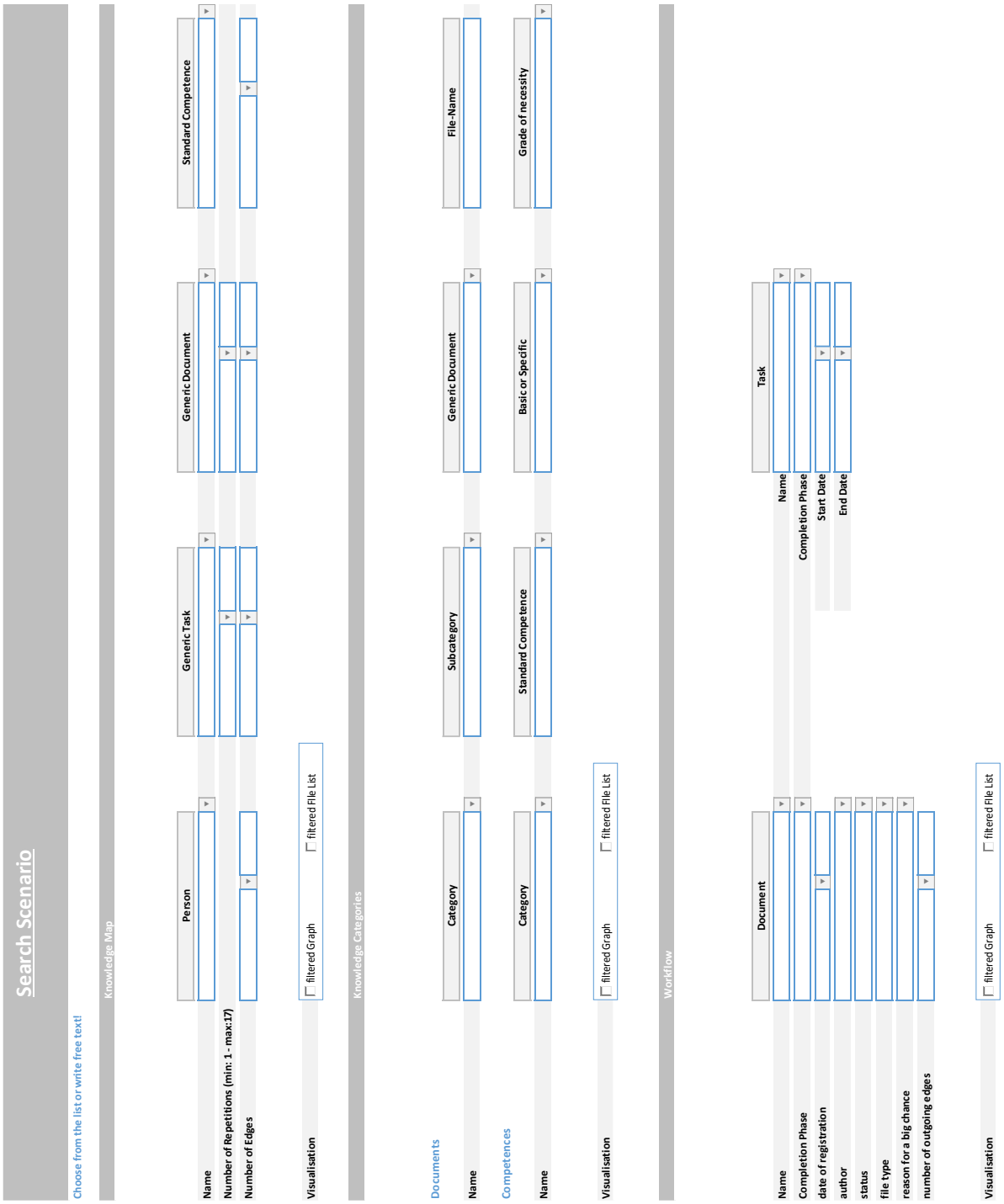
9.9.1 Methods' Interfaces

User-friendly Excel interfaces were prepared for the participants for the introduction of the input to apply the proposed search methods. One interface for the method Search Scenarios and one interface for the DeSiDe method were created.

Interface for the Method DeSiDe

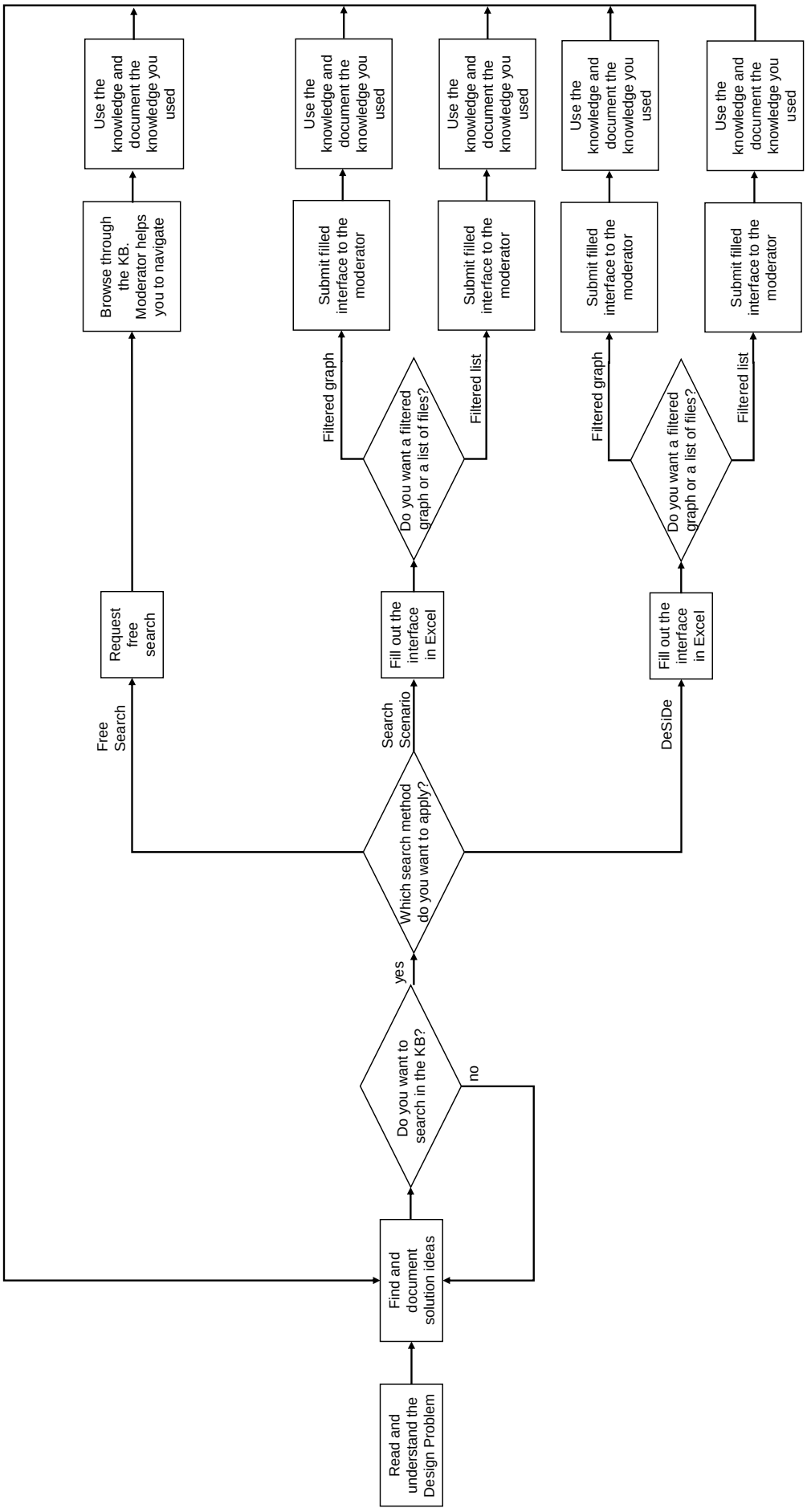


Interface for the Method Search Scenarios



9.9.2 Workflow for Application of the *k*-MORE KB and Search Methods

k-MORE proposes various search methods, among which the participants could select. A workflow was prepared to guide participants in the selection process and the steps for the application of the different methods.


Read and understand the Design Problem
Find and document solution ideas
Do you want to search in the KB?
yes
no
Which search method do you want to apply?
Free Search
Search Scenario
DeSiDe
Request free search
Fill out the interface in Excel
Fill out the interface in Excel
Browse through the KB. Moderator helps you to navigate
Do you want a filtered graph or a list of files?
Filtered graph
Filtered list
Do you want a filtered graph or a list of files?
Filtered graph
Filtered list
Submit filled interface to the moderator
Submit filled interface to the moderator
Submit filled interface to the moderator
Submit filled interface to the moderator
Use the knowledge and document the knowledge you used
Use the knowledge and document the knowledge you used
Use the knowledge and document the knowledge you used
Use the knowledge and document the knowledge you used
Use the knowledge and document the knowledge you used

9.9.3 Design Problems and Solution Templates

Introduction of Design Problem I (DP I)

The MVG now decides to start a new project, **MVG-eBike:** a **bike** with support of an **electric drive unit**. It will later be integrated into the existing **sharing system** along with the MVG-Bike and the MVG-eTrike.

You, as a team, are responsible for the **frame**. This is your first meeting to discuss the first steps of the development problem.

Introduction of Design Problem II (DP II)

The MVG now decides to start a new project, **MVG-Cargo**: a **four-wheeled** transport unit, which should run **emission free** and be integrated into the existing **sharing system** along with the MVG-Bike and the MVG-eTrike.

You, as a team, are responsible for the **drive unit and charging system**. This is your first meeting to discuss the first steps of the development problem.

Tasks and solution templates

1. Individual Task: make a list of requirements that need to be fulfilled for the MVG-eBike (DP I)/MVG-Cargo (DP II).

Requirements	
1	
2	
…	

2. Exercise 2: make a list of all the components that you need to consider and find suggestions for each component as well as positive and negative points regarding your project's requirements.

	Component	**Specifications**	**Advantages**	**Disadvantages**
1				
2				
…				

Knowledge Used
(Knowledge Type: Person, Document, Type, Filtered Graph, Knowledge Notation: Name of File/Node)

	Knowledge Type	**Knowledge Notation**	**How did you get the knowledge?** (fill when applying *k*-MORE methods)
1			◯ Free Search ◯ Search Scenario ◯ DeSiDe
2			◯ Free Search ◯ Search Scenario ◯ DeSiDe
…			◯ Free Search ◯ Search Scenario ◯ DeSiDe

3. Exercise 3: find the name of the former expert for the frame (DP I)/ drive unit and charging system (DP II) to contact him. To prepare for the meeting, find out what other knowledge he has (Documents, Tasks, Competences).

Name	

Knowledge of Expert	
1	
2	
…	

Knowledge Used

(Knowledge Type: Person, Document, Type, Filtered Graph, Knowledge Notation: Name of File/Node)

	Knowledge Type	**Knowledge Notation**	**How did you get the knowledge?** (fill when applying *k*-MORE methods)
1			◯ Free Search ◯ Search Scenario ◯ DeSiDe
2			◯ Free Search ◯ Search Scenario ◯ DeSiDe
…			◯ Free Search ◯ Search Scenario ◯ DeSiDe

4. Exercise 4: define important team competences and documents and assign them among your team members.

Important Documents	
1	
2	
…	
Important Competences	
1	
2	
…	

Knowledge Used
(Knowledge Type: Person, Document, Type, Filtered Graph, Knowledge Notation: Name of File/Node)

	Knowledge Type	**Knowledge Notation**	**How did you get the knowledge?** (fill when applying *k*-MORE methods)
1			◯ Free Search ◯ Search Scenario ◯ DeSiDe
2			◯ Free Search ◯ Search Scenario ◯ DeSiDe
…			◯ Free Search ◯ Search Scenario ◯ DeSiDe

9.9.4 Evaluation Questionnaire

Question number	**Question**	**Possible answers**				
Q1	How easy was it to find relevant documents?	1 (hard)	2	3	4	5 (easy)
Q2	How easy was it to find relevant persons?	1 (hard)	2	3	4	5 (easy)
Q3	How easy was it to find relevant tasks?	1 (hard)	2	3	4	5 (easy)
Q4	How easy was it to find relevant competences?	1 (hard)	2	3	4	5 (easy)
Q5	How easy was it to identify relationships between elements?	1 (hard)	2	3	4	5 (easy)
Q6	How do you rate the adequacy of the knowledge you received?	1 (bad)	2	3	4	5 (good)
Q7	How satisfied are you with your solutions?	1 (not satisfied)	2	3	4	5 (satisfied)

9.10 **Industrial Evaluation**

On the 8th and 9th of February 2018 the results of the Case Study IV conducted in cooperation with a construction company were presented in the company and evaluated by employees using a questionnaire. The details of the evaluation are presented in this Section of the Appendix.

9.10.1 Evaluation Questionnaire

This Subsection presents the template, which contains 24 questions distributed in four categories. The questionnaire was provided and filled in paper form.

Evaluation of the *k*-MORE methodology to plan the Knowledge Reuse in engineering design companies

This survey pursues the following **goals**:

1. Evaluate the **need** for knowledge reuse in industry
2. Evaluate the **results** of the proposed methodology
3. Evaluate the **applicability** of the proposed methodology

Your answers will be treated as strictly confidential, always remain anonymous, and they will not be passed to any third party under any circumstances.

We deeply thank you for contributing to our research with your experience!

1. Need for knowledge reuse in industry

Please rate the following statements:

	Completely disagree	Disagree	Neutral	Agree	Completely agree
Q1.1 **Reusing** knowledge increases the efficiency of the product development process					
Q1.2 **Reusing** knowledge increases the quality of the products developed					
Q1.3 The current company's **strategy** for knowledge reuse is efficient					
Q1.4 The current **amount** of knowledge reused in the company is sufficient					

Q1.5 Do you have any **comment** referring to the reuse of knowledge generally in industry or in your company?

……...

……...

……...

……...

……...

2. Results of the *k*-MORE methodology

Please rate the following statements referring to concrete elements of the *k*-MORE methodology:

	Completely disagree	Disagree	Neutral	Agree	Completely agree
Q2.1 The **knowledge map** provides a transparent overview of the company's knowledge in the selected areas					
Q2.2 The **critical elements** and **actors** identified by analyzing the knowledge map enable to establish a manageable focus to plan the knowledge reuse					
Q2.3 The **planning sheets** are helpful tools to support a structured planning of knowledge reuse					
Q2.4 The **employees' survey** based on the Worker-Centered Model enables a clear identification of individual factors influencing knowledge reuse					
Q2.5 The **methods' portfolios** provide a good base to select suitable methods to perform the phases of the knowledge reuse cycle					

Q2.6 Do you have any **comment** referring to the presented results of the *k*-MORE methodology?

……...

……...

……...

……...

……...

The **next step** for SCHÜCO is to iteratively go through the planning sheets until all actions to plan the knowledge reuse cycle in the company have been discussed and implemented.

Please **imagine the final result** and rate the following statements:

	Completely disagree	Disagree	Neutral	Agree	Completely agree
Q2.7 I believe that the company's **strategy** for knowledge reuse will be efficient					
Q2.8 I believe that the **amount** of knowledge reused in the company will be sufficient					

Q2.9 Do you have any **comment** referring to the expected results of the *k*-MORE methodology?

……...

……...

……...

……...

……...

3. Applicability of the *k*-MORE methodology

Please rate the following statements:

	Completely disagree	Disagree	Neutral	Agree	Completely agree
Q3.1 The **methodology** is understandable					
Q3.2 The **methodology** provides a helpful guide to plan knowledge reuse in industry					
Q3.3 The **methodology** is scalable (it can be applied at different level of detail depending on the needs)					
Q3.4 The **effort** to implement the methodology is appropriate					
Q3.5 The **methodology** is applicable independently of the company's field					
Q3.6 The **methodology** is applicable independently of the company's size					

Q3.7 Do you have any **comment** referring to the application of the *k*-MORE methodology?

……...

……...

……...

……...

……...

4. Personal information

Q4.1 Which is your position in your company?

☐ Head manager

☐ Group manager

☐ Technical expert

☐ Other: …….

Q4.2 Which is your working area in your company?

☐ Sales

☐ Product Development

☐ Marketing

☐ Knowledge Management

☐ Other: …….

Q4.3 How many years have you been working in your current working area?

☐ 0-2

☐ 2-4

☐ 4-10

☐ >10

Thank you very much for your contribution!

9.10.2 Results of the Evaluation

This Subsection presents the answers to the questionnaire. The questionnaire was conducted in German language and the participants' comments are the original ones.

Participants profile

Participant	Position	Working area	Years of experience
P1	Technical expert	Knowledge management	0-2
P2	Not given	Not given	Not given
P3	Technical expert	Product development	0-2
P4	Technical expert	Product management	2-4
P5	Head manager	Sales	4-10
P6	Technical expert	Sales	0-2
P7	Group manager	Sales	>10
P8	Not given	Not given	>10
P9	Not given	Not given	>10
P10	Head manager	Product development	>10
P11	Others	Product development	4-10
P12	Head manager	Product development	4-10
P13	Group manager and technical expert	Product development	4-10
P14	Technical expert	Sales and knowledge management	>10
P15	Trainee	Knowledge management	0-2
P16	Technical expert	Knowledge management	0-2
P17	Group manager	Product development	4-10
P18	Group manager	Process controlling	>10
P19	Head manager	Product development	>10
P20	Head manager	Sales	4-10
P21	Technical expert	Knowledge management	2-4

Answers

	Q1.1	Q1.2	Q1.3	Q1.4	Q1.5	Q2.1	Q2.2	Q2.3	Q2.4	Q2.5	Q2.6	Q2.7	Q2.8	Q2.9	Q3.1	Q3.2	Q3.3	Q3.4	Q3.5	Q3.6	Q3.7
P1	5	4	2	2	-	4	4	4	4	4	-	5	5	-	4	5	4	4	5	5	-
P2	5	5	3	2	-	3	3	4	3	4	-	4	3	-	3	3	4	4	3	4	-
P3	5	5	2	2	-	3	3	4	4	4	-	4	4	-	4	4	4	3	4	4	-
P4	4	5	2	1	-	3	3	2	3	4	-	4	4	-	2	3	4	4	3	4	-
P5	4	4	4	3	-	3	3	4	3	2	-	-	4	-	4	4	4	3	5	4	-
P6	5	4	3	2	-	4	4	4	4	4	-	3	3	-	4	4	4	3	4	4	-
P7	5	4	3	3	-	3	4	4	3	4	-	3	2	-	4	3	3	3	3	3	-
P8	4	4	3	2	-	3	4	3	3	3	-	2	2	-	3	4	4	2	4	4	-
P9	5	5	4	1	-	5	5	5	4	4	-	4	3	-	-	4	3	3	3	3	-
P10	5	5	4	1	-	4	4	4	4	4	-	5	1	-	4	4	4	3	4	3	-
P11	3	4	1	2	-	-	-	-	-	-	-	3	2	-	5	4	3	-	4	4	-
P12	5	3	2	2	-	3	3	4	4	4	-	5	4	-	3	4	4	3	3	4	-
P13	5	5	3	2	*	4	3	2	4	3	*	3	3	*	3	2	4	2	4	4	*
P14	5	5	3	2	-	4	5	5	5	4	-	4	4	-	5	5	5	4	5	5	-
P15	5	4	3	3	*	5	4	4	2	3	-	4	3	-	4	4	5	5	5	2	-
P16	5	5	3	2	*	4	4	3	5	5	*	4	3	-	4	4	3	5	5	5	-
P17	4	4	2	2	*	4	4	4	3	4	-	4	3	-	4	4	4	3	4	4	-
P18	5	5	3	2	-	4	3	4	4	4	-	4	4	-	5	4	5	3	4	5	-
P19	5	5	4	2	-	4	4	4	4	4	-	4	4	-	-	5	4	3	4	3	-
P20	4	4	2	2	-	4	4	3	3	4	-	4	3	-	4	4	3	3	4	4	-
P21	5	4	5	2	*	4	5	4	4	4	*	4	4	*	5	4	4	4	4	5	-

Legend:

- Completely disagree = 1
- Disagree = 2
- Neutral = 3
- Agree = 4
- Completely agree = 5
- No answer = -
- Comment = *

*P13/Q1.5: “Große Schwirigkeit liegt darum, wie lege ich Wissen am besten ab? Wie finde ich das abgelegte Wissen anderer?”

*P13/Q2.6: “zu theoretisch / analytisch, mehr konkrete Ansätze, Software Lösungen”

*P13/Q2.9: “ganz viel hängt von der Softwarelösung ab! Wie gut bekommen wir Regeln für eine Vereinheitlichung an alle MA kommuniziert?”

*P13/Q3.7: “zu hohe Flugebene, zu wenig konkret in der Praxis. Der Fragebogenkatalog und der Methodenkatalog und das Methodenportfolio sind sehr hilfreich!”

*P15/Q1.5: “Sollte selbsverständlich sein. Leider großes Defizit in der Praxis”

*P16/Q1.5: “Der Fokus auf Wissensverwendung sollte deutlich aufgebaut werden. Wir sind Wissensarbeiter!”

*P16/Q2.6: “Es wird schwierig ohne Unterstützung die Methode weiter umzusetzen”

*P17/Q1.5: “Nicht nur Informationen sondern auch Methodenwissen ist wichtig”

*P21/Q1.5: “Wird wenig genutzt, um Learnings aus bereits gemachten Erfahrungen Sinnvoll und Zielgerichtet einzusetzen”

*P21/Q2.6: “Die Ergebnisse der *k*-MORE Methode könnten zur "genaueren" Bewertung noch mit einer anderen (ähnlichen) Methode in den Vergleich gesetzt werden”

*P21/Q2.9: “Das im Unternehmen wiederverwendbare Wissen wird voraussichtlich besser sichtbar und nutzbar. Ob dies dann ausreichend sein wird, wird sich in der praktischen Umsetzung zeigen. Es ist sehr wünschenswert.”

10. List of Dissertations

Lehrstuhl für Produktentwicklung
Technische Universität München, Boltzmannstraße 15, 85748 Garching
Dissertations under supervision of:
• Prof. Dr.-Ing. W. Rodenacker,
• Prof. Dr.-Ing. K. Ehrlenspiel and
• Prof. Dr.-Ing. U. Lindemann

D1 COLLIN, H.:
Entwicklung eines Einwalzenkalanders nach einer systematischen Konstruktionsmethode. München: TU, Diss. 1969.

D2 OTT, J.:
Untersuchungen und Vorrichtungen zum Offen-End-Spinnen.
München: TU, Diss. 1971.

D3 STEINWACHS, H.:
Informationsgewinnung an bandförmigen Produkten für die Konstruktion der Produktmaschine.
München: TU, Diss. 1971.

D4 SCHMETTOW, D.:
Entwicklung eines Rehabilitationsgerätes für Schwerstkörperbehinderte.
München: TU, Diss. 1972.

D5 LUBITZSCH, W.:
Die Entwicklung eines Maschinensystems zur Verarbeitung von chemischen Endlosfasern.
München: TU, Diss. 1974.

D6 SCHEITENBERGER, H.:
Entwurf und Optimierung eines Getriebesystems für einen Rotationsquerschneider mit allgemeingültigen Methoden.
München: TU, Diss. 1974.

D7 BAUMGARTH, R.:
Die Vereinfachung von Geräten zur Konstanthaltung physikalischer Größen.
München: TU, Diss. 1976.

D8 MAUDERER, E.:
Beitrag zum konstruktionsmethodischen Vorgehen durchgeführt am Beispiel eines Hochleistungsschalter-Antriebs.
München: TU, Diss. 1976.

D9 SCHÄFER, J.:
Die Anwendung des methodischen Konstruierens auf verfahrenstechnische Aufgabenstellungen.
München: TU, Diss. 1977.

D10 WEBER, J.:
Extruder mit Feststoffpumpe – Ein Beitrag zum Methodischen Konstruieren.
München: TU, Diss. 1978.

D11 HEISIG, R.:
Längencodierer mit Hilfsbewegung.
München: TU, Diss. 1979.

D12 KIEWERT, A.:
Systematische Erarbeitung von Hilfsmitteln zum kostenarmen Konstruieren.
München: TU, Diss. 1979.

D13 LINDEMANN, U.:
Systemtechnische Betrachtung des Konstruktionsprozesses unter besonderer Berücksichtigung der Herstellkostenbeeinflussung beim Festlegen der Gestalt.
Düsseldorf: VDI-Verlag 1980. (Fortschritt-Berichte der VDI-Zeitschriften Reihe 1, Nr. 60).
Zugl. München: TU, Diss. 1980.

D14 NJOYA, G.:
Untersuchungen zur Kinematik im Wälzlager bei synchron umlaufenden Innen- und Außenringen.
Hannover: Universität, Diss. 1980.

D15 HENKEL, G.:
Theoretische und experimentelle Untersuchungen ebener konzentrisch gewellter Kreisringmembranen.
Hannover: Universität, Diss. 1980.

D16 BALKEN, J.:
Systematische Entwicklung von Gleichlaufgelenken.
München: TU, Diss. 1981.

D17 PETRA, H.:
Systematik, Erweiterung und Einschränkung von Lastausgleichslösungen für Standgetriebe mit zwei Leistungswegen – Ein Beitrag zum methodischen Konstruieren.
München: TU, Diss. 1981.

D18 BAUMANN, G.:
Ein Kosteninformationssystem für die Gestaltungsphase im Betriebsmittelbau.
München: TU, Diss. 1982.

D19 FISCHER, D.:
Kostenanalyse von Stirnzahnrädern. Erarbeitung und Vergleich von Hilfsmitteln zur Kostenfrüherkennung.
München: TU, Diss. 1983.

D20 AUGUSTIN, W.:
Sicherheitstechnik und Konstruktionsmethodiken – Sicherheitsgerechtes Konstruieren.
Dortmund: Bundesanstalt für Arbeitsschutz 1985. Zugl. München: TU, Diss. 1984.

D21 RUTZ, A.:
Konstruieren als gedanklicher Prozess.
München: TU, Diss. 1985.

D22 SAUERMANN, H. J.:
Eine Produktkostenplanung für Unternehmen des Maschinenbaues.
München: TU, Diss. 1986.

D23 HAFNER, J.:
Entscheidungshilfen für das kostengünstige Konstruieren von Schweiß- und Gussgehäusen.
München: TU, Diss. 1987.

D24 JOHN, T.:
Systematische Entwicklung von homokinetischen Wellenkupplungen.
München: TU, Diss. 1987.

D25 FIGEL, K.:
Optimieren beim Konstruieren.
München: Hanser 1988. Zugl. München: TU, Diss. 1988 u. d. T.: Figel, K.: Integration automatisierter Optimierungsverfahren in den rechnerunterstützten Konstruktionsprozess.

Reihe Konstruktionstechnik München

D26 TROPSCHUH, P. F.:
Rechnerunterstützung für das Projektieren mit Hilfe eines wissensbasierten Systems.
München: Hanser 1989. (Konstruktionstechnik München, Band 1). Zugl. München: TU, Diss. 1988 u. d. T.: Tropschuh, P. F.: Rechnerunterstützung für das Projektieren am Beispiel Schiffsgetriebe.

D27 PICKEL, H.:
Kostenmodelle als Hilfsmittel zum Kostengünstigen Konstruieren.
München: Hanser 1989. (Konstruktionstechnik München, Band 2). Zugl. München: TU, Diss. 1988.

D28 KITTSTEINER, H.-J.:
Die Auswahl und Gestaltung von kostengünstigen Welle-Nabe-Verbindungen.
München: Hanser 1990. (Konstruktionstechnik München, Band 3). Zugl. München: TU, Diss. 1989.

D29 HILLEBRAND, A.:
Ein Kosteninformationssystem für die Neukonstruktion mit der Möglichkeit zum Anschluss an ein CAD-System.
München: Hanser 1991. (Konstruktionstechnik München, Band 4). Zugl. München: TU, Diss. 1990.

D30 DYLLA, N.:
Denk- und Handlungsabläufe beim Konstruieren.
München: Hanser 1991. (Konstruktionstechnik München, Band 5). Zugl. München: TU, Diss. 1990.

D31 MÜLLER, R.
Datenbankgestützte Teileverwaltung und Wiederholteilsuche.
München: Hanser 1991. (Konstruktionstechnik München, Band 6). Zugl. München: TU, Diss. 1990.

D32 NEESE, J.:
Methodik einer wissensbasierten Schadenanalyse am Beispiel Wälzlagerungen.
München: Hanser 1991. (Konstruktionstechnik München, Band 7). Zugl. München: TU, Diss. 1991.

D33 SCHAAL, S.:
Integrierte Wissensverarbeitung mit CAD – Am Beispiel der konstruktionsbegleitenden Kalkulation.
München: Hanser 1992. (Konstruktionstechnik München, Band 8). Zugl. München: TU, Diss. 1991.

D34 BRAUNSPERGER, M.:
Qualitätssicherung im Entwicklungsablauf – Konzept einer präventiven Qualitätssicherung für die Automobilindustrie.
München: Hanser 1993. (Konstruktionstechnik München, Band 9). Zugl. München: TU, Diss. 1992.

D35 FEICHTER, E.:
Systematischer Entwicklungsprozess am Beispiel von elastischen Radialversatzkupplungen.
München: Hanser 1994. (Konstruktionstechnik München, Band 10). Zugl. München: TU, Diss. 1992.

D36 WEINBRENNER, V.:
Produktlogik als Hilfsmittel zum Automatisieren von Varianten- und Anpassungskonstruktionen.
München: Hanser 1994. (Konstruktionstechnik München, Band 11). Zugl. München: TU, Diss. 1993.

D37 WACH, J. J.:
Problemspezifische Hilfsmittel für die Integrierte Produktentwicklung.
München: Hanser 1994. (Konstruktionstechnik München, Band 12). Zugl. München: TU, Diss. 1993.

D38 LENK, E.:
Zur Problematik der technischen Bewertung.
München: Hanser 1994. (Konstruktionstechnik München, Band 13). Zugl. München: TU, Diss. 1993.

D39 STUFFER, R.:
Planung und Steuerung der Integrierten Produktentwicklung.
München: Hanser 1994. (Konstruktionstechnik München, Band 14). Zugl. München: TU, Diss. 1993.

D40 SCHIEBELER, R.:
Kostengünstig Konstruieren mit einer rechnergestützten Konstruktionsberatung.
München: Hanser 1994. (Konstruktionstechnik München, Band 15). Zugl. München: TU, Diss. 1993.

D41 BRUCKNER, J.:
Kostengünstige Wärmebehandlung durch Entscheidungsunterstützung in Konstruktion und Härterei.
München: Hanser 1994. (Konstruktionstechnik München, Band 16). Zugl. München: TU, Diss. 1993.

D42 WELLNIAK, R.:
Das Produktmodell im rechnerintegrierten Konstruktionsarbeitsplatz.
München: Hanser 1994. (Konstruktionstechnik München, Band 17). Zugl. München: TU, Diss. 1994.

D43 SCHLÜTER, A.:
Gestaltung von Schnappverbindungen für montagegerechte Produkte.
München: Hanser 1994. (Konstruktionstechnik München, Band 18). Zugl. München: TU, Diss. 1994.

D44 WOLFRAM, M.:
Feature-basiertes Konstruieren und Kalkulieren.
München: Hanser 1994. (Konstruktionstechnik München, Band 19). Zugl. München: TU, Diss. 1994.

D45 STOLZ, P.:
Aufbau technischer Informationssysteme in Konstruktion und Entwicklung am Beispiel eines elektronischen Zeichnungsarchives.
München: Hanser 1994. (Konstruktionstechnik München, Band 20). Zugl. München: TU, Diss. 1994.

D46 STOLL, G.:
Montagegerechte Produkte mit feature-basiertem CAD.
München: Hanser 1994. (Konstruktionstechnik München, Band 21). Zugl. München: TU, Diss. 1994.

D47 STEINER, J. M.:
Rechnergestütztes Kostensenken im praktischen Einsatz.
Aachen: Shaker 1996. (Konstruktionstechnik München, Band 22). Zugl. München: TU, Diss. 1995.

D48 HUBER, T.:
Senken von Montagezeiten und -kosten im Getriebebau.
München: Hanser 1995. (Konstruktionstechnik München, Band 23). Zugl. München: TU, Diss. 1995.

D49 DANNER, S.:
Ganzheitliches Anforderungsmanagement für marktorientierte Entwicklungsprozesse.
Aachen: Shaker 1996. (Konstruktionstechnik München, Band 24). Zugl. München: TU, Diss. 1996.

D50 MERAT, P.:
Rechnergestützte Auftragsabwicklung an einem Praxisbeispiel.
Aachen: Shaker 1996. (Konstruktionstechnik München, Band 25). Zugl. München: TU, Diss. 1996 u. d. T.: MERAT, P.: Rechnergestütztes Produktleitsystem

D51 AMBROSY, S.:
Methoden und Werkzeuge für die integrierte Produktentwicklung.
Aachen: Shaker 1997. (Konstruktionstechnik München, Band 26). Zugl. München: TU, Diss. 1996.

D52 GIAPOULIS, A.:
Modelle für effektive Konstruktionsprozesse.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 27). Zugl. München: TU, Diss. 1996.

D53 STEINMEIER, E.:
Realisierung eines systemtechnischen Produktmodells – Einsatz in der Pkw-Entwicklung
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 28). Zugl. München: TU, Diss. 1998.

D54 KLEEDÖRFER, R.:
Prozess- und Änderungsmanagement der Integrierten Produktentwicklung.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 29). Zugl. München: TU, Diss. 1998.

D55 GÜNTHER, J.:
Individuelle Einflüsse auf den Konstruktionsprozess.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 30). Zugl. München: TU, Diss. 1998.

D56 BIERSACK, H.:
Methode für Krafteinleitungsstellenkonstruktion in Blechstrukturen.
München: TU, Diss. 1998.

D57 IRLINGER, R.:
Methoden und Werkzeuge zur nachvollziehbaren Dokumentation in der Produktentwicklung.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 31). Zugl. München: TU, Diss. 1999.

D58 EILETZ, R.:
Zielkonfliktmanagement bei der Entwicklung komplexer Produkte – am Bsp. PKW-Entwicklung.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 32). Zugl. München: TU, Diss. 1999.

D59 STÖSSER, R.:
Zielkostenmanagement in integrierten Produkterstellungsprozessen.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 33). Zugl. München: TU, Diss. 1999.

D60 PHLEPS, U.:
Recyclinggerechte Produktdefinition – Methodische Unterstützung für Upgrading und Verwertung.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 34). Zugl. München: TU, Diss. 1999.

D61 BERNARD, R.:
Early Evaluation of Product Properties within the Integrated Product Development.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 35). Zugl. München: TU, Diss. 1999.

D62 ZANKER, W.:
Situative Anpassung und Neukombination von Entwicklungsmethoden.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 36). Zugl. München: TU, Diss. 1999.

Reihe Produktentwicklung München

D63 ALLMANSBERGER, G.:
Erweiterung der Konstruktionsmethodik zur Unterstützung von Änderungsprozessen in der Produktentwicklung.
München: Dr. Hut 2001. (Produktentwicklung München, Band 37). Zugl. München: TU, Diss. 2000.

D64 ASSMANN, G.:
Gestaltung von Änderungsprozessen in der Produktentwicklung.
München: Utz 2000. (Produktentwicklung München, Band 38). Zugl. München: TU, Diss. 2000.

D65 BICHLMAIER, C.:
Methoden zur flexiblen Gestaltung von integrierten Entwicklungsprozessen.
München: Utz 2000. (Produktentwicklung München, Band 39). Zugl. München: TU, Diss. 2000.

D66 DEMERS, M. T.
Methoden zur dynamischen Planung und Steuerung von Produktentwicklungsprozessen.
München: Dr. Hut 2000. (Produktentwicklung München, Band 40). Zugl. München: TU, Diss. 2000.

D67 STETTER, R.:
Method Implementation in Integrated Product Development.
München: Dr. Hut 2000. (Produktentwicklung München, Band 41). Zugl. München: TU, Diss. 2000.

D68 VIERTLBÖCK, M.:
Modell der Methoden- und Hilfsmitteleinführung im Bereich der Produktentwicklung.
München: Dr. Hut 2000. (Produktentwicklung München, Band 42). Zugl. München: TU, Diss. 2000.

D69 COLLIN, H.:
Management von Produkt-Informationen in kleinen und mittelständischen Unternehmen.
München: Dr. Hut 2001. (Produktentwicklung München, Band 43). Zugl. München: TU, Diss. 2001.

D70 REISCHL, C.:
Simulation von Produktkosten in der Entwicklungsphase.
München: Dr. Hut 2001. (Produktentwicklung München, Band 44). Zugl. München: TU, Diss. 2001.

D71 GAUL, H.-D.:
Verteilte Produktentwicklung - Perspektiven und Modell zur Optimierung.
München: Dr. Hut 2001. (Produktentwicklung München, Band 45). Zugl. München: TU, Diss. 2001.

D72 GIERHARDT, H.:
Global verteilte Produktentwicklungsprojekte – Ein Vorgehensmodell auf der operativen Ebene.
München: Dr. Hut 2002. (Produktentwicklung München, Band 46). Zugl. München: TU, Diss. 2001.

D73 SCHOEN, S.:
Gestaltung und Unterstützung von Community of Practice.
München: Utz 2000. (Produktentwicklung München, Band 47). Zugl. München: TU, Diss. 2000.

D74 BENDER, B.:
Zielorientiertes Kooperationsmanagement.
München: Dr. Hut 2001. (Produktentwicklung München, Band 48). Zugl. München: TU, Diss. 2001.

D75 SCHWANKL, L.:
Analyse und Dokumentation in den frühen Phasen der Produktentwicklung.
München: Dr. Hut 2002. (Produktentwicklung München, Band 49). Zugl. München: TU, Diss. 2002.

D76 WULF, J.:
Elementarmethoden zur Lösungssuche.
München: Dr. Hut 2002. (Produktentwicklung München, Band 50). Zugl. München: TU, Diss. 2002.

D77 MÖRTL, M.:
Entwicklungsmanagement für langlebige, upgradinggerechte Produkte.
München: Dr. Hut 2002. (Produktentwicklung München, Band 51). Zugl. München: TU, Diss. 2002.

D78 GERST, M.:
Strategische Produktentscheidungen in der integrierten Produktentwicklung.
München: Dr. Hut 2002. (Produktentwicklung München, Band 52). Zugl. München: TU, Diss. 2002.

D79 AMFT, M.:
Phasenübergreifende bidirektionale Integration von Gestaltung und Berechnung.
München: Dr. Hut 2003. (Produktentwicklung München, Band 53). Zugl. München: TU, Diss. 2002.

D80 FÖRSTER, M.:
Variantenmanagement nach Fusionen in Unternehmen des Anlagen- und Maschinenbaus.
München: TU, Diss. 2003.

D81 GRAMANN, J.:
Problemmodelle und Bionik als Methode.
München: Dr. Hut 2004. (Produktentwicklung München, Band 55). Zugl. München: TU, Diss. 2004.

D82 PULM, U.:
Eine systemtheoretische Betrachtung der Produktentwicklung.
München: Dr. Hut 2004. (Produktentwicklung München, Band 56). Zugl. München: TU, Diss. 2004.

D83 HUTTERER, P.:
Reflexive Dialoge und Denkbausteine für die methodische Produktentwicklung.
München: Dr. Hut 2005. (Produktentwicklung München, Band 57). Zugl. München: TU, Diss. 2005.

D84 FUCHS, D.:
Konstruktionsprinzipien für die Problemanalyse in der Produktentwicklung.
München: Dr. Hut 2006. (Produktentwicklung München, Band 58). Zugl. München: TU, Diss. 2005.

D85 PACHE, M.:
Sketching for Conceptual Design.
München: Dr. Hut 2005. (Produktentwicklung München, Band 59). Zugl. München: TU, Diss. 2005.

D86 BRAUN, T.:
Methodische Unterstützung der strategischen Produktplanung in einem mittelständisch geprägten Umfeld.
München: Dr. Hut 2005. (Produktentwicklung München, Band 60). Zugl. München: TU, Diss. 2005.

D87 JUNG, C.:
Anforderungsklärung in interdisziplinärer Entwicklungsumgebung.
München: Dr. Hut 2006. (Produktentwicklung München, Band 61). Zugl. München: TU, Diss. 2006.

D88 HEßLING, T.:
Einführung der Integrierten Produktpolitik in kleinen und mittelständischen Unternehmen.
München: Dr. Hut 2006. (Produktentwicklung München, Band 62). Zugl. München: TU, Diss. 2006.

D89 STRICKER, H.:
Bionik in der Produktentwicklung unter der Berücksichtigung menschlichen Verhaltens.
München: Dr. Hut 2006. (Produktentwicklung München, Band 63). Zugl. München: TU, Diss. 2006.

D90 NIßL, A.:
Modell zur Integration der Zielkostenverfolgung in den Produktentwicklungsprozess.
München: Dr. Hut 2006. (Produktentwicklung München, Band 64). Zugl. München: TU, Diss. 2006.

D91 MÜLLER, F.:
Intuitive digitale Geometriemodellierung in frühen Entwicklungsphasen.
München: Dr. Hut 2007. (Produktentwicklung München, Band 65). Zugl. München: TU, Diss. 2006.

D92 ERDELL, E.:
Methodenanwendung in der Hochbauplanung – Ergebnisse einer Schwachstellenanalyse.
München: Dr. Hut 2006. (Produktentwicklung München, Band 66). Zugl. München: TU, Diss. 2006.

D93 GAHR, A.:
Pfadkostenrechnung individualisierter Produkte.
München: Dr. Hut 2006. (Produktentwicklung München, Band 67). Zugl. München: TU, Diss. 2006.

D94 RENNER, I.:
Methodische Unterstützung funktionsorientierter Baukastenentwicklung am Beispiel Automobil.
München: Dr. Hut 2007 (Reihe Produktentwicklung) Zugl. München: TU, Diss. 2007.

D95 PONN, J.:
Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte.
München: Dr. Hut 2007 (Reihe Produktentwicklung) Zugl. München: TU, Diss. 2007.

D96 HERFELD, U.:
Matrix-basierte Verknüpfung von Komponenten und Funktionen zur Integration von Konstruktion und numerischer Simulation.
München: Dr. Hut 2007. (Produktentwicklung München, Band 70). Zugl. München: TU, Diss. 2007.

D97 SCHNEIDER, S.:
Model for the evaluation of engineering design methods.
München: Dr. Hut 2008 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D98 FELGEN, L.:
Systemorientierte Qualitätssicherung für mechatronische Produkte.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D99 GRIEB, J.:
Auswahl von Werkzeugen und Methoden für verteilte Produktentwicklungsprozesse.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D100 MAURER, M.:
Structural Awareness in Complex Product Design.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D101 BAUMBERGER, C.:
Methoden zur kundenspezifischen Produktdefinition bei individualisierten Produkten.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D102 KEIJZER, W.:
Wandlungsfähigkeit von Entwicklungsnetzwerken – ein Modell am Beispiel der Automobilindustrie.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D103 LORENZ, M.:
Handling of Strategic Uncertainties in Integrated Product Development.
München: Dr. Hut 2009 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2008.

D104 KREIMEYER, M.:
Structural Measurement System for Engineering Design Processes.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2009.

D105 DIEHL, H.:
Systemorientierte Visualisierung disziplinübergreifender Entwicklungsabhängigkeiten mechatronischer Automobilsysteme.
München: Dr. Hut 2009 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2009.

D106 DICK, B.:
Untersuchung und Modell zur Beschreibung des Einsatzes bildlicher Produktmodelle durch Entwicklerteams in der Lösungssuche.
München: Dr. Hut 2009 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2009.

D107 GAAG, A.:
Entwicklung einer Ontologie zur funktionsorientierten Lösungssuche in der Produktentwicklung.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2010.

D108 ZIRKLER, S.:
Transdisziplinäres Zielkostenmanagement komplexer mechatronischer Produkte.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2010.

D109 LAUER, W.:
Integrative Dokumenten- und Prozessbeschreibung in dynamischen Produktentwicklungsprozessen.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2010.

D110 MEIWALD, T.:
Konzepte zum Schutz vor Produktpiraterie und unerwünschtem Know-how-Abfluss.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D111 ROELOFSEN, J.:
Situationsspezifische Planung von Produktentwicklungsprozessen.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D112 PETERMANN, M.:
Schutz von Technologiewissen in der Investitionsgüterindustrie.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D113 GORBEA, C.:
Vehicle Architecture and Lifecycle Cost Analysis in a New Age of Architectural Competition.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D114 FILOUS, M.:
Lizenzierungsgerechte Produktentwicklung – Ein Leitfaden zur Integration lizenzierungsrelevanter Aktivitäten in Produktentstehungsprozessen des Maschinen- und Anlagenbaus.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D115 ANTON, T.:
Entwicklungs- und Einführungsmethodik für das Projektierungswerkzeug Pneumatiksimulation.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D116 KESPER, H.:
Gestaltung von Produktvariantenspektren mittels matrixbasierter Methoden.
München: Dr. Hut 2012 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2012.

D117 KIRSCHNER, R.:
Methodische Offene Produktentwicklung.
München: TU, Diss. 2012.

D118 HEPPERLE, C.:
Planung lebenszyklusgerechter Leistungsbündel.
München: Dr. Hut 2013 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2013.

D119 HELLENBRAND, D.:
Transdisziplinäre Planung und Synchronisation mechatronischer Produktentwicklungsprozesse.
München: Dr. Hut 2013 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2013.

D120 EBERL, T.:
Charakterisierung und Gestaltung des Fahr-Erlebens der Längsführung von Elektrofahrzeugen.
München: TU, Diss. 2014.

D121 KAIN, A.:
Methodik zur Umsetzung der Offenen Produktentwicklung.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D122 ILIE, D.:
Systematisiertes Ziele- und Anforderungsmanagement in der Fahrzeugentwicklung.
München: Dr. Hut 2013 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2013.

D123 HELTEN, K.:
Einführung von Lean Development in mittelständische Unternehmen - Beschreibung, Erklärungsansatz und Handlungsempfehlungen.
München: Dr. Hut 2015 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D124 SCHRÖER, B.:
Lösungskomponente Mensch. Nutzerseitige Handlungsmöglichkeiten als Bausteine für die kreative Entwicklung von Interaktionslösungen.
München: TU, Diss. 2014.

D125 KORTLER, S.:
Absicherung von Eigenschaften komplexer und variantenreicher Produkte in der Produktentwicklung.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D126 KOHN, A.:
Entwicklung einer Wissensbasis für die Arbeit mit Produktmodellen.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D127 FRANKE, S.:
Strategieorientierte Vorentwicklung komplexer Produkte – Prozesse und Methoden zur zielgerichteten Komponentenentwicklung am Beispiel Pkw.
Göttingen: Cuvillier, E 2014. Zugl. München: TU, Diss. 2014.

D128 HOOSHMAND, A.:
Solving Engineering Design Problems through a Combination of Generative Grammars and Simulations.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D129 KISSEL, M.:
Mustererkennung in komplexen Produktportfolios.
München: TU, Diss. 2014.

D130 NIES, B.:
Nutzungsgerechte Dimensionierung des elektrischen Antriebssystems für Plug-In Hybride.
München: TU, Diss. 2014.

D131 KIRNER, K.:
Zusammenhang zwischen Leistung in der Produktentwicklung und Variantenmanagement – Einflussmodell und Analysemethode.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D132 BIEDERMANN, W.:
A minimal set of network metrics for analysing mechatronic product concepts.
München: TU, Diss. 2015.

D133 SCHENKL, S.:
Wissensorientierte Entwicklung von Produkt-Service-Systemen.
München: TU, Diss. 2015.

D134 SCHRIEVERHOFF, P.:
Valuation of Adaptability in System Architecture.
München: Dr. Hut 2015 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D135 METZLER, T.:
Models and Methods for the Systematic Integration of Cognitive Functions into Product Concepts.
München: Dr. Hut 2016 (Reihe Produktentwicklung).

D136 DEUBZER, F.:
A Method for Product Architecture Management in Early Phases of Product Development.
München: TU, Diss. 2016.

D137 SCHÖTTL, F.:
Komplexität in sozio-technischen Systemen - Methodik für die komplexitätsgerechte Systemgestaltung in der Automobilproduktion.
München: Dr. Hut 2016 (Reihe Produktentwicklung).

D138 BRANDT, L. S.:
Architekturgesteuerte Elektrik/Elektronik Baukastenentwicklung im Automobil
München: TU, Diss. 2017.

D139 BAUER, W.:
Planung und Entwicklung änderungsrobuster Plattformarchitekturen
München: Dr. Hut 2016 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2016.

D140 ELEZI, F.:
Supporting the Design of Management Control Systems In Engineering Companies from Management Cybernetics Perspective
München: TU, Diss. 2015.

D141 BEHNCKE, F. G. H.:
Beschaffungsgerechte Produktentwicklung – Abstimmung von Produktarchitektur und Liefernetzwerk in frühen Phasen der Entwicklung
München: TU, Diss. 2017.

D142 ÖLMEZ, M.:
Individuelle Unterstützung von Entscheidungsprozessen bei der Entwicklung innovativer Produkte.
München: Dr. Hut 2017 (Reihe Produktentwicklung).

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Entwicklerzentrierte Hilfsmittel zum Gestalten von Nutzererlebnissen.
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